The AMATEUR RADIO HANDBOOK

SECOND EDITION

This Edition is Dedicated

to the Radio Amateurs of Great Britain and the British Empire
who in the Service of their Country, have kept alive the
Spirit of Amateur Radio. May the kindling of
that same Spirit in the hearts of all men
bring Peace in our Time, and in
the Years to come.

Published by
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OF GREAT BRITAIN**

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World Radio History

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World Radio History

CONTENTS

World Radio History

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World Radio History

FOREWORD TO SECOND EDITION

WHEN the first edition of this Handbook appeared during the winter of 1938, it was anticipated that its appeal would be chiefly confined to British Isles radio experimenters, who had, up to that time, been compelled to depend upon foreign publications for much of their technical information.

An unexpectedly heavy demand during the first six months of 1939 necessitated the preparation of a reprint which, as a matter of historical record, became available during the fateful week preceding the outbreak of War. For a few days early in September it seemed likely that the bulk of the reprint would remain unsold until the cessation of hostilities, but for many reasons the popularity of the Handbook continued unabated, with the inevitable result that stocks began to fall almost to vanishing point.

This then is the sole justification for a Second Edition at the present time.

To-day *The Amateur Radio Handbook* is to be found not only in " ham " shacks throughout the British Isles, but in barrack rooms, dug-outs, ship's wireless cabins, research laboratories and workshops. Hundreds of copies of the earlier edition were sent to the British Expeditionary Forces overseas, and many others were despatched to English-speaking countries within and without the British Commonwealth of Nations. Perhaps even more important is the fact that it is accepted as an authoritative instruction manual by many branches of H.M. Forces.

The secret of its popularity can be attributed in no small degree to the easy, yet comprehensive style in which it is written. The *reason* for this style is due entirely to the technical contributors themselves who, after years of practical experience in the amateur field, have acquired the knack of imparting information in a manner which they *know* will appeal.

The approach to the more difficult aspects of radio communication has been simplified by the inclusion of extensive chapters dealing with fundamental radio and electrical principles and with valve applications, whilst mathematical considerations have been reduced to a minimum.

The present edition is notable for the inclusion of two entirely new chapters, one dealing with Workshop Practice, the other with Crystal Band Pass Filters.

The necessity for acquiring a sound knowledge of mechanical principles, as applied to the construction of experimental radio equipment, has become increasingly important in recent years, and it is hoped that the new chapter will fulfil a long-felt want in this direction.

Any device aimed at improving the selectivity of communication types of radio receivers, whether for amateur or commercial purposes, deserves the fullest possible publicity. It is therefore with considerable pleasure that we include for the first time in this publication details of the special types of crystal band pass filters which have been recently developed by Dr. J. Robinson and his co-worker Mr. E. L. Gardiner, B.Sc. The introduction of these devices will rank as one of the most important contributions to the problem of overcoming interference within crowded frequency bands.

Due to the exigencies of the War and the demands upon the time of those who are listed opposite as the chief contributors to this edition, it has not been found possible to amplify certain of the chapters, but a general revision has been made and considerable new data included.

World Radio History

For the reason that British Isles amateur transmitting licences are temporarily determined, it has been deemed desirable to omit certain references which, at the moment, have no specific application. In the previous edition these references appeared in the chapters entitled " Operating an Amateur Station " and " How to obtain a Licence." In the present edition a new chapter, based no much of the information which was contained in those chapters appears under the title " The Newcomer to Amateur Radio." Whilst the advice given therein is intended primarily to cater for the needs of the beginner who wishes to take up an interest in amateur radio, it is anticipated that many readers, who are engaged in radio work in H.M. Forces, will find the information of use.

As this Handbook will fall into the hands of a large number of readers who are not members of The Incorporated Radio Society of Great Britain, it is perhaps permissible to state that the Society was largely responsible in pre-war days for sponsoring, and collaborating in the organisation of, the Royal Naval Volunteer (Wireless) Reserve, and the Royal Air Force Civilian Wireless Reserve. After five years of war the Society had recorded the names of 4,000 members on Active Service, the majority of whom were engaged in radio work.

The Radio Society of Great Britain continues to maintain the closest possible contact with its members in the Services, and in addition it will, through its governing Council, seek for a restoration of transmitting facilities immediately hostilities cease.

The attention of those who are not yet members of The Incorporated Radio Society of Great Britain, is directed to the special announcement which appears on Page 308. A cordial invitation is extended to all non-members who are genuinely interested in the science of radio to apply for election. Membership carries with it a subscription to *The R.S.G.B. Bulletin*, official monthly publication of the Society.

* * * * *

It is the earnest hope of those who have contributed to this war-time edition that it will be found of especial value to all who are serving their country in a technical capacity as soldier, sailor, airman, or civilian. To them and to all others who read this Foreword we extend our thanks for their practical support.

The Spirit of Amateur Radio shall never fail.

J. C.

NOTE TO SECOND EDITION (ELEVENTH PRINTING)

Since the original Foreword was written in July, 1940, some 120,000 copies of this Edition have been sold—the vast majority to men and women engaged on radio duties in H.M. Forces. The Council of the Incorporated Radio Society of Great Britain are grateful to all who have recommended the Handbook and to the many booksellers—large and small—who have brought it to the attention of their customers.

It is unfortunate that the Third Edition cannot yet be prepared but *Radio Handbook Supplement*, which is a companion volume, has helped to meet a demand for further up-to-date information.

With the passage of time back issues of the Society's Journal, which contained full descriptions of certain items of equipment referred to in this publication, are no longer available. Readers are, however, reminded that articles dealing with amplifiers, receivers and measuring apparatus are frequently published in war-time issues of the *R.S.G.B. Bulletin*.

It is of interest to record that the membership of the R.S.G.B. increased from 3,000 in July, 1940 to 7,300 in July, 1944. Much of this increase can be attributed to an initial interest in Amateur Radio created by reading this Handbook.

J. C.

World Radio History

Chapter One

RADIO FUNDAMENTALS

The Electron — Ohm's Law — Power — Impedance — Resonance — Wavelength — Frequency — Aerials — Propagation — Reception — Valves — Transmission — Modulation — Neutralisation — Straight Receivers — Beat Reception — Superheterodyne Receivers — Micro-Waves.

AN understanding of fundamental electrical and radio principles is essential not only to the professional engineer, but also to the experimenter. It is, for example, not sufficient to know that a specific size of coil and condenser will produce certain effects; the reason for these effects must be understood.

The main objectives in all branches of radio communication are to receive efficiently the signals radiated from a transmitting station, whilst the latter must be able to radiate electrical energy efficiently, to distant points. In the case of amateur communication, special problems arise due to the comparatively low power used, coupled with limitations on space for the erection of aerial systems.

In order to achieve efficient results from any piece of equipment forming a link in the chain between the source of transmission and the point of reception, the users of such equipment must appreciate the underlying principles governing the operation of radio circuits and aerial systems.

The information presented in this Chapter, although of necessity somewhat abridged, will, it is hoped, give a clear conception of these principles. Those who wish to delve more deeply into the theoretical aspects are recommended to read Chapter 22, which gives a list of publications dealing with both the elementary and advanced aspects of radio engineering.

The Electron

The whole foundation of electricity is based upon the electron, a minute negatively charged particle—so small that it cannot be sub-divided. Atoms, of which all matter is composed, consist of a positively charged central nucleus around which is grouped a sufficient number of electrons to cancel the charge. Upon the number of electrons, and the size of the nucleus, depend the physical properties of any material.

In all matter there is a certain number of free electrons, and it is the movement of these free electrons in an orderly direction which comprises a current of electricity. Electricity is not "generated" but, like water in a pipe, is present all the time; an "electric current," however, becomes evident only when some force is applied (equivalent to a pump) to cause it to move. If the circuit is not completed, no movement, beyond the initial "piling up" of the electrons to form a voltage stress, will take place, but in this condition no power is available.

Types of Electric Current

If the movement of electrons is in one direction only, a "direct current" results. The polarity, defined by the symbols + (positive) and − (negative), of the voltage across any two points in a circuit carrying such a current remains the same. If, however, the primary source of stress or voltage is alternated between positive and negative, the flow of electrons will follow suit, and an "alternating current" will result. Alternating current is now in general use for the transmission of power, as it offers a number of advantages over direct current. For domestic or commercial use the "frequency," or number of complete alternations per second, is practically standardised in Great Britain at 50, although systems working at 25, 60 and 100 cycles per second (c.p.s.) may be met with occasionally.

In equipment used for amplifying music, or the human voice, frequencies of between 40 and 15,000 cycles per second (a cycle being one complete alternation) are encountered, and these are known as "audio" (or low) frequencies. Above this spectrum lie the radio-frequencies, those in common use ranging up to 300,000,000 cycles. As such figures become cumbersome abbreviations are usually employed, thus "kc" represents a thousand cycles, and "Mc" represents a million cycles.

Ohm's Law

The amount of electrical force from any source present in a circuit is called the "Electro-Motive-Force," abbreviated to "E.M.F." and is measured in volts, hence the term voltage. Naturally the greater the E.M.F. employed, the greater will be the current which is measured in amperes or fractions of an ampere. The actual current will depend on the amount of opposition (resistance) present.

A definite relationship exists between these three factors which can be expressed by the equation :—

$$\text{Current (in amperes)} = \frac{\text{E.M.F. (in volts)}}{\text{Resistance (in ohms)}}$$

This is known as "Ohm's Law," and, for direct current, is expressed as :—

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

$$E = I \times R$$

World Radio History

where I equals current in amperes, E equals E.M.F. in volts, and R equals the total resistance in ohms.

Provided any two factors are known, substitution will readily enable the value of the third to be determined.

Ohm's Law is one of the most useful of all fundamental radio laws, and should be thoroughly learned by every beginner.

Resistance and Conductance

The opposition to a direct current will depend upon the physical size and the material of the conductors forming the circuit. This quantity, defined as resistance, is measured in ohms. Various metals, and other materials of the same cross section present different resistances, whilst resistance also varies with temperature. In the case of metals the resistance generally increases as the temperature increases, but the reverse applies to liquids and to carbon.

" Conductance " is the reciprocal or inverse of resistance, and is measured in mhos. Thus a resistance of 1 ohm has a conductivity of 1 mho, while a resistance of 1,000,000 ohms (*i.e.*, a megohm) has a conductivity of one-millionth of 1 mho, *i.e.*, 1 micro-mho.

Combinations of Resistances

If two or more resistances are included in a circuit so that the current through one is compelled to flow through the others, they are said to be " in series," and the resistance as a whole is the arithmetical total of each individual resistance. Expressed as a formula :—

$$R = R_1 + R_2 + R_3, \text{ etc.}$$

where R is the total resistance, and R_1, R_2, R_3, etc., the separate resistances.

If, however, the resistances are connected so that the total current flowing divides between them, they are said to be " in parallel " and the applicable formula is then :—

$$R = \cfrac{1}{\cfrac{1}{R_1} + \cfrac{1}{R_2} + \cfrac{1}{R_3} + \text{etc.}}$$

In this case the total resistance is reduced, and will be *less than that of the lowest individual resistance.*

Suppose, for example, two resistances of 10 ohms and 20 ohms are connected in parallel. Then the combined resistance will be given by :—

$$R = \cfrac{1}{\cfrac{1}{10} + \cfrac{1}{20}} = \frac{1}{0 \cdot 15} = 6 \cdot 66 \text{ ohms.}$$

Combinations of resistances in both series and parallel connection will frequently be found, in which cases the following formula will enable the total value of resistance to be ascertained

$$R = \cfrac{1}{\cfrac{1}{R_1 + R_2} + \cfrac{1}{R_3 + R_4} + \cfrac{1}{R_5 + R_6}}$$

Fig. 1 shows diagrammatically the three conditions described.

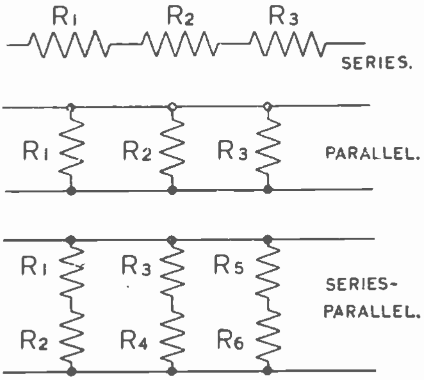


Fig. 1.

Illustrating various combinations of resistances. A circuit containing any number of resistances can be reduced to these basic forms.

Construction of Resistances

From the foregoing it will be clear that the purpose of a resistance is to offer a definite amount of opposition to a current, so limiting its value. Put another way, resistance will reduce the voltage applied to any part of a circuit by a known amount. A common type of resistance consists of a rod of special material, usually a mixture of carbon and clay baked at a high temperature, with metal end-caps or wires for connecting purposes. These are made to dissipate between ½ and 3 watts, which power is generated within them in the form of heat.

When it is necessary to dissipate more energy, or when small values of resistance are required, the resistance takes the form of a winding of special wire, made from alloys of various metals such as nickel, iron, and copper, etc., which offer a much higher resistance to the flow of current than does pure copper. The carbon rod type possesses practically no inductance, but the wire-wound types will have some, unless half the turns of wire are wound in the opposite direction. Variable resistances of high values usually have a hard carbonised strip as the resistance element, whilst those of low values and those intended to dissipate more than a watt or two, have wire-wound elements. Modern types of variable resistances have been greatly improved and give smooth noiseless control with the minimum of wear.

The resistance value of all types mentioned, with the possible exception of the higher value carbon rods, is greater at high frequency than when measured with direct current.

Power

The power in any direct current circuit is the product of the voltage (E.M.F.) and the current, and is directly proportional to both. Power may be available in various forms, such as heat, light or mechanical power (a rotating motor for example), or it may be converted into a different type of power to the original, such as, for example,

World Radio History

the high frequency oscillations produced by a valve supplied with direct current. Power is expressed in "Watts" and may be found from the formula :—

$$W = E \times I$$

where W equals watts, E equals E.M.F. in volts, and I equals current in amperes.

It is desirable to use conductors of a sufficiently heavy gauge to carry the current without any appreciable loss through heat. Heat losses would result in a lower voltage and current being available at the point where it is required to develop the maximum power.

Insulators

In addition to the materials which conduct electricity very readily it is necessary to have other materials which offer a very high resistance to it, in order to prevent it straying away at points where physical support is essential. Such materials are known as insulators Whilst there does not exist an absolutely perfect insulator, there are some, such as porcelain, glass and ceramic materials, which effectively prevent any leakage. Care must be exercised in the selection of an insulator for any specific purpose, as losses, other than leakage, can occur at high radio-frequencies.

Condensers

The condenser, which is probably the most common item in any piece of radio apparatus, may be simply defined as consisting of two (or more) electrically conducting surfaces which are highly insulated. The interposing medium between the plates is called the "dielectric," and, when a voltage is applied to the condenser, the dielectric is put into a state of "strain." It is this state of strain which enables a condenser to hold a charge. Any metallic object possesses capacity to earth. The capacity of a simple fixed or variable condenser depends (1) on the area of the metallic surfaces, (2) on the material used in the dielectric, and (3) on the thickness of the latter. Air is commonly used as a dielectric because it possesses very low losses, but by substituting other materials the capacity for a given area can be greatly increased, due to the higher "Dielectric Constant" of these materials. Taking air as 1, mica has a constant of about 7, paraffin wax 2½, whilst oil varies between 2 and 3. These figures mean that the capacity increases in proportion, but as the use of these materials enables much closer spacing of the elements for a given voltage (air breaks down fairly easily) it will be realised that the capacity can be increased greatly with their aid. This will explain why air dielectric condensers are somewhat bulky, and other types comparatively compact and physically small.

The variable air dielectric types are always used for tuning a circuit, the maximum capacity being chosen according to the frequency. They are also preferable for controlling reaction, both because of the lower losses introduced and because of the higher insulation. As transmitting variable condensers have to withstand the peak radio-frequency generated, plus the H.T. voltage, much greater spacing is necessary than in a receiving type condenser, although the latter is suitable when low power is used.

In all other parts of a radio-frequency circuit only good quality mica condensers, or those with ceramic dielectric, should be used. The positions in which they are usually found are (*a*) as a grid condenser, (*b*) as a by-pass condenser, and (*c*) as a coupling condenser.

Grid Condensers

A grid condenser allows the grid to become negatively charged, and prevents the charge being instantaneously reduced through the tuned circuit. Instead, it is allowed to leak away slowly through the grid resistance. As the time taken by this action is important it is desirable to use the correct capacity. A value of about ·0001 μF is usual for high frequencies, and about half this value for ultra-high frequencies.

By-pass Condensers

A by-pass condenser, as its name implies, serves to provide a low resistance path to the high frequency oscillations, and prevents power being dissipated through the latter having to traverse paths of high resistance. The size of such a condenser depends upon the frequency, and ranges from ·01 to ·0003 μF. An example is C_3 in Fig. 7.

Coupling Condensers

Coupling condensers serve to transfer a radio-frequency voltage from one point to another, whilst preventing a flow of direct current. The voltage across such a condenser is the sum of the peak radio-frequency and the high tension voltages, and it must be chosen accordingly. The capacity will depend upon the frequency and the position the condenser occupies, *i.e.*, whether it is placed at points of high R.F. voltage or otherwise.

Paper Dielectric Condensers

Waxed or oiled paper dielectric condensers should only be used in audio-frequency and smoothing circuits, for, besides having considerably higher losses, even the so-called "non-inductive" types invariably possess a certain amount of inductance, which at high frequencies opposes the passage of an oscillatory current. An exception is that the smaller values—·01 to ·25 μF—may be used in circuits of fairly low radio-frequency, such as the intermediate frequency stages of a superheterodyne receiver.

An ordinary broadcast receiving aerial is, in effect, a condenser of about ·0002 μF capacity depending on its length and height.

Inductance of Coils

A current flowing through a straight wire causes a magnetic field to form around it, and when the wire is made into a circle the field becomes stronger. By winding a coil with many turns the magnetic field can be made to store considerable energy. Such a coil possesses peculiar properties in that, when a growing current is flowing through it, the magnetic field increases in strength, cutting across the turns of the coil. This induces in the turns a voltage opposing that already there, so that the current is only allowed to increase slowly. The opposite effect takes place when the current is decreasing in value—the induced voltage adds to

World Radio History

that present and tends to prevent the current stopping. If the current is cut off suddenly the induced voltage is so strong that it causes a current, in the form of a spark, to jump across the gap at the point where the cutting-off occurs. A coil possessing these properties is known as an "inductance."

Coils for Receivers

The actual shape of a coil alters its efficiency, this being at a maximum when the length is a little less than the diameter. These dimensions are not critical, and it is only necessary to avoid long coils of small diameter. Spacing of the turns is desirable for short-wave work, in order to reduce the self-capacity, but it should not be carried to excess. More than one diameter spacing gives but little further reduction in self-capacity, whilst the inductance is considerably reduced, necessitating more turns to obtain a given inductance, thereby adding to its resistance. The thickness of the wire used depends on the frequency, and on the type of service required. Receiving coils are sometimes wound on ribbed formers of low loss material, the amount of which should be as small as possible, the wire being fairly thin, as the current carried is very small; 16 s.w.g. may be used on 56 and 28 Mc, 18 s.w.g. up to 7 Mc, and 20 to 24 s.w.g. for lower frequencies.

Connections are usually made to pins in the base of the former, enabling coils to be interchanged quickly. It is preferable to use thin wire, of about 30 s.w.g. for reaction coils, placing the winding as close as possible to the grid winding, and to use as few turns as will give satisfactory oscillation. By so doing reaction will be made smooth.

Coils for Transmitters

Coils for the low power stages of a transmitter are often of similar construction, but it is usual to employ a slightly heavier gauge of wire, although this is not essential. The final stage of a transmitter requires special coils which may be mounted on porcelain stand-off insulators. In the latter case it is essential to keep the amount of solid supporting material small, as the strong high frequency field will set up stresses in it, and losses due to heat will result. Coils of copper tubing are self-supporting, but the heavy mass of metal causes eddy current losses, and is a drawback. Due to the large spacing from centre to centre of the turns of such coils, more turns are required, and the increased high frequency resistance which results may offset the lower resistance obtained from the use of large area conductors. Satisfactory results are often obtained from coils made of 12 or 14 s.w.g. supported by celluloid strips.

Coupling coils which are similar to tuning coils frequently form part of a tuned circuit, and the same considerations outlined above apply.

Choke Coils

Choke coils are of two types, *i.e.*, those suitable for high and low frequencies. The former are wound with many turns of fairly fine wire, with the object of obtaining a high inductance with a very low self-capacity. Such coils offer a high impedance to the flow of oscillatory current, and are used in parts of a circuit where direct current, but not the radio-frequency current, must be allowed to pass. The wire gauge used must be stout enough to carry the direct current without heating up. The most commonly used R.F. choke, and one which can be recommended for nearly all positions in short-wave apparatus, is the type having four pie-wound coils on a narrow diameter former of special material, and with an inductance of the order of 2·5 milli-henrys.

A low frequency choke consists of very many turns of wire, wound round an iron core, the latter producing a big increase in the effective inductance. Inductance depends on the number of turns, and on the amount and quality of the iron. A low frequency choke allows direct current to pass, but offers a high impedance to low frequency alternating currents. It has many uses in modern radio equipment.

Reactance and Impedance

The opposition presented to a direct current is only that offered by the resistance of the components in the circuit. A condenser will prevent any steady direct current from flowing and will have no other effect, whilst the iron core of a low frequency choke coil will not influence the current, except at the commencement and cessation of application.

With alternating currents, matters are very different. Condensers (which are able to store electrical energy) and coils (which store magnetic energy) impede the flow of the current more or less, according to their reactances. "Reactance" differs from resistance in that it does not dissipate energy, but as its ultimate effect is similar, its value is also measured in ohms.

The reactance of a condenser increases as the frequency of the alternating current decreases and its value may be found from the formula :—

$$X_C = -\frac{1}{2\pi fC} \text{ ohms}$$

where X_C is the actual reactance, f the frequency, C the capacitance in farads and π is 3·14.

The reactance of an inductance coil decreases as the frequency decreases, which is the opposite effect to that of a condenser. The following formula applies :—

$$X_L = +2\pi fL \text{ ohms}$$

where L is the value of the inductance in henrys.

It should be noticed that the reactances of an inductance and a condenser are of opposite sign, and thus, when both are in the same circuit, they tend to neutralise each other. The total reactance in a simple series circuit is the algebraic sum of all the reactances.

When a circuit contains both resistance and reactance the total opposition to the current is termed the "impedance." Although the resistance and reactance are both measured in ohms, they cannot be added directly, consequently the following formula must be used :—

$$Z = \sqrt{R^2 + X^2}$$

where Z is the impedance, R the resistance, and X the total reactance, all measured in ohms.

If a series circuit contains a resistance R inductance L and a condenser C, then the total impedance will be given by :—

$$Z = \sqrt{R^2 + \left(2\pi fL - \frac{1}{2\pi fC}\right)^2}$$

It will have been noted when the formulæ for the application of Ohm's Law were given, that they referred to direct current only. To apply the Law to alternating current problems the term Z must be substituted for R.

Resonance

A circuit containing capacitance and inductance in series, as in Fig. 2, is said to be "resonant" to a particular frequency when the reactances of the capacitance and inductance are exactly equal in value. Under this condition they cancel each other out, and leave only the resistance to limit the current flowing. It should be carefully noted that immediately the value of inductance or capacitance is altered, the circuit falls out of resonance to the previous frequency, and becomes resonant to a different frequency.

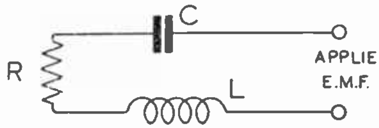


Fig. 2.
Connections of a series tuned circuit. The current flowing through each unit is identical.

The resonant frequency of a simple circuit such as Fig. 2 is given by the formula :—

$$f = \frac{1}{6{\cdot}28\ \sqrt{LC}}$$

As L and C represent henrys and farads respectively, this formula becomes unwieldy; it is bettei therefore to substitute for it the expression :—

$$f = \frac{1}{6{\cdot}28\ \sqrt{LC}} \times 10^6$$

where f is the frequency in *kilocycles*, L the inductance in micro-henrys (μH), C the capacitance in micro-microfarads ($\mu\mu$F).

These units are frequently used in present-day radio practice.

A parallel resonant circuit is one where the capacitance, inductance, and resistance are in series, but the E.M.F. is applied in parallel with the combination, as shown in Fig. 3. Under this condition the impedance presented by the tuned circuit as a whole is maximum at resonance, and the lower the value of R the greater the impedance.

The action of a parallel circuit is more complicated than that of a series circuit, as the current flowing through the tuned circuit is quite different from that flowing through the source of E.M.F., although, of course, it bears a definite relation to the latter. Nevertheless, the formula given for finding the frequency of a series tuned circuit applies equally to a parallel resonant circuit.

It should be pointed out that the resistance R shown in the circuits is not necessarily a separate resistance specially inserted, but may be the resistance of the wire forming the coil. This resistance is much higher at radio-frequencies than at low frequencies, and will vary with the type of coil. Some apparent resistance also results from the high frequency losses which are liable to occur in the condenser, but as these are usually very small compared with those in the coil, the resistance R in Fig. 3 is shown as being in series with L rather than in series with the condenser. High parallel impedance is generally desirable in this type of resonant circuit, and low impedance in the series circuit, so that in both cases it is necessary to keep the value of R as low as possible.

Tuning

As it is nearly always necessary to be able to adjust apparatus to a number of frequencies, some means must be provided for varying the values of the circuit components so that resonance can be produced over the desired range of frequencies. This action known as "tuning," is normally, accomplished by varying the capacitance of C, L remaining fixed, although arrangements are frequently provided for varying the inductance of L, either in steps by means of a switch, or by inserting separate coils.

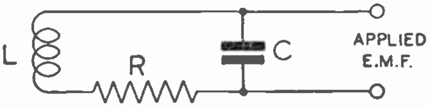


Fig. 3.
Connections of a parallel resonant circuit. The current flowing through LCR will be different from that flowing through the source of E.M.F.

Fig. 4 shows how the current will vary in a tuned circuit (to which an E.M.F. of a definite frequency is being applied) as the capacitance is varied. The current rises to a maximum at a value of capacitance C_r, which value is equivalent to the particular reactance necessary to produce resonance.

Inspection of the formula for finding the resonant frequency shows that either a small capacitance and a large inductance may be used, or vice versa, but in both cases the product of the two, LC, must be of a certain value for a given frequency. In other words, any ratio of inductance to capacity may be used, so long as the product is constant.

What will be the effect of using different L/C ratios? In the series circuit, the impedance at resonance is equal to R, no matter the value of the L/C ratio. Increasing the value of L and reducing that of C (*i.e.*, increasing the L/C ratio) will result in the reactance of both increasing, although still remaining equal. The alternating voltage across L and C will therefore increase in

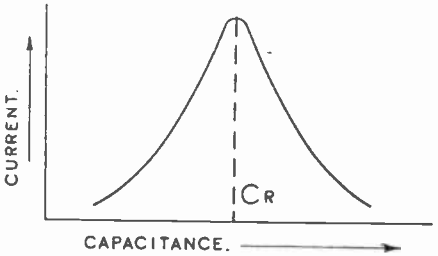


Fig. 4.
Illustrating the rise and fall of current in a tuned circuit as the condenser is varied through resonance.

World Radio History

proportion, and the value of R will also be increased, due to the greater amount of wire in the coil.

Dynamic Resistance

In the case of the parallel resonant circuit the L/C ratio is of great importance, as it affects the impedance presented to the source of E.M.F., and, as previously mentioned, it is often highly desirable to make this as great as possible. The impedance of such a circuit at resonance is found from the expression

$$\frac{L}{CR}.$$

At the resonant frequency it behaves as a resistance of this value, hence the commonly applied term "dynamic resistance."

"Q"

From the preceding paragraph it will be realised that the value of R is important, as this has a considerable effect on the *efficiency* of the circuit. The term "Q" expresses this efficiency or "goodness," and is the ratio of coil reactance to resistance. Its value should be stated at a definite frequency, because the reactance depends on this factor but as the resistance will increase with frequency, the Q may be assumed approximately constant over a band in the region of the particular frequency.

As an example consider a coil with an inductance of 100 μH and a resistance at 1 Mc of 10 ohms. Then the value of Q is given by

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

$$= \frac{6{\cdot}28 \times 10^6 \times 100 \times 10^{-6}}{10}$$

$$= 62{\cdot}8$$

Eddy Current Losses

Every electric current has associated with it a magnetic field, and if the current is an alternating one, then the field also alternates. Conversely, alternating magnetic fields induce alternating currents in any conductor they traverse, and this principle is made use of to-day in almost every branch of electrical science. However, whilst circuits are arranged deliberately to transfer energy in this way, the alternating field will induce currents in other metal work, resulting in definite losses. These are obviously undesirable, and it is necessary to be careful, particularly in high frequency circuits, to see that no large metal objects are close to the coils or parts of the circuit carrying large currents.

Transformers

One example of a component in which electro-magnetic coupling is deliberately used is the transformer.

Transformers which can be designed for use in either high frequency or low frequency circuits consist of two coils in close proximity, the energy in one coil of wire being transferred to the other, which is insulated electrically from the first, by allowing the magnetic field produced by one to cut the turns of the other, and so induce a voltage in it. The output voltage may be higher or lower than the input voltage, according to the ratio of the number of turns in each coil, and to the degree of coupling. In the case of transformers for use in low frequency circuits the coupling is generally made as high as possible by the use of a core consisting of iron laminations upon which both coils are wound. Transformers only "transform" alternating voltages and currents—direct current, once it attains a steady value, has no other effect than the production of a static magnetic field.

Skin Effect

A direct current, or an alternating one of low frequency, is carried over the whole cross-sectional area of a conductor, but as the frequency is increased the current tends more and more to keep nearer the surface of the conductor, and at high radio-frequencies is carried entirely on the surface. When the conductor is in the form of a coil the current distribution on the "skin" of the conductor is not uniform, because of the effect of the current in adjacent turns; it is therefore necessary to use conductors having adequate surface area. In modern circuits incorporating high L/C ratios, the currents carried are not large, and it is seldom necessary to use wire thicker than 12 or 14 s.w.g. except in high power transmitters.

Radiation

When an electron is accelerated some energy is radiated in the form of an electro-magnetic wave. The steady drift of a direct current represents no acceleration (except at the commencement or cessation of the current) and therefore there is no radiation. In a circuit carrying alternating current the electrons are being continually started, stopped, started in the reverse direction, and so on, with the result that a steady radiation of energy occurs. The amount radiated at the normal commercial frequency of 50 cycles per second is infinitesimal, but, as the frequency increases, the energy radiated in the form of electro-magnetic, or radio waves becomes considerable.

Wavelength

The length of any wave will obviously depend on its frequency and the speed at which it travels. In the case of radio waves this is 300,000,000 metres per second. As an example, if the frequency is 300,000 per second, the wavelength, or distance travelled during one complete cycle, will be 1,000 metres. Any other wavelength may be found by dividing 300,000,000 by the frequency.

The ability of a circuit to radiate energy is dependent partly upon its linear dimensions with respect to the wavelength. If a wire is very short compared with the wavelength corresponding to the frequency of the current which it carries, very little radiation will occur. At 50 c.p.s. the wavelength would be 6,000,000 metres, or nearly 4,000 miles. It is small wonder that a wire of any practical dimensions radiates negligible energy at 50 c.p.s.

If the frequency is raised to a radio-frequency, such as 5 Mc, the wavelength falls to 60 metres, or about 200′. At such a frequency, a piece of wire 100′ in length is one-half of a wavelength, and would form an efficient radiator if suitably fed with current at 5 Mc. It is thus fortunate that most amateur radio work is carried out on short wavelengths.

World Radio History

Aerials

To transmit the generated frequency efficiently, or, conversely, to receive that generated by a distant station, it is necessary to erect, as high and clear as possible, an open aerial system, in order that the electro-magnetic waves may receive a good start in the first case, and be intercepted at maximum strength in the latter. Such an aerial may be considered to consist of inductance, capacitance, and resistance, and it is usual to make the total of these values form a tuned resonant circuit. This occurs when the length of the aerial is made equal to half the wavelength in use. When such an aerial is fed with energy at the resonant frequency, "standing waves" are set up on it, and, under this condition, radiation is very strong. A full explanation of this effect, and the theory relating to aerials will be found in Chapter 12.

Propagation

In the early days of radio development it was thought that the waves followed the surface of the earth from one point to another, and that the strength of signals depended directly on the distance between the transmitter and receiver. As waves of less than 200 metres were found to be rapidly attenuated (weakened) in passing over the earth, scant attention was paid to them, interest being almost wholly devoted to long waves, and in increasing the range of them by using greater and greater power, with longer aerial systems.

When Marconi first transmitted radio signals across the Atlantic Ocean in 1901 a controversy arose as to how the signals could follow the curvature of the earth. It was known that waves would not go far through the earth, and it was soon shown that the "dragging" effect of the ground on the bottom of the wave front did not give sufficient curvature. Finally a theory was put forward by Heaviside in England, and Kennelly in the United States, that the entire earth is surrounded by a conducting atmospheric shell, which is capable of acting as a reflector, and so, of sending back to earth the waves impinging upon it. Exploration of the upper atmosphere by physicists, using radio and other means, has shown this theory to be correct, and has resulted in the development of a great new branch of science which is of interest to the meteorologist as well as to the radio scientist.

Heaviside and Appleton Layers

It is known that two major electrically conducting layers exist, of prime importance in radio communication, as well as several subsidiary layers at different heights. The two main layers are the Heaviside, or "E," layer, and the Appleton or "F" layer, so named after their discoverers.

As shown in Fig. 5, the Heaviside layer is at a height of about 60 miles, and the Appleton layer at a height of about 140 miles over the earth. Both are formed by the ionising action of the sun on the gases comprising the earth's outer atmospheres, and, as the ionisation varies with the rotation of the earth itself, and with the seasons (the rotation of the earth round the sun) the height is liable to vary. Further, the layers are not well defined thin slices, but vary in thickness, and, at periods of dense ionisation, each may split up into two more or less separate layers, commonly referred to as the E_1 and E_2, and F_1 and F_2 regions. The whole of the atmosphere above 50 miles is ionised to some extent, and this region is known as the "ionosphere."

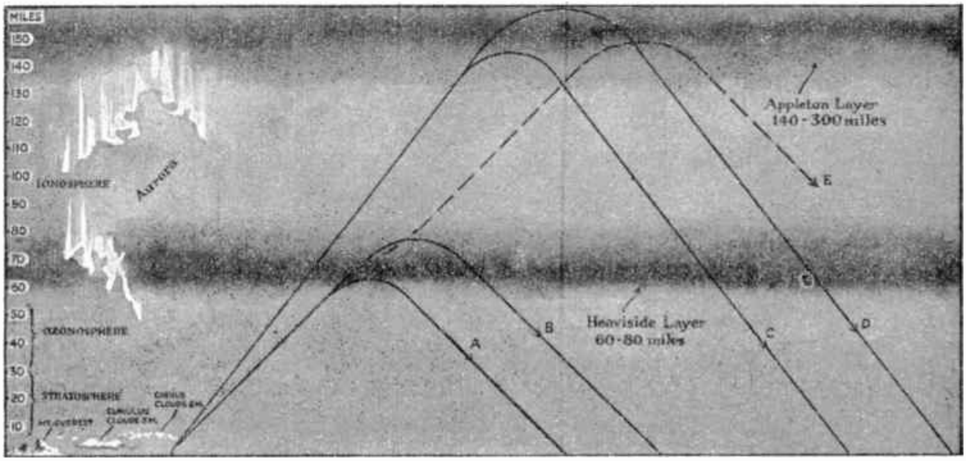


Fig. 5.
This picture will make clear the paths wireless waves travel when covering long distances.

During the night, when the source of ionising energy is absent, the ions, or electrically charged atoms, will tend to combine again with free electrons, forming neutral atoms, and the conductivity of the layers decreases. This recombination is, however a slow process, so that, during the summer, when the night is only of comparatively short duration. the layers retain their reflecting powers throughout the 24 hours; in the winter, when the period of bombardment is short, the layers rise in height and lose much of their reflecting power to short-waves, so that communication is often impossible for many hours on end.

World Radio History

Sun-spots and Fade-outs

Another variation of the ionisation of the layers is caused by the internal disturbances within the sun itself, these being of a very complex nature. Solar disturbances are made manifest by "sun-spots," and it would appear that, on occasions, the sun radiates a ray which reduces the ionisation, resulting in temporary "fade-outs" which can cause serious dislocation of both amateur and commercial radio communication.

A particularly severe electrical storm occurred during Easter, 1940, which considerably interfered with broadcasting and cable systems.

Layer Reflection

The energy radiated along the ground from a short-wave transmitting aerial is rapidly attenuated; as a result a 20 metre ground-wave signal is seldom audible more than 25 miles away. The wave radiated upwards, at a small angle, soon gets clear of the earth, and eventually reaches one of the layers, where it is turned back again, either directly, or after refraction (*i.e.*, gradual bending within the layer) in a similar way to a beam of light from a bright surface. Different frequencies penetrate the layers to different depths before they are bent back, the higher frequencies penetrating to the greatest extent, and being returned to earth at the furthest point. In Fig. 5, which illustrates the simpler aspects of wave propagation, the lines represent wave tracks under various conditions. A and B show the paths that 7 and 14 Mc (40 and 20 metres) signals would respectively take during the daytime, the lower layer effecting the reflection, so that the range is comparatively short. At night the waves would follow the paths C and D, giving a greater range. If, as occasionally happens in the summer, the E layer is at a very low height and is heavily ionised, strong signals may be received on the 14 and 28 Mc amateur bands from stations only between 100 and 500 miles away. At the same time, moderately distant stations may also be heard; reflection of such signals being effected from the F_1 or F_2 layers.

Skip Distance

For reflection to take place, the wave must impinge on the layer at an angle less than a certain limiting value, which is different for each frequency. If the angle is steeper than this particular value the wave simply penetrates the layer, and is lost. It will be realised therefore that, outside the range of the ground-wave, nothing can be received inside the distance at which the reflected wave appears. This area, annular in shape, is an area of no signals, and its radius is referred to as the "skip distance." Fig. 5 shows why this distance is greater at night than during the day, and also why it is greater for waves of higher frequency.

Weak signals may occur within the skip area, and this is due to the fact that the surface of the reflecting layer is not a perfectly uniform one. This results in "scattering," *i.e.*, the reflection of waves at various odd angles. It is often impossible to receive British amateur signals on 14 Mc in Great Britain, whilst the signals are audible at good strength in America, Asia, and elsewhere.

On wavelengths greater than about 200 metres, reflection is always possible, to some extent, at any angle, so a definite skip area does not exist, although the change-over from the E to the F layer at sunrise and sunset is very noticeable. On the medium broadcast waves distant European countries are weak in this country, due to the number of "hops" the waves have to make to cover the distance, consequently considerable losses occur. After sunset, when the E layer gives place to the F layer, the "hops" are longer and fewer in number, with a consequent increase in signal strength. As the frequency is increased (wavelength reduced) the skip distance becomes greater until, at some limiting frequency, the wave is not sufficiently bent to follow the curvature of the earth, and hence communication is no longer possible.

The limiting frequency, *i.e.*, the highest frequency at which layer reflection occurs, has gradually increased from about 25 Mc (12 metres) to the region of 56 Mc (5 metres), but in the opinion of many observers the peak was reached in 1937–38, and a slow decline is likely to set in during the next few years. Observations made during 1939 and 1940 confirm this view.

Daylight signals on 7 and 14 Mc are usually not very strong, because part of their energy passes through the lower layer, to be reflected by the upper; as a consequence they are not completely reflected, as indicated by E in Fig. 5. The range during the day is also less because of the larger number of hops necessary to cover a given distance, but, at night, the E layer becomes inoperative, and reflection takes place from the much higher and more intense F layer, resulting in much greater hops and a greater skip distance. World-wide range with comparatively low power then becomes possible. Commercial stations use high power in order to cover long distances during bad conditions, but as the signals during the night will travel round the earth, and give rise to more or less strong echoes at the receiving station, means often have to be provided to reduce the power to quite low values. It is possible that very short waves may penetrate the E layer, be reflected by the F layer and then instead of coming back down to earth, they may be again reflected by the upper surface of the E layer, and so on until their energy is dissipated.

Cyclic Variation of Conditions

Present knowledge indicates that the maximum frequency at which reflection takes place, and conditions in general, follow an eleven-year cycle of the sun, but it will be necessary to continue propagation studies over many years before the general trend can be definitely established. During this eleven-year cycle, conditions gradually improve and then fall off again, but there are subsidiary variations in addition.

Fading

The waves from a transmitting aerial are radiated at various angles, with the result that it is possible for signals reaching a distant station to have travelled by different routes, taking different times in transit. Further, the reflecting layers are never perfectly steady, and so angles of reflection are liable to vary. The result is that, at any given point, two positive wave crests can arrive at one moment, and a positive and negative together at the next. The latter will cancel out, giving rise to a fade in the received signal. Intermediate positions also occur, of course, so that the fading of several different types is experienced. The signal variation may be very rapid in which case it is audible as a low frequency "flutter" or it may be very slow, taking several minutes to rise from minimum to maximum. These effects are most noticeable during the transition of reflection from one layer to another, and when the layers are rising or decreasing in ionisation density.

From the foregoing it will readily be appreciated that a wide field of research is possible in the study of propagation, for although present knowledge is well advanced, the daily, seasonal, and yearly variations enable valuable new data to be collected. Much valuable information has been recorded in this connection by the Propagation Group of the Experimental Section operated by the Radio Society of Great Britain.

The Amateur Bands

In normal times British Isles amateurs are permitted by international agreement to transmit continuous wave telegraphy and telephony in narrow channels of frequencies, usually referred to as the 1·7, 3·5, 7, 14, 28 and 56 Mc bands. Particulars of the actual allocations are given in Chapter 20.

The 1·7 Mc (or 160 metre) band is situated just below the medium broadcast band, and is used chiefly for working over the British Isles.

The 3·5 Mc (80 metre) band, besides offering a useful channel for British and European contacts, permits long distance communication during the winter months. Both the 1·7 and 3·5 Mc bands are liable to be affected by atmospheric interference during the summer.

The 7 Mc (40 metre) band is used extensively for both short and long distance contacts, although the latter are often difficult to effect, owing to the somewhat congested state of the band, and the consequent high degree of interference experienced. The skip effect on this band often allows the reception of European and long distance signals simultaneously, which makes it necessary to use a highly selective receiver in order to eliminate the unwanted local stations, and to make the distant stations readable.

For all-round long-distance work the 14 Mc (20 metre) band has no equal, but, as with all other amateur bands, the best time or period must be chosen if reliable contacts are to be established. Usually east coast American amateur stations can be worked from Great Britain at most hours of the day, but the more distant American stations come in at peak periods, occurring in the early morning in summer, or just before sunset at other times of the year.

The 28 Mc (10 metre) band has frequently been as good as the 14 Mc band for long distance (DX) contacts during recent winters, but conditions are liable to fall off during the summer, and DX working is usually only possible over north-south paths, although European stations may be sometimes worked all the year round. The period of good conditions on 28 Mc from 1935 to 1938 was prophesied by radio amateurs, and the fact that the prophecy was fulfilled indicates the value of the work carried out by them.

The 56 Mc (5 metre) band is enigmatical—it is definitely useful for contacts up to 30 miles or so at almost any time, and with the much improved technique now used, it is being proved that communication is possible over much greater distances during certain periods. In past years the R.S.G.B. have sponsored numerous tests on 56 Mc and it is hoped that many more such tests will be arranged in the future. Recent improvements in the design of equipment, particularly in the case of valves, have been responsible for an increasing use of these high frequencies.

Comparatively little information is available for publication concerning the 112 Mc (2½ metres) 224 Mc (1¼ metres) and 448 Mc (⅝ metre) bands, but interest is continually increasing. The peculiarities of these ultra-high frequencies lend them special importance for service purposes.

The various amateur bands are in approximate harmonic relationship, that is to say, certain of the higher frequencies are even multiples of the lowest frequency. As will be seen later, this is of great value in the design of crystal-controlled transmitters.

Reception of Radio Waves

The rapidly alternating currents in a transmitting aerial result in the radiation of electromagnetic waves. When these encounter a receiving aerial, the reverse process occurs, and small E.M.F.s are set up in it. The power from a transmitter is radiated in all directions, so that at a distance of 1,000 miles the energy may be visualised as being spread out over a circle of 6,000 miles or more in circumference. A receiving aerial system could therefore only collect a very small part of the radiated energy at best, whilst, in practice, owing to the inevitable propagation losses, the energy actually received is even smaller.

In broadcast reception, the voltage available to actuate the receiver is often as much as ·001 volt, but in amateur long-distance work, seldom more than a few millionths of a volt is available. The received signals, although so tiny, are exact replicas of those sent out by the transmitter, and the very high sensitivity of modern valves enables their magnitude to be greatly increased, so that they can usually be made fully intelligible.

In commercial point-to-point communication, where the location of the receiver is known, the aerial system is often arranged to concentrate the radiated energy in a narrow beam. The considerable gain obtained by this means enables communication to be carried on through all but the worst conditions. Directive reception is also employed, because it helps in reducing interfering signals and noises from unwanted directions.

High directivity, even if possible, is not usually desirable in amateur work, because it prevents communication with stations in widely separated areas. Considerable attention is, however, being paid at the present time to moderately directional aerial systems, because the resulting gain is equivalent to a large increase of power to the transmitter, a matter of importance when only low inputs are used. The reduction in the strength of signals from undesired directions, made possible by the use of a directive aerial system applied to a receiver,

World Radio History

also makes considerable difference in increasing the intelligibility of the desired signal. Particulars of such aerial systems will be found in Chapter 12.

The Valve

The advent of the thermionic valve made long distance radio communication an economical and practical proposition, and, as present-day technique centres round this valuable device, it will be well to give a brief outline of the principles underlying its operation.

The simplest form is the two element valve, known as the "diode," of which the rectifier is an example. When the filament is heated to a sufficient temperature, governed by the characteristics of the materials from which it is made, the free electrons within the wire are forced into great agitation, and some are emitted. The anode, which is kept at a high positive potential, exercises a strong attraction on the free electrons, and thus a stream of them passes through the evacuated space inside the valve, and on through the external circuit. The point to note is that the electrons only travel in one direction; the anode does not emit electrons, and no current can pass in the reverse direction, so that if an alternating potential is applied to the anode, instead of an alternating current passing, a uni-directional current results.

The original vacuum type of valve which was useful for rectification only was greatly improved by the insertion of another element, known as the "grid." It was found that the potential applied to this third electrode exercised great control over the number of electrons passing to the anode, i.e. very small variations of grid potential caused considerable fluctuations in the anode current. This is the fundamental principle of the valve amplifier.

To avoid confusing those who have heard the term "A.C. Resistance" applied to a valve, it is necessary to point out that although the actual electronic current flows through the valve in one direction only, the current is, at the same time, varying in amplitude from a maximum to a minimum value (provided, of course, a signal is being applied to the grid). A current of this nature may be mathematically resolved into two components, one a mean direct current and the other an alternating current superimposed upon it. It is the opposition to the rate of change of the latter which is referred to as the "A.C. Resistance," or anode impedance, the value of which is likely to be very different to the resistance offered by the anode-cathode path of the valve to direct current.

Improvements are continually being made in the performance of valves, and the amateur is fortunate in having a specialised type available for every class of service. Detailed information on these will be found in Chapter 2.

Production of Damped Oscillations

The whole essence of transmission is bound up with the necessity for producing continuously maintained high frequency oscillations, the actual frequency being determined by the size of the tuning coil and associated condenser, as mentioned earlier.

The simplest form of oscillating circuit is shown in Fig. 6 (a), a study of which will enable the reader to visualise how oscillations are produced. When the switch is thrown to the right, condenser C receives a charge from the battery. On operating the switch to the left the charge causes a current A to flow through the coil L. This flow creates a strong magnetic field around L, and the collapse of this field, when the current dies down, produces an E.M.F. across the coil which results in C being charged again, but in the opposite direction; thus a reverse current, B, flows. The whole process repeats itself, and continues until the energy is dissipated in the resistance of the circuit. The oscillatory current so produced is of the form shown in Fig. 6 (b) and as the peaks of each cycle gradually decrease in amplitude, it is termed a "damped" oscillation.

Production of Undamped or Continuous Wave Oscillations

If the circuit possessed no resistance, or if a sufficient amount of energy could be supplied to make up for that lost in the resistance, the current variations would not die away, but would rise and fall continuously to the same peak values. If too much energy was supplied the amplitude of the oscillations would increase, but so also would the losses in the resistance; consequently balance would be automatically restored when the energy lost in the resistance equalled that supplied externally.

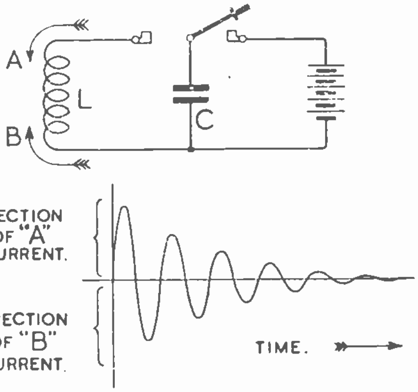


Fig. 6a (top). Fig. 6b (bottom).
How a damped oscillatory current is produced, illustrated in a simple manner.

These constant oscillations are of the "continuous wave" (c.w.) type, and. in practice, are produced by connecting a valve to the circuit in a particular manner. As the effect of so doing is apparently to reduce the resistance of the circuit this method of feeding back energy is often referred to as producing "negative resistance," in contrast to positive resistance.

Reaction

In the case of receivers the feedback can be adjusted to give the tuned circuit a very low effective resistance, so that any received signal builds up to a much greater value than it would do otherwise, although, as some resistance is present, it is still a damped oscillatory current. Selectivity as well as signal strength, is improved by this process.

When the feedback, or "reaction" is increased beyond this point the circuit breaks into self-oscillation, which is a condition where the valve maintains oscillations independent of any externally applied voltages The amplitude of these oscillations will depend upon the conditions of operation of the valve, and is generally proportional to the applied anode voltage Once so adjusted any disturbance, such as the switching on of the filament, is sufficient to set the valve oscillating.

Fig. 7 illustrates the simplest form of oscillatory valve circuit. The main tuned circuit, L_1C_1, is connected between the grid and filament of the valve, whilst the "reaction coil," L_3, in the anode circuit, is placed so that its magnetic field interacts with that of L_1. On connecting the high tension voltage a current will pass through the reaction coil and through the valve. The magnetic field so produced will cut L_1 and induce, say, a negative voltage on the grid. This will reduce the current through the valve, and hence the E.M.F. induced in L_1 will be reversed, since the current in L_3 is decreasing instead of increasing. A positive voltage will then be applied to the grid, resulting in the anode current again increasing. This process will continue, and because the electron stream within the valve alters instantaneously in sympathy with the applied grid voltage, it is possible to produce alternating currents with frequencies of millions of cycles per second.

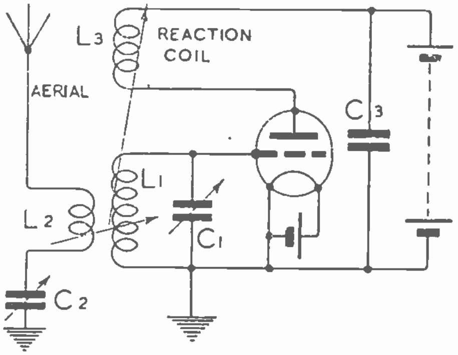


Fig. 7.
Elementary form of oscillating valve circuit for producing undamped oscillations.

Oscillations can be produced in other ways, notably by capacitative, instead of inductive, coupling, but the process is always equivalent to the one already explained. The net result, therefore, will be, that an alternating E.M.F. will appear between the grid and filament of the valve, and an oscillatory current will be produced in the circuit L_1C_1. As the reaction coil has a small oscillatory current (in addition to the direct current from the battery) flowing through it, the by-pass condenser (C_3) shown across the battery is designed to prevent any high frequency energy being dissipated in the resistance of the latter.

If now an aerial circuit is coupled to L_1, the oscillations in the latter will set up a current of exactly the same frequency in the former. The aerial circuit shown in Fig. 7 is of the "series tuned" type, and current in it will therefore be at a maximum when the impedance presented is at its lowest value, *i.e.*, when it is tuned to resonate at the frequency of L_1C_1.

Radiation Resistance

The actual resistance presented by an aerial system is made up of (1) the ohmic resistance of the wire, which, due to "skin effect," is somewhat higher than the normal D.C. resistance; (2) that introduced by leakage and other losses; (3) the "radiation resistance." The latter, which is the only useful factor, is an imaginary value and may be considered to account for the power radiated into space. The current flowing in the aerial will depend on the sum of these resistances. The first two must be kept low by suitable design, but it is desirable to make the radiation resistance as high as possible by adjusting the length of the aerial so that it resonates exactly at the frequency of transmission.

Consider a practical case, if 5 watts of energy is being radiated, and the aerial meter reads ·25 amperes, the application of the usual formula $R = \frac{W}{I^2}$ will give the radiation resistance; in this case $\frac{5}{(\cdot 25)^2}$, or 80 ohms.

With the same aerial carrying ·5 amperes, the power radiated would be 80 $(\cdot 5)^2$, or 20 watts, from which it will be clear that doubling the aerial current results in the power radiated being quadrupled. Conversely, in order to double the radiated power it is not necessary to double the aerial current.

It is of interest to mention that the radiation resistance measured at the centre of a half-wave aerial is about 80 ohms.

Frequency Stability

To produce a steady, reliable signal, which will cause minimum interference with other transmissions, it is essential that the frequency of the transmitter shall be maintained at an extremely constant value. As variations of the aerial circuit will react back on the main oscillatory circuit, when the simple type of circuit shown in Fig. 7 is used, the aerial must not be allowed to sway in the wind, whilst mechanical vibration, and overheating of valves or other components of the oscillator itself must be avoided.

The circuits used in modern transmitters are of a much more complicated type than that shown in Fig 7. For example, some form of frequency stabilisation is usually incorporated in the first stage—the actual oscillator—after which the power is built up through several further amplifying stages, culminating in the power amplifier stage (which feeds the aerial), variations in the capacity of which, do not then affect the frequency.

Modulation

Having produced the necessary continuous waves, some means must be provided for conveying intelligible signals through their medium to the distant listener. This process is known as "modulation," and, in its simplest form, consists of completely interrupting the radiated waves to form the dots and dashes of the Morse Code. To effect this method of communication a key must be inserted in some part of the transmitter circuit, so that it becomes possible to cut off the power supply to one or more valves.

Numerous methods of keying have been evolved, and it is necessary to pay particular attention to whichever is adopted, for the reason that interference may be caused to neighbouring broadcast receivers. Keying circuits, and the means used for the avoidance of key-clicks are given in Chapter 7.

The carrier " envelope," as it is called, of a telegraphic wave is as shown in Fig. 8 (a), from which it will be seen that the amplitude of the oscillations, under keying conditions, is maintained at a steady value.

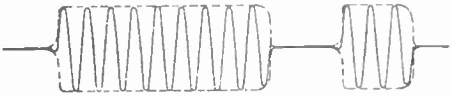


Fig. 8a.
The carrier envelope resulting when employing telegraphy.

To effect the modulation necessary for the transmission of speech or music, the carrier envelope must be continuously maintained, and the audio-frequency superimposed upon it. The resulting shape is shown in Fig. 8 (b), the dotted line representing the audio-frequency variations, and the full line the amplitude of the high-frequency oscillations, of which there are many more than those shown. A faithful copy of this envelope is carried to the receiver, where, after rectification, to eliminate the high-frequency component, the speech or music becomes audible. There are many methods of achieving modulation; those most suited to amateurs being described in Chapter 7.

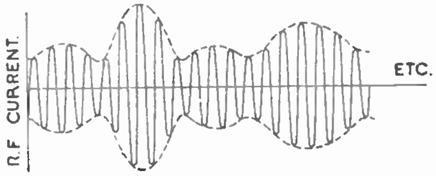


Fig. 8b.
The carrier envelope resulting when telephony is employed.

Crystal Oscillators

In later chapters particulars are given of various types of transmitters, but the reader will probably appreciate at this stage an outline of the fundamental principles upon which practically all modern transmitters depend.

Of the several types of oscillator available, the best, and most popular, is the one which has its frequency controlled by means of a thin slice of quartz. The latter is usually placed between the grid and filament of the valve, and acts as a very sharp resonant circuit, possessing extremely low losses.

There are different types of quartz, and several methods of cutting it to produce oscillation, each giving different degrees of stability (frequency change with temperature) and thereby allowing the crystal to control more or less power. The property which enables a quartz crystal to produce oscillations (called " piezo-electricity ") acts in two ways. If the crystal is inserted between two metal surfaces, and subjected to a slight pressure, it causes a slight difference of potential between the metal plates. Conversely, if an alternating voltage is applied to the plates, the crystal will mechanically vibrate. In practice, the applied alternating voltage (which must be of the same frequency as the crystal), is taken from the anode of a valve *via* the small internal capacity between it and the grid. Since this voltage is also applied to the grid, a magnified version of it appears across the tuned anode circuit, the frequency of which is controlled entirely by the crystal. If, for the sake of argument, the anode circuit was tuned to a frequency different from the natural one of the crystal, the voltage fed back to the grid would be out of phase, and the mechanical vibration of the crystal would cease, resulting in the whole circuit becoming lifeless.

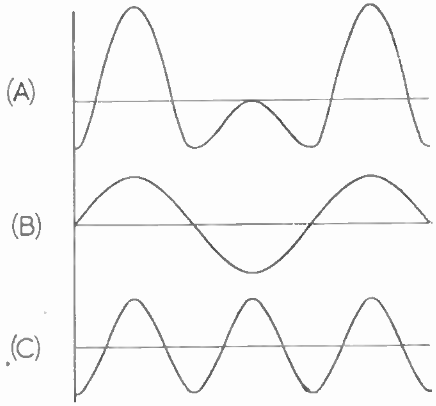


Fig. 9.
Any wave, no matter how distorted, can be broken up into a number of sine waves. A simple example is shown.

A crystal may possess subsidiary resonant frequencies, but these seldom give trouble, because it needs a much greater amount of feedback to produce oscillations at a subsidiary frequency, whilst, in addition, the anode circuit, when tuned to the main frequency, and presenting a high impedance to it, would offer only a low impedance to the subsidiary one, and little or no voltage would be developed at this frequency.

Sine Waves

Cycles of current have been referred to a number of times, and, as mentioned earlier, this term refers to one complete alternation starting at zero, rising to a positive maximum, falling again to zero, rising to a maximum in the reverse direction, *i.e.* negative, and finally reaching zero again. If this operation takes place smoothly, according to certain mathematical laws, it is referred to as " sine wave," an example of which is shown in Fig. 9 (B). Domestic 50 cycle alternating current mains as a general rule give a pure sine wave form.

Production of Harmonics

When a sine wave voltage is applied to the grid of a valve working on the straight portion of its characteristics, the magnified wave superimposed on the anode current is an exact copy of the original, thereby giving distortionless amplification, as coil used—a somewhat difficult matter, since the electrical centre is not always the same as the physical centre.

It will be readily appreciated that, at any given instant, the polarity of the voltages appearing at opposite ends of the coil will be equal and opposite, since the circuit as a whole is balanced. A voltage is fed back to the grid *via* the capacity between the grid and anode while another voltage is also fed back through the neutralising condenser, but since this is connected to the other side of the circuit, the second voltage is of opposite polarity. When N.C. is adjusted to have exactly the same capacity as that existing in the valve the two voltages cancel out and the valve will operate in a perfectly stable manner.

There are several ways of determining the correct adjustment of the neutralising condenser. A reliable one is to disconnect the H.T. supply to the power amplifier and rotate the tank condenser. When it passes through resonance an upward kick will be seen in the meter measuring the anode current to the previous stage. (This is because additional power is being drawn from the earlier stage, and the input to it increases). Now reduce the capacity of the neutralising condenser and note whether the meter reading is higher or lower, at the same time resetting the tank condenser to resonance, because the variations of the neutralising condenser will upset it slightly. If the reading is higher, increase the capacity of the neutralising condenser, and continue the process until no change takes place in the meter reading when the tank condenser is rotated.

Instead of using the meter which reads the anode current to the earlier stage, the indications may be observed on a grid current meter fitted to the power amplifier.

Push-pull amplifiers also require neutralising, the methods being the same, except that two condensers are required, and both must be adjusted simultaneously keeping their capacities as nearly equal as possible.

The only valves which do not require neutralising are the modern screen-grid, pentode and tetrode valves specially designed for transmission, in which the anode-grid capacities have been reduced to very small values. When used, care is necessary in the layout, whilst screening must be provided to prevent inter-action between the anode and grid circuits.

Grid Bias

All valves, with the exception of a few battery types which operate at low anode voltages, and "Class B" valves specially designed to operate without it, require grid bias for their correct functioning.

The various methods of obtaining grid bias may be roughly classified as (*a*) from a battery or other fixed source, such as a rectified A.C. supply, (*b*) from a cathode resistance, and (c) by means of grid current. Combinations of these are frequently used in practice.

Fig. 14 illustrates circuits applicable respectively to each method. Method (*a*) is self-explanatory: the positive pole of the battery, which, for transmitting purposes, is often a 120 volt H.T. battery, is connected to the filament of the valve, the applied bias being varied by connecting the lower end of the coil to a suitable tapping on the battery.

In method (*b*) the whole of the direct current passing through the valve is also made to pass through a resistance, which may be either fixed or variable, but which must be capable of carrying the current, and of dissipating the heat generated. The voltage drop across this resistance will result in the cathode becoming positive with respect to the earth line, and, therefore, to the grid. This is the equivalent of stating that the grid is negative to the cathode which is the essential requirement.

Method (c) is not quite so simple to explain. The drive is obtained from the coil L, which is inductively coupled to the previous stage. An alternating E.M.F. appears across the grid and filament of the valve, and, as these two elements form a diode, current will flow through the valve in one direction only, *i.e.* rectification will occur. The rectified current will also flow through R, and the voltage set up across it will result in the grid receiving a negative bias. This action is independent of the anode connections, but the amount of current will vary according to the loading and circuit conditions of the anode.

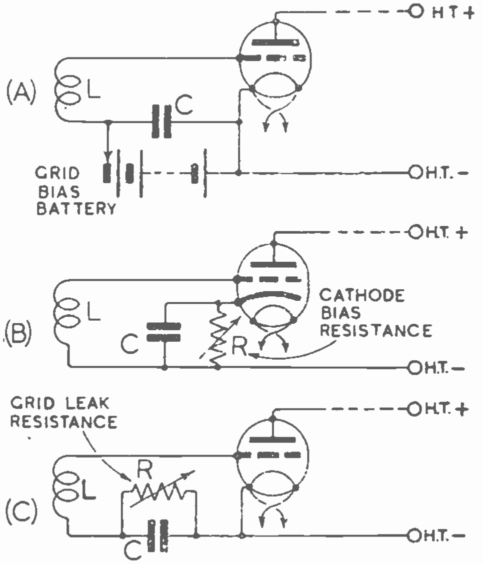


Fig. 14.
The three common methods of obtaining a negative grid bias voltage.
A. Fixed Battery Bias.
B. Cathode Resistance Bias.
C. Grid Current Bias.

Method (*a*) or (*b*) is often used to provide a certain amount of fixed bias, first to protect the valve, and second to prevent high anode currents flowing, whilst a resistance connected in the grid return provides additional bias, varying according to the amount of drive. This feature is useful, as the more drive applied the greater the bias required.

Care must be taken in using a battery, because the grid current which flows, tends to charge it, whilst the internal heating which results has a tendency to dry it up and to increase its resistance, so that the applied voltage is greater than the measured voltage, owing to the latter itself acting as a grid resistance. If only a few milliamperes flow this effect is negligible.

Method (*b*) is generally used when indirectly heated valves are employed as audio amplifiers, or for crystal oscillators and frequency doublers in the early stages of a transmitter. A combination of methods (*a*) and (*c*) is desirable with power amplifiers.

In Fig. 14 it is assumed that *inductive coupling* is used. This method is to be preferred, as it enables the source of bias to be placed at the low potential end of the coil, giving lower losses. In the case of capacitative coupling, coil L must be replaced by a radio-frequency choke, in order to prevent the radio-frequency currents being short-circuited to earth and also to keep them to their proper path.

The condenser C provides the radio-frequency currents with a low resistance path to the filament of the valve, as losses would occur if these currents were allowed to traverse the resistance or battery. This condenser, which must be of large value, is not connected with the tuning of the circuit.

Static and Man-made Interference

Interference may be of several types. That known as static consists of noises which have nothing to do with the receiver or with signals additional to the one it is desired to receive. Static noises or, to give them a more familiar name, " atmospherics " can be a nuisance on broadcast wavelengths during periods of thunder or electrical storms, and they can be very troublesome on the lower frequency amateur bands (80 and 160 metres), especially during summer nights, making it, at times, difficult, if not impossible, to read signals. Atmospherics are caused by lightning discharges between clouds and earth or between cloud and cloud, and as they cover a very wide frequency spectrum, it is impossible to tune them out. The power involved in a lightning flash is tremendous and the electromagnetic radiations resulting can be heard over a radius of hundreds of miles. Fortunately, their effect becomes less as the frequency increases and they are not very noticeable on the higher frequencies unless the source is comparatively close. " Mush " is sometimes in evidence, being, as its name indicates, a steady roar in the background instead of sharp crackles of noise. It is probably due to the combined effect of many distant storms. Mush may either be continuous or may come in " waves." Another effect sometimes experienced consists of waves of " hissing," rising to a peak and dying away again. This is probably connected with phenomena in the upper atmosphere.

Rain or hail falling from an electrified cloud is itself negatively charged, and on striking an aerial, the charge is transferred and gives rise to a succession of crackling noises in the receiver, whilst if a series condenser is included in the aerial circuit, sparks will jump across it. To avoid this, if for no other reason, it is desirable to earth directly each and every aerial during such storms.

" Man-made " static is the name given to electrical interference from machinery or similar apparatus. Motors with worn commutators or brushes, and neon signs are bad offenders in this respect and, if the noise is received through the aerial, little can be done at the receiving end to eradicate it. If the noise is mains-borne, suitable filters will minimise it, but the only really satisfactory method is to fit suppressors as close as possible to the offending apparatus. As the interference caused in this way can be severe on any frequency, including those allotted to television, it is possible that a law will be passed in the future prohibiting the installation of apparatus or machinery liable to offend in this way.

The ignition systems of motor cars, and buses are another cause of interference, especially at high frequencies, resulting in a loud crackling noise in the receiver. The range of these spurious transmissions fortunately is limited to a radius of a few hundred feet, nevertheless a receiver located near to a busy road can be rendered useless by this form of interference.

Diathermy apparatus has, however, been known to cause interference up to several thousands of miles.

Interference between Stations

The other type of interference often experienced is that caused by the carrier of a station operating on a frequency near that of the one it is desired to receive, causing a heterodyne whistle. The severity of the interference is affected by the design and operating conditions of both receiver and transmitters. As the receiver has to separate the desired signal from the noise and interference, it is necessary to make the ratio of signal strength to noise strength as high as possible. External noise has been discussed previously and the internal noise, due chiefly to valves and resistances, can be kept low by using good components, whilst an R.F. stage will help considerably. The reader is here referred to the series of diagrams given in Fig. 15.

To receive telegraphy, only a very narrow band width is necessary—a few hundred cycles—so that, if the receiver is made very selective, it will receive the desired signal and little (in proportion to the noise and interference) on each side of it. This point is illustrated in Fig 15 (B). If, on the other hand, the receiver possesses broad tuning (*i.e.* is unselective), it will receive far more of the interference than is necessary, as shown in Fig 15 (A). The band width must be wider for the clear reception of telephony, but need be no more than two kilocycles (*i.e.* one kilocycle each side of the carrier frequency) unless experiments particularly directed at high quality are being carried out.

Fig. 15 (C) illustrates the effect which occurs when a broad signal (shown by the shaded portion) is transmitted and received on a broadly tuned receiver. The latter must be unselective to receive the signal properly, and therefore may receive a good deal of noise and interference in addition.

Should a selective receiver be used, only a small portion of the signal will be received, and the signal will sound proportionately weaker, Fig. 15 (D). When two broad signals are transmitted, as in Fig. 15 (E), on nearby frequencies, a broadly tuned receiver will accept both almost equally well, but if the desired signal is a sharp one Fig. 15 (F), a sharply tuned receiver will receive it with only a

World Radio History

small amount of interference from the broad signal.

It should be explained that the term " broad " signal is used to indicate one which is of poor frequency stability and one which is varying about the actual frequency intended. Additionally it may be one of poor quality having a certain degree of A.C. modulation, caused by the use of imperfectly filtered high tension supplies or a badly designed master oscillator. Signals of this type are rarely emitted from stations in Great Britain but very bad examples may still be heard originating from countries in various parts of the world.

From a consideration of the foregoing it will be seen that, from all points of view, it is essential to ensure that the transmitter emits a signal of first-class quality, *i.e.* one which is perfectly clean, clear-cut and steady and having the added advantage of concentrating its power on one single frequency. Furthermore, it is necessary to use a selective receiver which will make the most of such a signal, whilst responding very little to noise and interfering signals. In these days of crowded frequency bands there is no room for bad signals ; in any case, with the modern receiver it is often difficult to decipher poor quality signals at all.

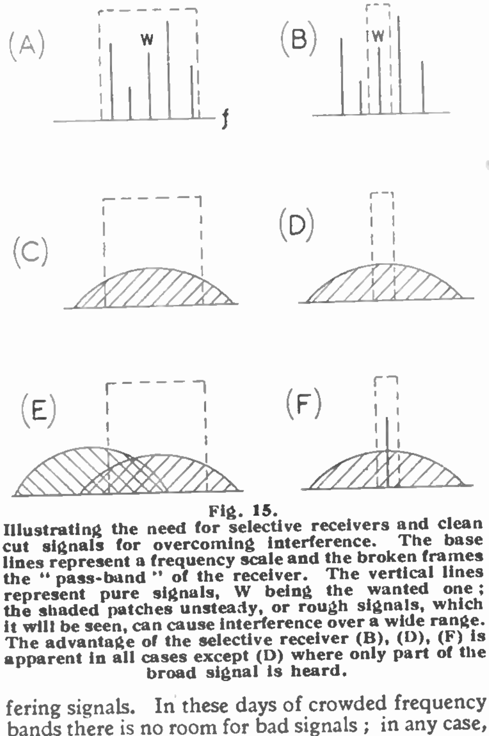


Fig. 15.
Illustrating the need for selective receivers and clean cut signals for overcoming interference. The base lines represent a frequency scale and the broken frames the " pass-band " of the receiver. The vertical lines represent pure signals, W being the wanted one ; the shaded patches unsteady, or rough signals, which it will be seen, can cause interference over a wide range. The advantage of the selective receiver (B), (D), (F) is apparent in all cases except (D) where only part of the broad signal is heard.

Short-Wave Receiver Technique

The technique applied to short-wave receivers used for communication work is quite different from that which applies to broadcast receivers.

The chief requirement of a short-wave receiver is that it should be capable of bringing in weak signals from distant stations with maximum intelligibility. This does not mean loudness only, but also quietness of background noise, and good selectivity, *i.e.* ability to discriminate against signals on a nearby frequency which are likely to interfere with the one it is desired to receive. As the amateur bands, for example, occupy only small channels in the radio-frequency spectrum it is desirable to spread any one band over the major portion of the tuning dial. For this purpose a slow-motion dial must be used, and this should be free from " backlash " (*i.e.* a tendency for the relative position of the dial and the driven condenser to change) and from inherent noise. This tuning control is necessary in order to make it easier to pick out any particular signal, and also to avoid the possibility of passing over weak ones without hearing them. This refinement, known as " band-spreading," is accomplished by using one condenser for rough tuning which is set to the band in use, and another of much smaller capacity (15 $\mu\mu$F or thereabouts) in parallel with it. The percentage variation of the total tuning capacity is then very small.

In order that the signal voltage reaching the grid may be at a maximum the L/C ratio of the tuned circuit should be moderately high, and the components selected (especially the coil and condensers) of the highest possible quality. These requirements are to avoid the introduction of losses and a reduction of the " Q " of the circuit.

Straight Receivers

A single valve, used as a leaky grid detector, becomes, with the aid of reaction, a most sensitive device, and is capable of detecting signals transmitted thousands of miles away. It is usual to add a single stage of audio-frequency amplification —two stages tend to bring up the noise level, and confer little benefit as a rule—and two-valve receivers of this type are in use at many amateur stations. The coupling between the two valves may be any of the usual types—transformer, choke, or resistance-capacity. In amateur parlance this type of receiver is referred to as an " 0–V–1," the " V " meaning the detector valve, and the " 1 " the audio-frequency amplifier. If a radio-frequency amplifier is used in front of the detector the receiver becomes an " 1–V–1."

With an 0–V–1 receiver it is not desirable to use an aerial cut to resonate at a frequency within the amateur bands, because by so doing it will impose a heavy load on the tuned circuit at the resonant frequency (or a harmonic of it). This will cause the detector valve to stop oscillating, necessitating constant adjustment of the aerial coupling. The latter may be either inductive or capacitative. Often an aerial accidentally resonates, and to prevent this occurring a small variable condenser in the aerial lead-in may be set at such a value as to cause the resonance to disappear ; alternatively a small loading inductance may be added. The best method of all, however, is to include a screened grid valve acting as a radio-frequency amplifier, as this confers many additional advantages. Signal strength is increased in greater proportion to the background noise, selectivity is increased, the reaction control is smoother, and a swaying aerial will not affect incoming signals, as it is otherwise likely to do.

Beat Reception

For the reception of c.w. signals a local oscillation must be provided of a frequency very near to

World Radio History

that of the incoming signal. The frequency of the resulting beat-note heard in the telephones is the difference between the two radio-frequencies, so that by varying the frequency of the local oscillator the pitch of the note can be altered. The local oscillations are produced in a "straight" receiver by allowing the detector valve to oscillate weakly, so that the frequency of the tuned circuit must be slightly different to that of the signal; this does not affect the strength of the signals to any extent. In a superheterodyne receiver a separate valve, known as the "beat-frequency oscillator" (B.F.O.) is usually provided. It is good practice to adopt this same device in a straight receiver, but more skill is then required in tuning.

The frequency of the receiver may be adjusted either higher or lower than that of the desired incoming signal to produce the audible "beat-note"; and it is often useful to change from one side to the other of the beat to avoid interference. To give an example: suppose the desired signal to be on 7,200 kc, whilst another signal on 7,201 kc is causing interference. If the receiver is set to 7,200·5 kc the desired signal will produce a beat-note of the difference in frequency, namely 500 cycles. The interfering station which will also be separated by the same difference, will produce an identical beat-note, making the wanted signal very difficult to read. If, however, the receiver is set at 7,199·5 kc the desired signal will still produce a 500 cycle beat, but the other will give a 1,500 cycle note, so that the two can be more easily distinguished.

Superheterodyne Receivers

As many stations operate within the narrow amateur bands, it is often difficult to separate a particular signal sufficiently on an 0–V–1 receiver to make it clearly readable. A three-valve receiver, with a radio-frequency amplifying stage, improves matters, but to obtain high selectivity some sensitivity has to be sacrificed. The "superheterodyne" receiver will, however, when properly adjusted, give both high selectivity and high sensitivity.

The principle upon which a superheterodyne works is similar to that previously described for receiving c.w. on a straight receiver. A local oscillator must be provided, but in this case the difference in frequency is much greater, being usually in the region of 450 kilocycles. The incoming signal (this time tuned in exactly on resonance), and the locally produced oscillations, are injected into a common valve, where "mixing" will take place, by virtue of the rectifying action. Such a valve is known as a "mixer." The radio-frequency beat is then extracted in the anode circuit, and passed on to one or more "intermediate frequency" (I.F.) amplifying stages.

The "Q" of the tuned circuits relative to the I.F. amplifier is made very high, and the circuits therefore become very sharply resonant, or, in other words, highly selective. Their response falls off rapidly on either side of the resonance peak, consequently interfering signals are attenuated, and are much less likely to be audible. The selectivity (and the gain) increases with the number of I.F. stages, but in practice it is not usual to use more than two, as it then becomes difficult to prevent instability occurring. The selectivity may be varied by altering the coupling between the two coils comprising the I.F. transformer—loose coupling gives high selectivity, and tight coupling the reverse. This is the principle used in a "variable selectivity" heterodyne receiver, and is a desirable feature when receiving telephony, as too narrow a band width will result in distortion.

Second-Channel Interference

Interference is still likely to result from an incoming signal of such a frequency as to produce the correct intermediate frequency. This is known as "image" or "second channel interference," and will be made clear by reference to Fig. 16, in which the desired signal is shown as being on 7,200 kc, and the local oscillator on 7,700 kc, O_2 in this case, giving the necessary beat frequency of 500 kc. A commercial signal on 8,200 kc occupying position C_2, which is 500 kc the other side of the oscillator frequency, would also produce the same beat frequency, but the receiver would respond much less readily to it, as the input circuit would be 1,000 kilocycles off tune. Changing the oscillator frequency to 6,700 kc (position O_1) would not effect a cure, as interference from a station on 6,200 kc (C_1) would be likely. A higher intermediate frequency places the interfering signal further off tune, but amplification falls off as the I.F. is increased.

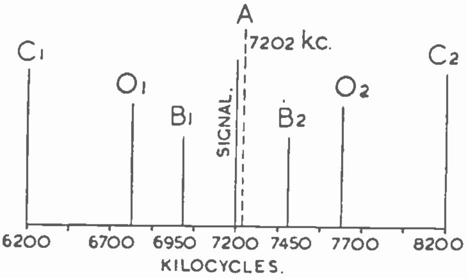


Fig. 16.
This diagram indicates with the text the basic principle of a superheterodyne receiver.

Another peculiar effect may occur when two signals are being received, their frequencies giving the beat frequency, without the aid of the local oscillator. In Fig. 16 such signals may occupy positions B_1 and B_2, and an interfering signal would be heard on top of the desired one.

The cure for both trouble is to use a radio-frequency stage or "pre-selector," preceding the frequency changer, so that the input circuits are made more selective to the desired signal and do not pass on signals on near-by frequencies.

Single Signal Superheterodyne Receivers

To make c.w. signals audible another local oscillator, beating this time with the intermediate frequency, is necessary; when the latter is 500 kc the beat oscillator will be on kc 499 giving an audio-frequency beat-note of 1,000 cycles. In Fig. 17, A represents the desired signal, and B the local oscillator. Another signal at C, which may be caused by a local transmitter, and be fairly strong despite the previously mentioned precautions, will also give rise to a 1,000 cycle beat-note. The sharper the response curve the lower will be the audibility of the interfering signal. There are two common methods of producing this result. One is the introduction of regeneration (reaction), so reducing the resistance of the I.F. circuits; the other is the use of a quartz crystal, which, as has been shown, is equivalent to an exceedingly resonant tuned circuit. By introducing special phasing arrangements, one side of the curve shown in Fig. 17 may be made to fall off very rapidly, with the result that signals only become audible on one side of it; thus they take up only one half of the space otherwise occupied. Interference may be completely removed by these means. Receivers embodying either of these methods are known as single signal superheterodyne receivers.

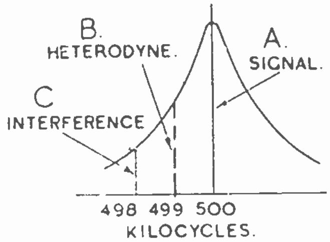


Fig. 17.
Illustrating the principle of a single signal superheterodyne receiver.

Crystal Band Pass Filters

The use of crystal band pass filters is fully described in a later Chapter. The installation of such filters will in all cases greatly improve the selectivity of a superheterodyne receiver.

Micro Waves

As the frequency is increased beyond normal amateur frequencies, it becomes increasingly difficult to obtain good efficiency. This has led to the development of several types of oscillators working on principles somewhat different from those outlined earlier. The Barkhausen oscillator is an example, in which there is no tuned circuit; the grid is given a higher potential than the plate—both through chokes—and the output is delivered to a pair of parallel conductors connected to plate and grid. The principle of this oscillator is that the electrons are attracted to the grid, but shoot through its meshes and come into the region of the lower plate potential. They slow up and swing back to the grid, but some again miss the meshes. They finally fall into the grid, but may make several oscillations through its meshes before doing so. The frequency is determined primarily by the grid potential.

Gill-Morrell oscillations are really Barkhausen oscillations generated when a tuned circuit is connected to the oscillator; the tuned circuit is found to have a modifying influence on the frequency.

The Magnetron

The Magnetron which is often used for generating appreciable powers at ultra-high frequencies consists of a split anode of cylindrical form surrounding a filament. The tuned circuit is connected between the anodes, and the H.T. is supplied to the anodes by a centre tap on the coil. The valve requires a rather bulky magnetic field system, but is capable of producing comparatively large powers at good efficiencies, although it is difficult to modulate the oscillations.

Further information regarding very high frequencies is given later in this book. Suffice it to say that radio amateurs are especially interested in this wide and little known part of the spectrum.

Conclusion

In the space available it has not been possible to enlarge upon any one subject, but it is hoped that the beginner will find pointers to many of the problems which are likely to require solution once he decides to make amateur radio his hobby.

TECHNICAL ABBREVIATIONS

Numerous technical terms used in this publication are frequently abbreviated. The more general abbreviations are given in the List which follows:—

A.C.	Alternating Current.
A.F.	Audio-frequency.
B.F.O.	Beat Frequency Oscillator.
C.O.	Crystal Oscillator.
c.p.s.	Cycles per second.
D.C.	Direct Current.
E.C.O.	Electron-coupled Oscillator.
E.M.F.	Electro-motive Force.
F.C.	Frequency Changer.
F.D.	Frequency Doubler.
G.B.	Grid Bias.
H.T.	High Tension.
I.F.	Intermediate Frequency.
kc.	Kilocycle.
L.F.	Low Frequency.
L.T.	Low Tension.
mA.	Milliampere.
Mc.	Megacycle.
P.A.	Power Amplifier.
R.F.	Radio-frequency.
R.F.C.	Radio-frequency Choke.
S.S.S.	Single Signal Superheterodyne Receiver.
T.P.I.	Turns per inch.
T.P.T.G.	Tuned Plate-Tuned Grid.
T.R.F.	Tuned Radio Frequency.
U.H.F.	Ultra-high Frequency.
V.	Volt.

World Radio History

Chapter Two

RADIO VALVES AND THEIR USES

Valve Theory—Valve Functions—Amplifiers, Oscillators, Rectifiers, Detectors—Valve Types—Receiving, Transmitting, and Rectifying—Footless Valves—Electron Multipliers—Valve Data.

IT is intended in this Chapter to cover a general survey of modern valves, but before the various types are dealt with, it is desirable to explain briefly the theory of operation and the constants and nomenclature in general use.

VALVE THEORY

The simplest form of valve is the two electrode or *diode*, which consists of a filament (or cathode) and anode, the latter surrounding the filament more or less completely. The two electrodes are contained in a bulb in vacuum, the reason for which will be discussed later. If the filament is heated to a fairly high temperature, the molecules of which the filament is composed will be in a state of violent agitation. If the temperature is high enough, atoms composing the molecules will fly off from the filament; these atoms have numbers of free electrons associated with them.

Electron Flow

When an electron leaves the parent molecule the latter becomes positively charged due to the fact that the number of electrons remaining are insufficient to neutralise the positive charge in the molecule. As the electrons are themselves negatively charged, there is, as a result, a force tending to pull them back to the filament. A positively charged body (the anode) is placed near the hot filament in order to attract these electrons. As they travel through the space between the filament and anode they may encounter molecules of gas, which impede their progress. Consequently, it is essential that the amount of gas in the valve should be a minimum. A valve which has been properly evacuated of gas is described as " hard." If there is some gas present, the collision between the electrons and molecules of gas will ionise the gas and a visible blue haze will appear between the electrodes.

Space Charge

As there are electrons travelling from the filament to the anode, they form a cloud in the intervening space. This cloud is in itself an electric field or charge in the space between the filament and anode, hence its name, *space charge*. The charge tends to repel the electrons leaving the filament because it is of the same polarity, consequently the potential applied to the anode, in the form of H.T. voltage, must be sufficient to overcome it. If sufficient potential is applied to the anode, electrons will travel from filament to anode, and *via* the external circuit back to the filament. This means that there is an electron flow externally from anode to filament, and due to the fact that current, as we know it, is in the opposite direction to electron flow, a meter will show a current flowing from the positive H.T. to the anode.

If the H.T. voltage or anode potential is increased the electron flow or current will increase, and it will continue to increase with an increase in voltage up to a point when the space charge is completely neutralised, and the *total emission* of the filament is reached. This value can only be altered by changing the filament temperature.

It will be obvious that if no potential, or a negative potential, is applied to the anode, there will be no electron flow due to the space charge being unneutralised. Hence in regard to anode current, the valve is a unilateral device, in other words, current can only flow in the anode circuit in one direction. Thus the principal use of a diode is as a rectifier.

Purpose of the Grid

In order that the anode current may be controlled by other means, another electrode is placed between the cathode and the anode. This third electrode, which is known as a *grid*, consists of a helix of fine wire. The additional electrode changes the diode into a *triode*.

By varying the potential on the grid the space charge can be modified in the same way as the anode current is varied by varying the anode voltage. The grid, because it is an open helix or mesh, does not present any obstacle to the electron flow, and as long as the potential on it is negative with respect to the cathode or negative end of the filament it will attract no free electrons, but if it becomes positive, electrons will flow to it in the same way as to the anode. When this occurs *grid current* will flow.

World Radio History

If the grid potential is varied, the anode current will vary in the same way ; further, if a resistance (or load) is connected in the anode circuit, a voltage drop will be obtained across it, which will vary in the same way. If this resistance has a suitable value the variation of voltage drop will be of greater amplitude than that of the variation of grid voltage ; hence the property of the triode valve to amplify.

Mutual Conductance

The ratio of the change of anode current to the change of grid voltage is known as the *mutual conductance* (*g*), or slope of the valve, and is measured in milliamperes per volt. It is also sometimes expressed in micromhos, which is a unit of conductance. A thousand micromhos equal one milliamp. per volt ; for example, a valve with a slope of 4,000 micromhos has a slope of 4 mA/V.

Amplification Factor and Impedance

If the grid is made more negative, and the anode voltage raised, or the grid made less negative and the anode voltage lowered, it is possible to arrange the values so as to keep the anode current constant and of the same value in each case.

The ratio of change of anode volts to change of grid volts for constant anode current is known as the *amplification factor* (μ).

The amplification factor divided by the mutual conductance is known as the *impedance* (Ra) or A.C. resistance of the valve, and is equivalent to a resistance in series with the external H.T. circuit. In this case the mutual conductance must be in amperes per volt in order to express the units correctly.

The formula for finding the impedance of a valve is :—

$$\text{Impedance (Ra) ohms} = \frac{\text{Amplification factor } (\mu)}{\text{Mutual conductance (amps./volt)}}$$

For example, if a valve has an amplification factor of 600 and a mutual conductance of 10mA/V or 0·01 amps./volt, then :—

$$\text{Impedance} = \frac{600}{0{\cdot}01} = 60{,}000 \text{ ohms.}$$

Load Impedance

The resistance or load connected in the anode circuit of a valve is known as the *load impedance.* This has a value for triodes of between one and ten times the valve impedance (except in special cases), depending upon whether the valve is used as a voltage amplifier or as a power amplifier. A voltage amplifier is one such as would be used as an intermediate stage in an audio amplifier, usually resistance capacity coupled. A power amplifier would be used in an output stage feeding a loudspeaker, or as the modulator in a transmitter.

Voltage Gain

In the case of a voltage amplifier the gain per stage is proportional to the ratio of the external load impedance to the valve impedance. This can be expressed as :—

$$\text{Voltage gain} = \frac{\text{Amplification factor} \times \text{external load impedance}}{\text{External load impedance} + \text{valve impedance}}$$

For example, a valve possessing an amplification factor of 50, working into an external load of 50,000 ohms and possessing an impedance of 50,000, will give a stage gain of :—

$$\frac{50 \times 50{,}000}{50{,}000 + 50{,}000} = 25$$

That is to say, the ratio of the external load to the valve impedance has reduced the effective amplification factor by one-half. If a valve is chosen having a higher mutual conductance, *i.e.*, for the same amplification factor a lower impedance, the stage gain will be increased. In the example chosen above the valve has a mutual conductance of

$$\frac{50}{50{,}000} = 1 \text{ mA/V}$$

but if it had a mutual conductance of 2 mA/V and the same amplification factor, the voltage gain would be :—

$$\frac{50 \times 50{,}000}{50{,}000 + 25{,}000} = 33$$

In the case of an amplifier where the load impedance is very low compared with the valve impedance (such as in a television receiver), an approximation can be obtained from the expression :—

Voltage gain = mutual conductance × load impedance.

This expression is obtained from the fact that in the earlier formula the term amplification factor can be replaced by " mutual conductance × valve impedance " and the denominator can be written as valve impedance, since the load impedance is so small when compared with it.

Anode Dissipation

Anode dissipation is the power measured in watts which is expended in the anode of a valve and dissipated as heat. The term must not be confused with either power output or power input (anode watts from H.T.).

In any valve the anode dissipation is the remaining power left, after the useful R.F. or A.F. power output has been deducted from the power input, *i.e.*, the H.T. supply. In the case of amplifiers operating under Class A, or normal bias conditions, the anode dissipation can be considered as the input power, but for oscillators or Class B, C or Driven Class A amplifiers the dissipation may be only 40 per cent. of the input power, depending upon the efficiency obtained. (The terms Class A, B and C are described on p. 30).

Output or Optimum Load

Output load or *optimum load* is the load connected in the output circuit, the values of which are determined to suit the valve at various operating conditions. These values are usually quoted in makers' catalogues. The load for a triode is determined as the load that gives a reasonable power output consistent with a low harmonic distortion. For push-pull operation the load is known as plate-to-plate load and is usually rather lower in value than twice that of one valve alone. Particularly is this so in the case of pentodes, because such valves are matched as a single ended stage for minimum second harmonic, whereas in push-pull they are matched for minimum third harmonic. Where Class B or reversed feedback is used the conditions are quite different and in no case must the catalogue figure for normal Class A operation be taken as correct.

World Radio History

Power Output

Power output is always a relative and often an ambiguous term because a definite figure is difficult to rely upon. In the case of an amplifier the harmonic content of the output must be stated, and in the case of oscillators the circuit conditions and frequency must be known. For Class A amplifiers the approximate power output may be calculated by multiplying the R.M.S. input voltage ($0\cdot707 \times$ grid bias), by the mutual conductance at the operating point, then squaring the result and multiplying this by the output load impedance.

For example, if a valve has grid bias of 16 volts and a mutual conductance of 2·5 mA/V working into an output load of 6,000 ohms, the power output would be :—

$$\left(\cdot 707 \times 16 \times \frac{2\cdot 5}{1000}\right)^2 \times 6{,}000 = 4\cdot 1 \text{ watts.}$$

It should be borne in mind that this formula takes no account of distortion, therefore, for greater accuracy 1 volt should be deducted from the grid bias, because in practice it is not possible to swing the grid more positive than -1 volt, as grid current will flow. Furthermore, this formula assumes that the output load is low compared with the valve impedance.

Load Lines

Load lines are lines which can be drawn on the anode volts—anode current curves of a valve from which the power output and harmonic content can be studied.

For example, in Fig. 2 the line AB represents a load impedance given by :—

$$\frac{450 \text{ volts}}{180 \text{ mA}} \text{ } i.e., \text{ } 2{,}500 \text{ ohms.}$$

Input Impedance

Input impedance is the apparent resistance of the grid to cathode or filament of a valve, and is a figure difficult to determine as it is dependent upon the frequency and the type of load in the anode circuit of the valve (*i.e.*, inductive, resistive, etc.). In the case of triodes, it is approximately equal to the reactance of a condenser whose value is the grid to anode capacity multiplied by the amplification factor. In the case of screened grid and pentode valves the grid to anode capacity is very small and no approximate figure can be calculated easily.

Grid Emission

Grid emission is the condition where the grid of a valve commences to emit electrons itself and, figuratively speaking, competes with the cathode, thereby producing a flow of grid current. If a high resistance is present between the grid and cathode, the current will be in such a direction as to neutralise the grid bias and, at the same time, damp the circuit heavily. The effect is due to the heating of the grid by the close proximity of the hot cathode and by radiated heat from the anode. The effect is accentuated if any active cathode coating adheres to the grid. The effects are avoided by keeping the grid-cathode resistance path low and by avoiding excessive heater or anode temperatures (*i.e.*, by avoiding over-running the valve).

The symptoms of grid emission in a P.A. or F.D. stage are falling output and falling drive when the key is held down, whilst the symptoms in an output stage are an increase in anode and screen current, accompanied by distortion, after the valve has been run for some time.

Anode Emission

Anode emission is similar to grid emission but occurs when the anode attains sufficient temperature to emit electrons. This effect gives most trouble in the case of rectifiers, causing breakdown between anode and cathode (or filament) or loss of emission.

Conversion Conductance

Conversion conductance is the term used in conjunction with detectors or frequency changers to represent the ratio of the output current of one frequency to the input voltage of another frequency, as, for example, in a first detector of a superheterodyne receiver. The conversion conductance is the current in the anode circuit at I.F. (measured in micro-amperes) divided by the input voltage to the grid of R.F., the symbol being µA/V.

Conversion or Translation Gain

Conversion or *translation gain* is the ratio of I.F. output voltage to R.F. input voltage. The figure is bound up with the dynamic resistance of the I.F. transformer used in the anode circuit. Both are a measure of the efficiency of the valve as a detector or frequency changer.

Screen Grid Valves

When an A.C. input voltage is applied to the grid of a valve an amplified A.C. voltage appears across the output load in the anode circuit, and, due to the fact that there is a capacity between the grid and anode which acts as a condenser, some of this voltage returns to the grid again. Whether it appears in a direction tending to aid the input voltage or to cancel it depends upon the type of load in the anode, *i.e.*, inductance, capacity or resistance. Since the reactance of a condenser is lowest at high frequencies, the feedback from anode to grid becomes most serious at high frequencies, causing either instability or low amplification depending on the output load.

In an endeavour to overcome this difficulty a *screened grid* valve was developed from the early *tetrode.* The latter is a triode valve having an additional grid between the normal grid and the anode, known as the *screen.*

In practice the screen has a lower voltage applied to it than the anode, but, as it is virtually connected to the cathode (*i.e.*, *via* a large condenser) it acts as an accelerator of the electrons towards the anode. In the screened grid valve additional screening is used in order to reduce the capacity between the grid and anode, so that instead of a capacity occurring between grid and anode, there is a capacity between grid and screen, and anode and screen. Nevertheless, some capacity exists, due to the fact that the screen has of necessity a grid formation in order to allow electrons to pass through it, but its magnitude is much lower than that of a triode.

World Radio History

Pentode Valves

A *pentode* is a tetrode valve which has an additional grid between the screen and the anode. The object of the extra grid is to prevent a kink in the characteristic which occurs when the anode voltage of a tetrode is made lower than the screen voltage. This kink is known as *secondary emission* effect. Briefly the explanation of this effect is that when an electron hits a body, such as the anode, electrons are knocked off. These electrons are attracted to any body at higher potential than the anode—in this case, the screen—thereby causing a drop in the anode current, and a corresponding rise in the screen current.

The effect of this secondary emission kink in practice is to limit seriously the available swing in anode voltage in a downward direction with the result that the output is very distorted and the consequent useful power output is thereby greatly reduced.

In a pentode, the effect of the additional grid, which is known as the *suppressor grid,* is to repel these secondary electrons back to the anode and prevent them reaching the screen. The suppressor grid is usually placed between the screen and anode and earthed.

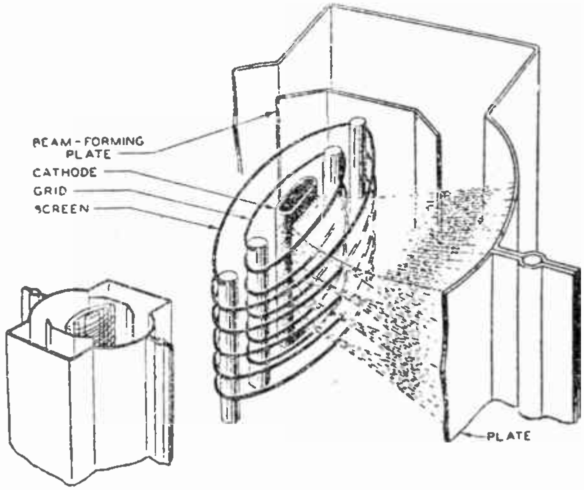


Fig. 1.

Internal construction of a beam power tetrode valve. The focused stream of electrons between the grid and screen turns can be seen, also the beam-forming or confining plates which shield the anode from the electrons coming from the regions of the support wires.

There are other methods in use for suppressing secondary emission besides the one mentioned. One of these methods is to make the distance between the screen and the anode such that the secondary electrons have insufficient energy to reach the screen. An elaboration of this principle is utilised in the *Harries Critical Anode Distance* valve.

A third method is to use small fins projecting inwards from the anode, whilst yet another method is to use earthed plates near the anode. This latter arrangement is used in the modern ***beam tetrode.***

Beam Tetrodes

A beam tetrode employs principles not found in other types of valves in that the electron stream from the cathode is focused towards the anode. The control grid and the screen grid are arranged so that they have the same winding pitch; further, they are assembled in the valve so that the turns in each grid are in optical alignment. Fig. 1 shows in diagrammatic form the construction of such a valve. The effect of the grid and screen turns being in line is to reduce the screen current compared with non-beam construction. For example, in a pentode of usual construction the screen current is about 20 per cent. of the anode current, whereas in a beam valve the figure is between 5 and 10 per cent. The lower the value the better the alignment for any given construction.

The earthed plates referred to above are bent round and utilised to shield the anode from any electrons coming from the regions exposed to the influence of the grid support wires at points where the focusing of the electrons is imperfect. These plates which both shield the anode from part of the electron stream and prevent secondary emission are known as *beam confining* or *forming* plates. They can be seen in Fig. 1, as can the flat pencils of electrons focused towards the anode.

Beam valves were originally developed for use as A.F. output valves, but the principle has now been applied to many types of R.F. pentodes. Their superiority over pentodes for A.F. output purposes is due to the fact that the shape of their characteristic curves is such that the harmonic distortion is principally second with very little third harmonic present, which is opposite to the result obtained with a pentode. Two such valves used in push-pull give a very large output with small harmonic distortion due to the fact that the second harmonic cancels out with push-pull connection. Fig. 2 shows the characteristic curves of a beam valve and pentode of equivalent size. The line AB is a load line drawn on the curve. It will be seen that the line extends further to the left before it cuts the zero grid-volts curve than is the case with the pentode, indicating a greater power output.

The widespread use of beam power valves as R.F. amplifiers and frequency doublers, etc., will be referred to later in this Chapter.

VALVE FUNCTIONS

It is necessary now to consider how a valve performs the functions of amplifier, rectifier or oscillator under practical conditions.

World Radio History

The Valve as an Amplifier

When a valve has an impedance connected in series with its anode supply and the voltage on its grid is varied, the resultant change in anode current will cause a voltage change across the impedance. This impedance may be a resistance, an inductance, or in some cases may behave like a capacity, as, for example, in a circuit tuned above resonance.

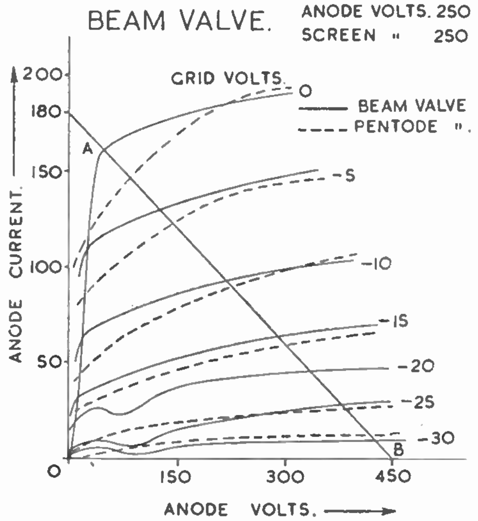


Fig. 2.

Comparative characteristic curves of beam and pentode valves of equivalent sizes. AB is a load line.

Class A Operation

The curve in Fig. 3 shows graphically the operation of a valve working as an amplifier. This curve, which is known as a characteristic curve, plots anode current against grid voltage. If now the D.C. grid bias is fixed at the point A, which is in the centre of the straight portion of the curve, then an A.C. sine wave input applied to the grid will be reproduced as an amplified sine wave in the anode circuit. Since the travel of the operating condition is up and down the straight portion of the curve, the output wave shape will be exactly similar to that of the input and no distortion will result, but if the operating point is fixed so that the valve operates over a *curved* portion of the characteristic, distortion, *i.e.*, a flattening either of the negative or positive half-cycle, will result. The method of operation where the grid bias is fixed at the centre of the straight portion of the curve is known as *Class A* operation.

When the output from a valve is not the exact reproduction of the input wave, distortion results. It can be shown that for a periodic wave shape, the output can be resolved into a number of simple sine waves of different amplitudes and phase relationships, all being in harmonic frequency relationship. The amount of these other sine waves of harmonic frequency, compared with the fundamental sine wave, is known as the *percentage harmonic content* present in the output.

Push-pull and Parallel Amplifiers

When it is necessary to obtain more output than can be furnished by one valve, two may be connected in *push-pull* or in *parallel.* Fig. 4 shows the connections in each case. The arrangement for push-pull is such that when the grid of one valve is positive, the other is negative and in consequence the anode current of one valve is rising as the other is falling, hence the name " push-pull."

In parallel operation, the grids and anodes are connected in parallel, with the result that the output is either doubled or directly dependent on the number of valves in parallel. The relative harmonic content is the same as for one alone, whereas for push-pull all even harmonics (2nd, 4th, 6th, etc.) are cancelled out, due to the method of connection. It follows, therefore, that two valves connected in push-pull will give a considerably greater output than twice that obtained from a single valve.

Class B Operation

As pointed out above it is necessary to operate over the straight portion of the characteristic if distortion is to be avoided. Actually the straight portion of a valve curve is only a small part of the whole; consequently, if it were possible to use a larger part, more output would be available. This effect is achieved in practice by a method known as *Class B* operation. In this method, the valve is operated at " cut-off " on the curve, as is shown graphically in Fig. 5, from which it will be evident that the negative half-cycle is almost completely suppressed. If the valve is used as an R.F. amplifier, this fact is unimportant, as the inherent *Q* of the tuned circuit will restore the other half-cycle and remove the harmonics, but for A.F. amplification as it stands the method is impossible. If, however, two such valves are used in push-pull then each valve will supply the missing half-wave of the other and a normal sine wave will result in the output.

Class C Operation

The Class B principle is carried a stage further in *Class C* amplification, by using the entire valve

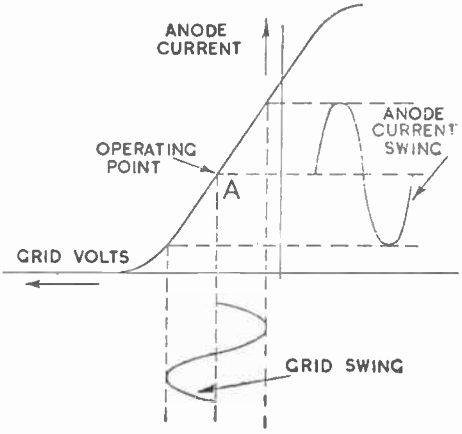


Fig. 3.

A triode valve operating as a Class A amplifier.

World Radio History

characteristic. Here the grid is biased to approximately *twice* cut off and is driven far into the positive region in order to reach saturation point; as is shown in Fig. 6. Since the grid is driven positive, grid current flows, with the result that the anode is robbed of current at the peak of the cycle, thus causing the anode current pulse to be indented at the top. As the wave form is poor and distortion very considerable, Class C operation is almost entirely used for R.F. amplification where high efficiency is very desirable. Due to the presence of grid current, considerable driving power is necessary.

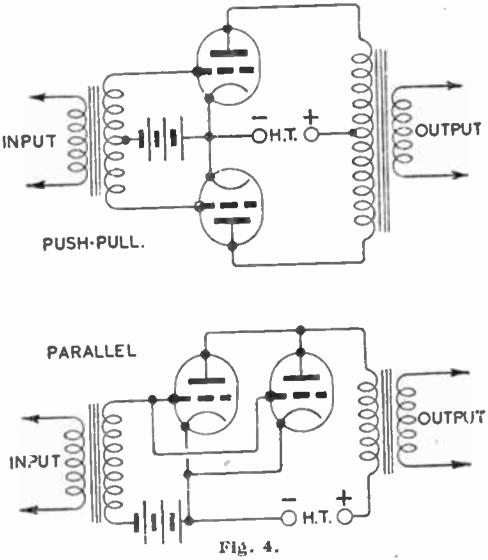


Fig. 4.

Push-pull and parallel amplifier circuit.

There are several varieties of Class A, B and C operation, which are known as *Driven Class A*, *Class AB*, *Class BC* and *Quiescent*, but these are fundamentally the same, differing only in the position of the fixed grid bias used for the operation point, or to the use of a low impedance grid circuit and/or driver valve, to overcome the effects of grid current, which would cause input circuit damping.

Cut-off

Reference has been made above to the term "cut-off." Cut-off is defined as that point on the anode-current, grid-volts characteristic curve at which the anode current falls to zero, when the steady D.C. grid bias is increased to a certain value. A more detailed description is given on page 19.

The Valve as an Oscillator

If a triode valve is so arranged that its output circuit is coupled back to its input circuit, in such a way that the alternating voltage applied to the grid is opposite in phase to that which exists in the anode circuit, the valve will operate as an oscillator. The frequency of oscillation will depend upon the frequency to which either the input or output circuit is tuned.

Valve oscillators and suitable circuits are fully described in Chapter 6.

The Valve as a Rectifier or Detector

Consider first the case of a diode valve used as a rectifier. If such a device is inserted in a circuit through which A.C. is flowing, current will only pass through the diode in one direction, thereby producing pulses of D.C. energy. Such a current is said to have been rectified. If now a condenser of suitable capacity is connected across the output it will store up the D.C. energy during the missing pulse, and a more or less steady D.C. output will be obtained. This arrangement produces half-wave rectification.

A detailed description of the use of diodes as power rectifiers will be found in Chapter 9.

A further and important application of the diode principle of rectification is to be found in their use as half-wave rectifiers of radio frequency signals.

If a modulated R.F. carrier wave of the form illustrated in Fig 7a is applied to a diode connected as in Fig. 7b, the diode will rectify the modulated carrier. Assume the carrier frequency to be F_1 and the modulated frequency F_2, then that portion shown above the horizontal line *x—x* in Fig. 7a will appear as a direct current in the output circuit across R_1 in Fig. 7b. This current will vary up and down at a rate depending upon the frequencies F_1 and F_2. If now a condenser C_1 is connected across R_1 of a value such that its reactance to the frequency F_1 is very low, and its reactance to the frequency F_2 is high, then the variation of voltage due to F_1 will charge it up to some mean value, which is constant as far as F_1 is concerned, but which will vary up and down around this mean value at the frequency F_2. Hence an A.C. voltage appears across C_1 R_1 which varies according to the audio modulation frequency F_2. If this voltage is applied to the grid of an amplifying valve, an audio output will be obtained in the anode circuit.

The diode type of rectifier is used chiefly in superheterodyne receivers and monitors; the principle is, however, applicable to all types of detectors.

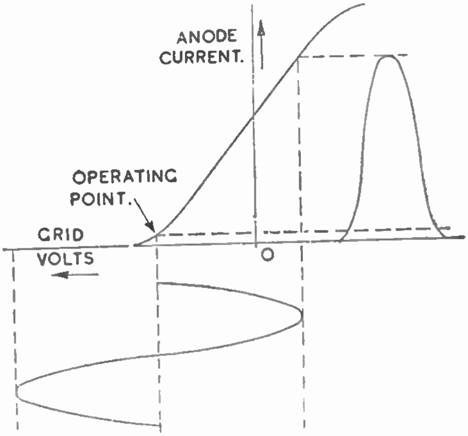


Fig. 5.

Operation of a valve as a Class B amplifier.

The Anode Bend Detector

This form of detector depends for its action upon the fact that the anode current-grid voltage characteristic of a valve is curved both at the bottom and top. As the top bend is rarely used in practice only the effects which occur at the bottom bend will be considered.

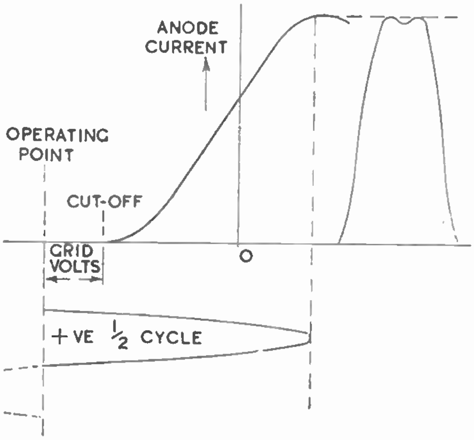


Fig. 6.
Operation of a valve as a Class C amplifier.

Consider now Fig. 8, which shows the characteristic of an HL. type battery valve. If, for example, an unmodulated signal of a value 1·5 volts R.M.S. is applied to the grid, which is biased to −2·7 volts, the resultant anode current variation will be as shown to the right of the curve. The shaded area represents reverse current, indicating that rectification is not perfect as with a diode. The efficiency of such a valve as a rectifier can be represented as one area divided by the other.

Fig. 9 shows the effect of applying a modulated carrier, projected in the same way. It will be noticed that as in Fig. 8 the anode current shows the rectified peaks of carrier, but in this case they vary in height according to the modulation. In both cases the mean anode current rises above the initial value.

If a circuit is connected to the anode arranged in such a way as to separate the modulated and modulating frequencies, it is possible to select the required frequency. Fig. 10 shows such a circuit. R.F.C. is a choke which presents a high impedance to R.F. but a negligible impedance to A.F. The condenser C by-passes the R.F. current to earth, but will not pass A.F. current as is the case when a diode detector is used. The audio output appears across the load R, which may be a resistance or the primary of an A.F. transformer. It will be seen that in Fig. 9 as long as the valve operates over the straight portion of its curve, ABC, the resultant A.F. voltage will be linear and an exact reproduction of the original modulation, but if the portion ABC is curved the A.F. output will be distorted. The grid bias corresponding to the point C must be chosen so that it is just on the bend of the curve as shown. Further, the R.F. input to the grid must not be allowed to exceed a value where the point A swings up the curve further than the zero line; in other words, the grid should not be allowed to run positive, otherwise distortion will result.

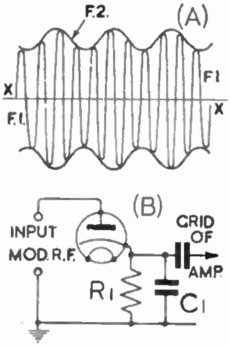


Fig. 7.
The valve as a diode detector. The values of R_1 and C_1 are discussed in the text.

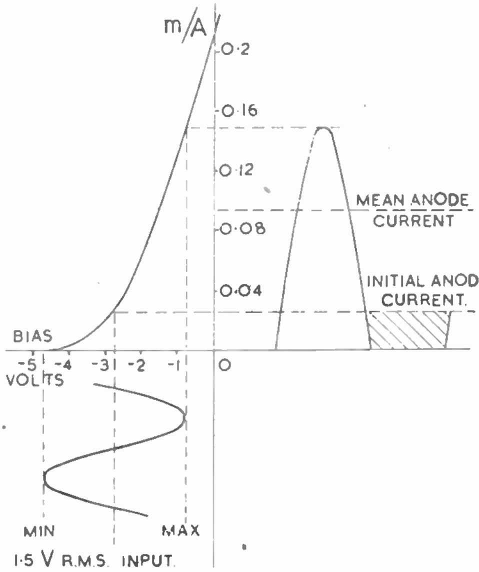


Fig. 8.
Anode bend rectification—unmodulated signal. The resultant anode current variation is obtained by geometric projection. The shaded area represents reverse current, showing that rectification is not perfect.

Leaky Grid Rectification

The leaky grid method of detection depends for its action upon the fact that when the grid of a valve is made positive, grid current flows from the grid to the filament or cathode.

The circuit of a grid-leak detector is given in Fig. 11, from which it will be seen that a resistance R_1 and a condenser C_1 are connected between the grid and the tuned circuit L_2 C_2. If an unmodulated carrier is set up in L_2 C_2 (corresponding to the carrier of a station) then at a time when the voltage is zero, *i.e.*, the sine wave of R.F. passes through zero, there will be no voltage across L_2 C_2, and both plates of the condenser C_1 will be at zero potential.

World Radio History

If it is assumed that the resistance R_1 is disconnected and the carrier increased to, say, 2 volts negative, the anode current will be at some steady value and no grid current will flow. The grid itself will be 2 volts negative with respect to the filament, and as the condenser C_1 is as yet uncharged, its plates will be at equal potential.

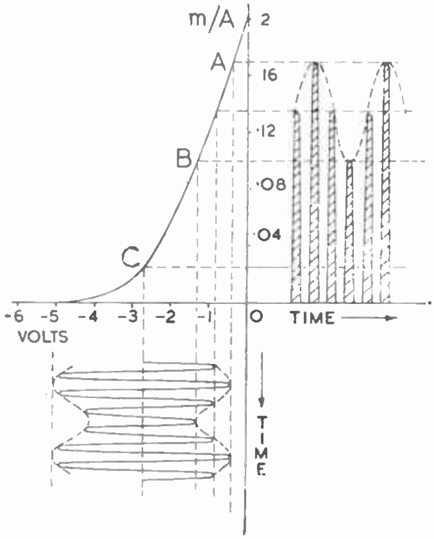


Fig. 9.

Anode bend rectification—modulated signal.

If it is now assumed that the carrier rapidly changes polarity to a position of 2 volts positive (at 20 metres wavelength this would take 1/30 of a millionth of a second), then the left-hand plate of C_1 is 2 volts positive, and since the condenser is still uncharged the grid will also become 2 volts positive and the anode current will suddenly rise. But as the grid has become positive, grid current will start to flow and the right-hand plate of C_1 will begin to lose its positive potential, whilst the left-hand plate remains at + 2 volts; in other words, C_1 is acquiring a charge. After an interval of time, depending on the value of C_1, the grid will lose its positive potential entirely, and, assuming it returns to its original value of − 2 volts (at which value grid current ceases to flow), no further change takes place.

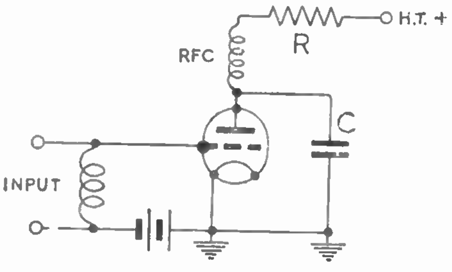


Fig. 10.

Arrangement of a triode operating as an anode bend detector. Condenser C by-passes R.F. current to earth. R may be a resistance or the primary winding of an A.F. transformer.

Now, if the carrier again rapidly reverses its polarity to the original condition or on to the next half-cycle, the left-hand plate of C_1 becomes − 2 volts and simultaneously the right-hand plate becomes 2 volts more negative or − 4 volts. As no grid current flows at − 4 volts the grid will remain at this potential indefinitely providing no further change takes place and providing the insulation is perfect. Hence the need for the high resistance grid leak R_1. With the leak connected, the charge will leak away and the grid will take up a potential such that the current from grid to filament equals the current through the leak in either the positive or negative half cycle. If now an R.F. voltage is applied, the left-hand plate of C_1 will vary from + 2 volts to − 2 volts as before, but the grid will not vary in quite the same way as previously described. On the positive half cycle the condenser will again become fully charged, but on the negative half cycle the time will be insufficient for the condenser to discharge completely through R_1, with the result that it will remain charged slightly negatively as long as the R.F. input is applied. This will cause the mean anode current to drop.

When a modulated R.F. voltage is set up in the circuit L_2 C_2 the anode current will always tend to rise to the same value for each positive half cycle but will fall more or less on the negative half cycle, depending upon whether the modulating frequency is aiding or opposing the effective carrier voltage.

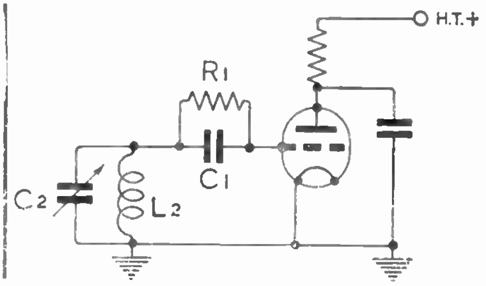


Fig. 11.

Circuit of a leaky grid detector. Suitable values for C_1 and R_1 are given in the text.

This is shown diagrammatically in Fig. 12, where A represents the modulated R.F. across the coil L_2, and B the resultant grid potential under perfect conditions. In actual practice the positive peaks do not quite lie on a straight line.

It will be seen from the diagram that rectification is present and that the effect is the same as for anode bend rectification but inverted. The values of C_1 and R_1 are chosen so that their time constant is long compared with one cycle of the carrier, but short compared with one cycle of audio-frequency. The time constant in micro-seconds is taken as the product of C_1 and R_1, where C is in micro-micro farads and R in megohms. A usual value of C_1 for short wave operation is ·0001 μF and R_1 from 1 to 5 megohms.

Power Grid Detection

In the so-called *power-grid* detector the mode of operation is the same except that a considerably higher anode voltage is used and due to the different grid-current characteristic under these conditions it is possible to employ more suitable values for C_1 and R_1, thereby obtaining a condition more nearly approaching Fig 12B, *i.e.*, one which gives less distortion.

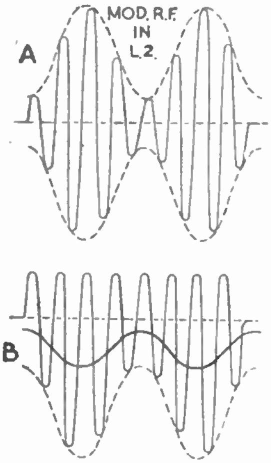


Fig. 12.

Leaky grid rectification. (A) Represents the modulated R.F. across L_2 of Fig. 11. (B) Resultant grid potential under perfect conditions.

As previously mentioned the effects of rectification and grid current are to set up a steady negative bias on the grid as long as the carrier is applied. This system of a grid leak and condenser is used to provide bias in self-excited or crystal oscillators, and in driven power amplifiers or frequency doublers, and will be referred to later in Chapter 6.

RECEIVING VALVES

Amongst the receiving valves, figure those of the filament type (commonly known as battery or directly heated) and the indirectly heated type. It is not proposed to deal separately with each of the two types, as almost any receiving valve has a counterpart in both types; in fact, there are now available quite a number of indirectly heated 2 volt battery valves as well as many with "economy" filaments suitable for operation on a single 1·5 volt dry cell.

Triodes

The general tendency during recent years has been to increase considerably the efficiency of triodes. This is marked in the battery range by an enhanced performance for a lower filament power consumption, and in the indirectly heated range by a very improved mutual conductance resulting in a higher amplification factor or a lower impedance, or both. The use of a modern triode does not involve any new difficulties except that the higher stage gain obtainable, requires precautions to be taken in decoupling and in the prevention of parasitic oscillation.

Pentodes and Tetrodes

Modern pentodes fall into two classes, namely, radio frequency types and audio frequency output types. The former type has almost entirely replaced the screen grid valve due to the fact that it is capable of handling a much larger signal without distortion, at the same time giving a higher stage gain.

As the anode impedance is higher in the case of a pentode or tetrode, there is less damping on the tuned circuit connected in series with the anode, consequently selectivity is higher. R.F. pentodes are available with straight or variable *mu* characteristics.

A usual application is as an R.F. or I.F. amplifier; additionally they are also very useful as a combined first detector and oscillator in a superheterodyne receiver.

R.F. pentodes may also be used for a frequency changer, by injecting a local oscillation from an oscillator valve (which may also be a pentode) into the suppressor grid. This system is not, however, recommended for ultra short-wave frequency changers, as some portion of the local oscillator output is likely to be picked up by the control grid, which would result in demodulation of the suppressor grid injection. A typical suppressor grid injection frequency changer circuit is shown in Fig. 13.

Many types of R.F. pentodes are also available as tetrodes, in which beam confining plates replace the suppressor grids. Most R.F. pentodes have the suppressor grid brought out to a separate pin, a great advantage for certain types of oscillator circuits, apart from their use as a frequency changer as mentioned above. Television R.F. pentodes have mutual conductances up to 10 mA/V, and are available in short seal construction giving

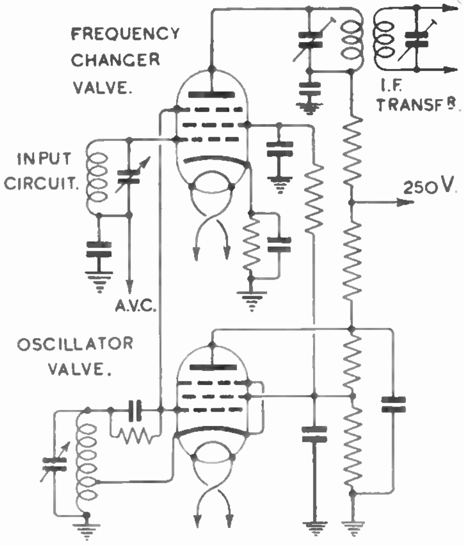


Fig. 13.

Suppressor grid injection frequency changer circuit suitable for use with a 6K7 (frequency changer) and a 6J7 (oscillator).

World Radio History

much shorter leading-in wires and thus improving their ultra short-wave performance, particularly as regards raising the input impedance.

The modern A.F. output pentodes and tetrodes are much more efficient than their predecessors, some of the indirectly heated types giving 3 watts output for an input swing of about 3 volts and having a mutual conductance of about 12 mA/V. Others, namely, in the A.C.-D.C. range, give 2·5 watts output with anode and screen voltages as low as 110 volts. The battery types are correspondingly also more efficient.

Double Diode Triodes

Double diode triode valves comprise a high-gain triode with two diodes, efficiently screened from the triode, and having a common cathode or filament. Their chief application is in circuits using automatic volume control. The types of circuit are legion but in the main they comprise full- or half-wave diode detection with A.F. amplification, with or without a delay voltage on the A.V.C. In addition, the triode is used as a direct current amplifier as well as an A.F. amplifier, thus giving the above variations or arrangement with amplified A.V.C. Fig. 14 shows a typical circuit using one diode (D_1) for the A.F. output and the other (D_2) for the A.V.C. voltage. The A.V.C. is delayed by the amount of bias on the triode, namely, the drop across the auto-bias resistance. Other useful applications are in valve voltmeter circuits and in various types of measuring apparatus.

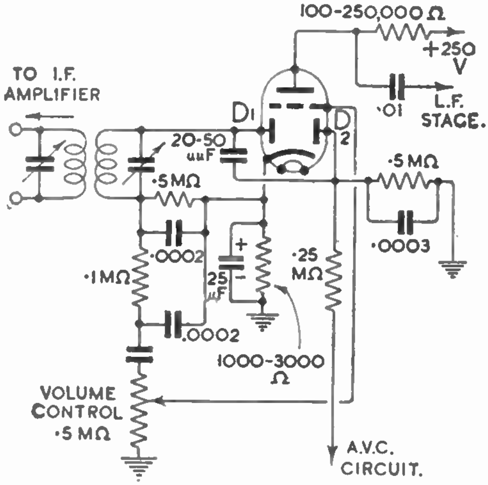


Fig. 14.

Typical circuit using a double-diode triode. D_1 is used for the A.F. output and D_2 for the A.V.C. voltage.

A variation of the double diode triode is the *treble diode triode*, which has an additional diode, thereby enabling the advantages of quiet amplified and delayed A.V.C. to be achieved in one valve, where previously an additional valve was necessary.

Double Diode Pentodes

These valves comprise either an A.F. pentode and two diodes, or an R.F. pentode and two diodes, utilising a common cathode mounted within the same bulb. The double diode A.F. pentode is largely used in small receivers where the R.F. voltage on the diodes is reasonable in magnitude and where in consequence the A.F. amplification need not be great. The double diode R.F. pentode may be used in such a way that the pentode acts as an I.F. amplifier followed by the diodes as detector. In certain cases the R.F. pentode may be used as a resistance capacity-coupled A.F. amplifier following the diodes.

Triode Pentodes

Triode pentodes were originally introduced for use as combined detector oscillators in super-heterodyne receivers. They comprise a small triode and an R.F. pentode screened from one another but having a common cathode. The triode is arranged as an oscillator, injecting its oscillations into the common cathode lead of the R.F. pentode. These valves, although suitable for use on medium and long waves, are unsuitable for short wave operation, due to the necessity for using cathode injection, which causes locking between the oscillator and the R.F. signal. They have, nevertheless, several other useful applications.

Pentagrids or Heptodes

A *pentagrid* consists of a screen grid and a triode element coupled by a common cathode electron stream. It comprises: a heater and cathode (or filament), five grids and an anode; the grids in order being: (1) triode control grid, (2) triode anode, (3) electrostatic screen, (4) tetrode control grid, (5) tetrode screen grid.

The triode is screened from the tetrode (screen grid) unit by the electrostatic screen (grid 3); consequently if it is connected up in any conventional oscillator circuit the tetrode unit will be modulated by the oscillator, solely by virtue of the variations of the electron stream from the cathode, due to the triode. A typical circuit of a pentagrid frequency changer is shown in Fig. 15. The

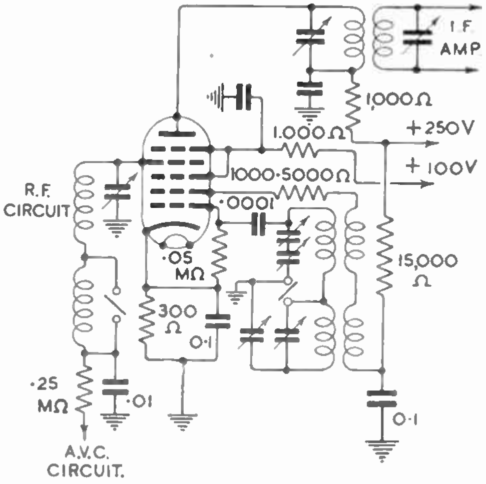


Fig. 15.

Typical circuit employing a pentagrid frequency changer.

World Radio History

tetrode unit has a variable *mu* characteristic enabling A.V.C. to be applied to the frequency changer, thereby giving improved A.V.C. operation.

A pentagrid is in general quite satisfactory for use in short-wave frequency changers, but difficulties may be encountered due to a small residual coupling between grid (2) and grid (4) which may cause a drop in conversion gain when the signal frequency and the oscillator frequency are very close together. In some cases this effect may be "bucked out" by means of a very small capacity between grids (1) and (4). There is also a drift in the oscillator frequency when the grid bias on the control grid (4) is varied (as with A.V.C.), and this may amount to about 0·01 per cent. These effects can, however, be largely overcome by driving grid (1) from a separate oscillator, preferably of an electron-coupled type.

Pentagrids may be used in push-pull for ultra-short wave work, *i.e.*, 28 and 56 Mc, the control grids (4) being in push-pull and grids (1) and (2) in parallel. This arrangement enables satisfactory oscillation to be obtained on these frequencies.

Pentagrids are obtainable in A.C., A.C.–D.C., and battery types.

Hexagrids or Octodes

As their names imply, these valves have six grids or eight electrodes. They are essentially the same as pentagrids with the addition of a suppressor grid which converts the tetrode unit into an R.F. pentode. They have no great advantage over a pentagrid except that when the R.F. input voltage is large there is less change of overload and consequent cross-modulation. The conversion gain is of the same order, but they give somewhat improved performance on short waves

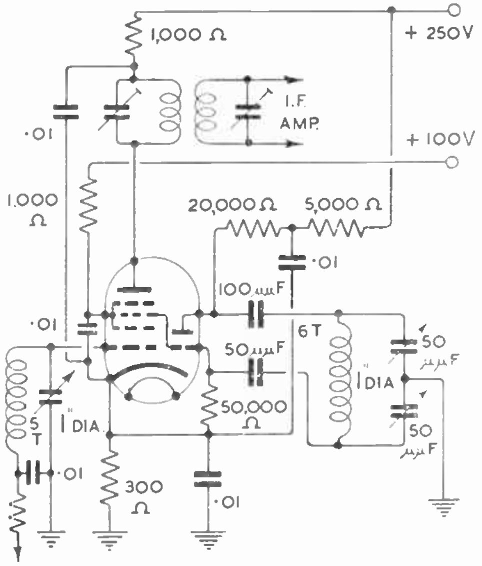


Fig. 16.

Circuit showing the connections for a triode hexode for frequencies between 28 and 56 Mc using a valve such as the Osram X65.

Triode Hexodes or Triode Heptodes

A *triode hexode* consists of a triode valve and a mixer valve with a common cathode. The mixer has four grids between the cathode and the anode; the first is the control grid, which has variable *mu* characteristics, the second is an electrostatic screen, the third is the oscillator grid, which is connected internally to the triode grid, and the fourth is a screen which is strapped to grid (2). The triode is connected in any conventional oscillator circuit as is shown in Fig. 16.

A triode heptode is similar to the triode hexode but has in addition a suppressor grid. This type of valve will give a higher conversion gain than the pentagrid, due to the fact that the control grid is nearest the cathode and in consequence has the highest mutual conductance. Furthermore the valve does not suffer from oscillator drift (due to A.V.C.) or to coupling between the oscillator and signal grid, although it possesses all the advantages of electronic coupling. The amplitude of the oscillator of modern type requires to be in the order of 7·5 volts R.M.S.

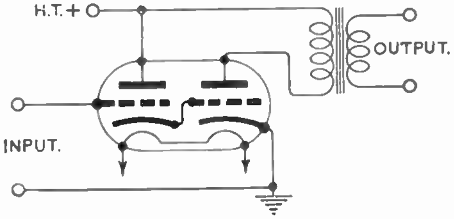


Fig. 17.

Connections for triple-twin valve.

Triple Twin Valves

A *triple twin* valve is a special type of output valve comprising two triodes contained in one bulb which are internally connected as a direct coupled amplifier. The cathode of the first triode (input) is connected to the grid of the second triode (output). The anode of the input triode is connected to H.T. and the output of the first triode is the grid cathode impedance of the second, the output load in effect being in its cathode, instead of its anode circuit. No external grid bias is required, and the power output is of a higher order than for a triode or pentode, being 4 watts for one valve and over 12 watts for two in push-pull. The connections of a triple-twin valve are given in Fig. 17.

Beam Power Output Valves

The *beam*, which is the latest type of output valve, is a tetrode (*i.e.*, screen grid output valve), but it employs principles used in Cathode Ray tubes, in that the electron stream is focused towards the anode by grids of special shape, arranged with their turns exactly opposite and with two focusing plates. Two such valves arranged in push-pull give an output of 60 watts of audio-frequency power when an H.T. voltage of 400 is applied.

Fuller details of beam power valves are given earlier in this Chapter.

World Radio History

Acorns and Midget Valves

Acorn valves are small varieties of indirectly heated diodes, triodes and pentodes. They have no base, the connections being by means of small clips, whilst the length and diameter are of the order of ¾". The capacities are very small, thus making them suitable for use up to frequencies around 600 Mc. A full size illustration of an *Osram* acorn appears below.

Midget valves are ordinary types of very small dimensions, suitable for use in portable receivers and in deaf aid equipments.

The Osram ZA1 R.F. Pentode Acorn type, suitable for ultra-short-wave receivers.

Metal Valves

These valves, which at one time were very popular in America, are ordinary valve types assembled in a metal bulb, welded or brazed together and having the lead-out wires passed through eyelets of *Fernico* metal mounted in the metal bulb. They have characteristics similar to normal types, but are somewhat smaller in bulk. Although available for all purposes they are now principally used for R.F. purposes where they have the advantage of better screening than their glass counterparts.

Magic-eye Tuning Indicators

This form of tuning indicator, marketed under various trade names, contains a cone-shaped piece of metal (known as the target) coated with fluorescent material. Electrons emitted from a cathode impinge on the target and cause it to be illuminated with a green glow over a part or the whole of its surface. Two or more small rods act as grids and when the anode voltage applied to them is altered a shadow moves, which opens and closes on the target. A small triode is also mounted within the bulb in order to amplify the voltage applied to the grid rods, *i.e.*, to improve the sensitivity. The grid of the triode is normally connected to the A.V.C. line in the receiver, with the result that the "eye" opens and closes in accordance with the tuning of the receiver.

Fig. 18 shows the connections used for a magic eye indicator in a superheterodyne receiver.

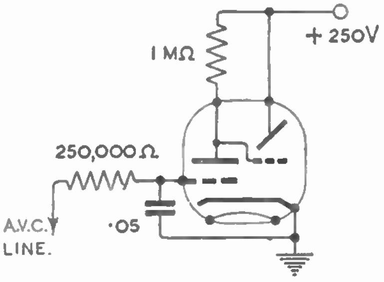


Fig. 18.

Connections for a "magic eye" when used as a tuning indicator in a superheterodyne receiver.

Footless Valves

Recent developments in valve technique have made it possible to manufacture valves having a circular glass seal in the base instead of the customary glass pinch. When this form of construction is used the lead-out wires are the actual pins used to make connection to the valve socket. By this means the leads between the electrodes and the socket can be made much shorter, inter-electrode capacities are reduced and the losses associated with the base are avoided; at the same time a single ended construction (*i.e.*, the top cap is dispensed with) is adopted.

Manufacturers have adopted different arrangements of pins, and in some types a locking device is fitted to prevent the valve being easily ejected by accident from the socket.

The various types of footless valves in current use are represented by the ***Loktal*** and the ***R.C.A.*** midget types in the U.S.A., and by the ***Phillips-Mullard*** and the ***Tungsram*** types in Europe. An illustration is given of a ***Mullard*** EE50 footless construction valve before pumping and before the bulb has been sealed. The glass tube projecting below the pins is used to evacuate the valve, and after sealing off, this is protected by a hollow metal base having a hollow key arranged to lock into the socket.

Electron Multipliers

Earlier in this Chapter, when discussing tetrode and pentode valves, the phenomena of secondary emission was explained. This effect is utilised in electron multipliers in order to increase the slope (mutual conductance). When a single primary electron impinges on an electrode under suitable conditions, many *secondary* electrons are liberated from that electrode; consequently, if these secondary electrons can be utilised to furnish the final anode current, a big increase in electron density (or slope) will result. Since a considerable velocity is essential for the original electron (and a reasonable voltage is required to produce this velocity), each stage of electron multiplication demands a certain minimum voltage, and in practice this will usually lie between 100 and 300 volts. In passing it should be mentioned that, whilst multi-stage electron multipliers have been developed, they require H.T. voltages up to 1,000 volts or even greater.

It is necessary to focus the secondary electrons towards the anode, otherwise they may be attracted back towards an earlier electrode, as is the case in the tetrode valve. This focusing condition is effected by applying the laws of electron optics such as are used in the modern cathode ray tube.

World Radio History

For general receiving purposes it is undesirable, for many reasons, to use a H.T. line voltage of more than 300, and from the considerations outlined above it will be clear that only a single-stage multiplier is practicable at present; the reason for this is that in order to attract the secondary electrons a difference in potential is necessary between the secondary electrode and the anode, in addition to that existing between the cathode and the secondary electrode, which leaves about 150 volts available for each region of the valve.

A typical example of a single stage electron multiplier is the *Mullard* EE50 previously referred to. This valve is rated to operate with a H.T. of 300 volts, and has a slope of 14 mA/V. It is primarily designed for use in television receivers, where, due to the band-width required, the stage gain is low with valves of more moderate slope.

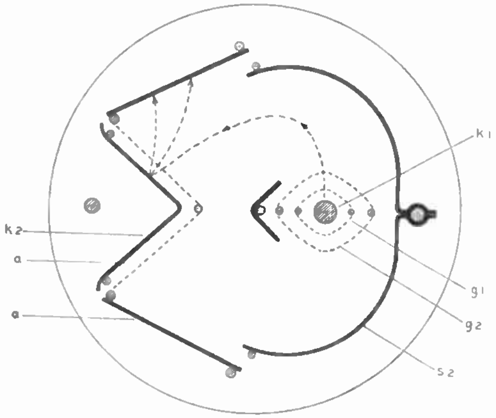


Fig. 19.

A cross section of a Mullard EE50 single stage electron multiplier showing the path of the electron stream.

Fig. 19 illustrates a cross-section of the EE50, in which the dotted arrow lines indicate the path of the electrons; K_1 is the main cathode (which is indirectly heated) and G_1 is the control grid.. G_2 is an auxiliary or screening grid, which is intended to screen the control grid from the remainder of the valve in order to raise the effective voltage in the region of the control grid and to increase the internal impedance. The screening electrode S_2, which is maintained at cathode potential, deflects the electrons accelerated through G_2 towards the secondary electrode or second cathode, K_2. The other small shield in the centre of the valve prevents a direct electron flow between K_1 and K_2, and also prevents any cathode material from being volatised upon K_2 during processing. The electrons deflected by S_2 impinge upon K_2, where the secondary electrons are liberated and attracted towards the anode A. The part of the anode opposite, and in close proximity to, the second cathode is made of gauze mesh in order to allow the passage of both primary and secondary electrons.

In operation the control grid obtains its bias by means of a resistance in the cathode lead, whilst the screen grid G_2 is maintained at H.T. line potential. The screen current is usually about 0·5 mA, and the anode current about 10 mA. The second cathode, K_2, is maintained at a voltage of about 150 volts by means of a potentiometer network, but, as is usual with secondary emitting electrodes, the current is negative and has a value of about 8 mA. Those who have experimented with tetrode valves as dynatron oscillators will be familiar with the phenomena of a negative anode current when secondary emission occurs.

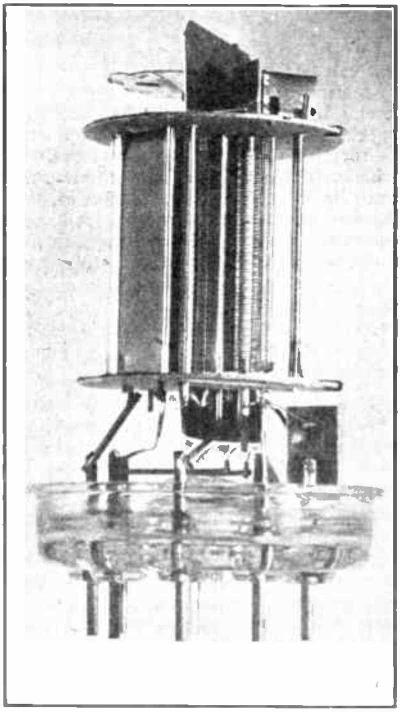
TRANSMITTING VALVES

Under this classification only valves used solely for R.F. purposes will be considered. The types in general use are: triodes, screen tetrodes and pentodes. The use of electronic oscillators and magnetrons is confined to ultra-high frequencies (56 Mc or higher) and does not come within the scope of this Chapter.

Transmitting Triodes

These range in size from small receiving battery valves for very low power circuits to water-cooled valves for high power. As a rule, they have dull-emitter filaments up to a power of 250 watts, and above that figure bright-emitter tungsten filaments. Indirectly-heated cathode valves are not usually made with ratings above 25 watts.

In general, valves are chosen which (*a*) do not



Type EE50 Mullard single stage electron multiplier showing its construction. The illustration shows a valve before the bulb has been sealed and with the glass tube for attachment to the pump in position. This valve is of the footless construction, the pins being the actual lead wires.

World Radio History

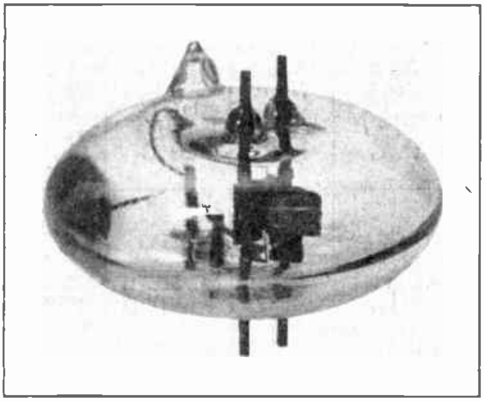
have an exceptionally high mutual conductance (a usual figure being between 1 and 4 mA/V) and (*b*) have a medium impedance (between 3,000 and 25,000 ohms). A high mutual conductance valve presents difficulty in neutralising, whilst valves with very low or high impedances result in low efficiencies. In the former case this is due to awkward LC ratios of tuning circuits, and in the latter case is due to the difficulty of designing a short-wave tuning circuit, with a high dynamic resistance which will give at the same time adequate selectivity in order to reduce harmonics.

Valves designed especially for short-wave work usually have the grid or anode, or both, brought out through the top or side of the bulb, and more often than not no base at all is provided. This is a desirable feature, as it helps to reduce the capacity between the electrodes, at the same time reducing the possibility of leakage or breakdown at high voltage. This condition is likely to occur with the more usual type of pinch, where the lead-out wires are bunched together in the glass near the base.

In the case of valves especially designed for use on ultra-short waves the anode is often made of graphite in the form of a hollow block or of molybdenum or tantalum. Anodes of this type are capable of dissipating more energy with less chance of gas being driven off. Triodes constructed in this manner can be used quite satisfactorily up to a frequency of 300 Mc.

Transmitting Acorns

The original transmitting acorns, which were built on the same lines as receiving acorns, but of somewhat larger dimensions, were of 30 watts dissipation and capable of delivering an output of 4 watts at 600 Mc. These have recently been improved upon, and one of the latest types (the 3B/250–A) is illustrated. This valve is designed on double-ended lines, *i.e.*, the connections are brought out at the top and bottom. It is rated at 25 watts dissipation at 500 volts, and is capable of an output of 4·5 watts at 700 Mc, the limit of oscillation as a normal triode being 1,800 Mc.

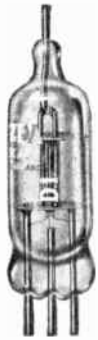


Type 3B/250A Standard Telephones and Cables transmitting Acorn of double-ended construction. The illustration is full-size. This valve will oscillate down to a wave-length of 18 centimetres.

There are other valves having a remarkable performance at ultra-high frequencies, but at the time of publishing this Handbook obvious reasons prevent details from being included.

Tetrodes and Pentodes

Receiving types of tetrodes and pentodes are largely utilised as crystal oscillators, master oscillators (either of the dynatron or electron-coupled type), Tritet oscillators and frequency doublers. For the latter function output pentodes are very useful, whilst for higher power circuits screened tetrodes and R.F. pentodes are obtainable. A tetrode or R.F. pentode gives somewhat higher amplification and the vital necessity for neutralisation is removed, although it is advised as a precaution against the possibility of self-oscillation. The chief advantage of their use as a power amplifier at radio frequencies, is that due to their high amplification factor, only a small amount of driving power from the previous stage is necessary. This is an important point where very high frequency operation is concerned, for it is often difficult to obtain sufficient drive from doubler stages operating on 28 and 56 Mc. Because such valves can be driven easily there is always a danger of *over* driving them, especially in view of the greater efficiency obtained from modern doubler valves. Over driving causes severe peaks of current both in the grid and anode circuits and is liable to shorten considerably the life of the valve by encouraging gas or grid emission. Furthermore, due to their high anode impedance, dangerous voltages are set up in the anode circuit if the aerial or following valve load is removed whilst the drive is being applied. This voltage may cause an interna flash-over in the value.



Type D1 Mazda Acorn Diode designed for use in television receivers but adaptable for such purposes as ultra-short wave field strength meters.

Beam Valves

Beam valves, referred to earlier, are also used extensively for transmitting purposes. They make extremely efficient Tritet oscillators and frequency doublers up to 60 Mc or higher. The reason for their large output compared with a normal screen tetrode or R.F. pentode is primarily due to the fact that they will give a large output into a relatively low impedance circuit, whilst retaining a low grid drive. The usual load for a 6L6 valve is about 3,000 ohms, which is not a difficult value to obtain for a tuned circuit even at 56 Mc.

Tetrodes or pentodes can be modulated by simultaneous modulation of the anode and screen voltage, whilst pentodes can also be modulated by variations of the suppressor grid potential. The variation can be supplied by a small receiving valve, effecting a great economy in speech frequency equipment.

RECTIFYING VALVES

Rectifiers fall into two classes: vacuum diodes and vapour-filled diodes.

Vacuum types, which may be either directly or indirectly heated, are usually made full wave for handling small powers, and half wave for higher power. The indirectly heated types have the advantage that they heat slowly and, in consequence they allow the heaters of other valves in the receiver or amplifier to warm up before the H.T. voltage is applied, thereby effecting an appreciable saving in the cost of smoothing condensers. The maximum power obtainable from the indirectly heated full-wave type is 500–600 volts at 250 mA. The directly heated types range from 250 volts 60 mA up to water-cooled types giving 20,000 volts at several amperes.

Vapour-filled types are usually directly heated, having a filament in the form of a spiral or zigzag, and a flat or concave plate for an anode. Such valves are filled with mercury vapour. The smaller types are half-wave valves giving 1,000 volts at about 250 mA, and the largest (being three- or six-phase) deliver 20,000 volts with a power output of about 100 kilowatts.

The chief advantage of the mercury vapour rectifier is the low voltage drop obtained (in the order of 15 volts) and this is almost independent of current. Hence a high efficiency is secured. The disadvantages are: (a) delayed switching is necessary—usually about 30 seconds, except for very low currents (*i.e.*, the filament must be hot before the anode voltage is applied) and (b) poor power factor of the transformer unless special precautions are taken. A usual figure for medium-loaded valves is in the order of 0·5; whilst for heavier loads the phase angle is improved.

It is desirable when using vapour-filled rectifiers to use a choke input circuit for the filter, as explained in Chapter 9. Some large size vapour-filled rectifiers are made with a grid, and by applying bias to this grid a measure of control of output voltage is possible, in the same way a regulated source of H.T. can be made more or less independent of output load.

When using mercury vapour rectifiers of all types care should be exercised in order to prevent short circuits occurring on H.T. supplies. The short circuit current may be extremely heavy, and although the valve may not suffer unduly, the transformer will undoubtedly do so.

The heater or filament should be maintained at the correct operating voltage or current, depending upon which is specified. Overrunning or underrunning may equally well reduce the life, the latter because the life is dependent to some extent on reactivation of the coating during running, and this cannot take place at a low temperature.

The reader would do well to remember that modern valves will give really good service providing the makers' recommendations are strictly followed.

RECEIVING VALVES

THE valves listed below represent a few of the many types available for short-wave receivers of the tuned radio frequency and superheterodyne type.

	TUNED RADIO FREQUENCY RECEIVERS			SUPERHETERODYNE RECEIVERS				
	Radio-Frequency	Detector	Output	Radio-Frequency	Frequency Changer	Inter-mediate Frequency	Second Detector	Output
BATTERY TYPE								
Osram ..	W21	Z21	KT21	W21	X22	W21	HD22	KT21
Mazda ..	VP210	SP210	PEN231	VP210	TP23	VP210	DD207	PEN231
Tungsram	VP2D	SP2D	PP222	VP2D	HL2 VX2	VP2D	DDT2	PP222
Mullard ..	VP2	SP2	PM22D	VP2	FC2	VP2	TDD2	PM22D
Brimar ..	IN5G	IN5G	IC5G	IN5G	IA7G	IN5G	IH5G	IC5G
A.C. TYPE								
Osram ..	W63 Z62	Z63 Z62	KT63	W63	X64 Z63 X65	W63	DH63	KT63
Mazda ..	AC/VP2 VP41	AC/SP1 SP41	AC/4PEN PEN45	AC/VP2 VP41	AC/TH1 TH41	AC/VP2 VP41	AC/HLDD HL41DD	AC/4PEN PEN45
AMERICAN TYPE (Brimar, Tungsram Mullard)	6U7G	6J7G	6F6G	6U7G 6K7G	6L7G 6J7G 6K8G	6U7G 6K7G	6Q7G 6R7G	6F6G 6V6G

TRANSMITTING VALVES

THE valves listed below represent typical types of British manufacture. Certain American equivalents are quoted for reference purposes.

Class	Type.	Filament or Heater.		Max. Dissi- pation Watts.	Max. Anode Volts.	Max. Screen Volts.	Max. Screen Dissi- pation Watts.	Base.	Operating Conditions.									Grid Dri- ving Power Watts	Out- put Power Watts	Remarks.
		Volts.	Amps.						Condition.	Anode Volts.	Scrn. Volts.	Suppr. Grid Volts.	Grid Bias Volts.	An- ode Cur- rent. mA.	Scrn. Cur- rent. mA.	Grid Cur- rent. mA.	Screen Resist- ance Ohms.			
Triodes	ESW20 TZ08–20 T20	7·5	1·75	20	750	—	—	UX 4-Pin	Class C cw	750	—	—	−100	75	—	17	—	5	40	—
	4074A RK34 TVO3–10 DET19	6·3	0·85	10	300	—	—	UX 7-Pin	Class C cw	300	—	—	− 36	80	—	20	—	1·8	16	Twin Triode. Up to 240 Mc.
	4304B DET12 TY1–50	7·5	3·25	50	1,250	—	—	UX 4-Pin	Class C cw Class C phone	1,250 1,000	— —	— —	−200 −180	100 100	— —	25 25	— —	5 5	85 65	Output at 60 Mc. —
	4316A TYO4–30	2·0	3·65	30	450	—	—	None	Class C cw Class C phone	450 400	— —	— —	−150 −150	80 80	— —	12 12	— —	1·5 1·5	8·5 6·5	Output at 300 Mc. Transmitting Acorn.
	3B/250–A	1·4	5·0	25	500	—	—	None	Oscillator	500	—	—	—	50	—	—	—	—	4·5	Output at 700 Mc. Transmitting Acorn.
	4211$^{D}_{E}$ 0/75/1000	10·0	3·0	65	1,000	—	—	Bayonet	Class C cw	1,000	—	—	−160	95	—	15	—	7·0	65	—
	T55 OQQ/50/1500	7·5	3·25	55	1,500	—	—	UX 4-Pin	Class C cw	1,500	—	—	−200	150	—	30	—	9·5	140	—
Pentodes and Tetrodes	4061A RK25	6·3	0·8	12	500	200	6	UX 5-Pin	Class C cw phone	500 500	200 150	+45 −30	−100 − 75	48 30	15 20	— 7·5	— —	·5 ·4	15 3	— —
	6L6G	6·3	0·9	30	400	300	5	Octal	Doubler	375	200	—	−300	80	—	3	—	1·5	15	—
	OS/12/501	6·3	0·7	12	500	200	8	UX 7-Pin	Class C Sup. mod.	500	200	−65	− 20	30	23	3·5	14,000	·1	5	Equivalent to 837.
	4052A RK20 OS/40/1250	7·5	3·0	40	1,250	300	15	UX 5-Pin	cw phone	1,250 1,250	300 300	+45 −40	−100 −100	92 47	32 36	5 5	26,000 25,000	1·0 1 0	80 21	— —
	5B/250A KT8 807	6·3	0·9	25	600	300	3·5	UX 5-Pin	Class C cw	600	300	—	−200	100	12	5	40,000	0·2	40	KT8 heater 6·3 v. 1·27 A
	PVO4–10	12·0	0·7	10	500	250	3	English 7-Pin	Class C cw	500	250	—	− 50	50	12	5	21,000	0·35	15	Near equivalent to 802.
	APP4E	4·0	2·1	18	375	275	3	English 7-Pin	Crystal Oscillator	375	250	—	—	50	10	2	—	—	7·5	—

Chapter Three

WORKSHOP PRACTICE

Soldering—Design and Layout—Aluminium Chassis Work—Tools and their Uses—Hardening and Tempering—Screws and Screw Threads

THE serious experimenter should be as capable of using his hands for the construction of the apparatus he will operate as he is of applying his technical knowledge to the design of the circuits which will embody such apparatus.

The information given in this Chapter is intended to place before readers a concise account of the precautions to be taken, and tools to be used, in producing radio equipment.

Happily, the days of " hay-wire " contraptions have passed, but there still remains a tendency on the part of certain radio amateurs to put-off the final touches to a job on the score that results have been moderately successful. The newcomer as well as the experienced worker should realise that for *consistent* electrical results a sound mechanical construction is of paramount importance.

SOLDERING

Primary consideration has been given to soldering, because a good soldered joint is the basis of every piece of radio and electrical apparatus.

When we pause to consider the number of soldered joints in a modern receiver and the slipshod way in which many amateurs make their joints, it is surprising that poor soldering does not cause more trouble, for it only needs one bad joint to produce a fault which may take a week to locate. Further, it is not always possible to find a bad connection by means of a test meter since the joint may behave quite normally when an appreciable current is flowing, yet its action under a minute R.F. current is that of a high, variable resistance. The moral, therefore, is to see that all soldered joints are properly made in the first instance.

Radio is a good servant but a very bad master. You can be perfectly certain that whenever you decide to chance an item, be it a minor component, a doubtful resistor, or a poor soldered joint, it will let you down. Take no risks but do the job properly the first time.

The Use of Flux

We all know why a connection is soldered, but few ever stop to consider what happens during the process. When we solder we endeavour to produce a continuous metallic connection of very low resistance between the tag and the wire. We want the solder to form a microscopically thin alloy with the two parts to be joined. Unfortunately all metals in common use oxidise rapidly when heated in contact with the air, and it is to prevent oxidisation that a flux is used which covers the joint to form an airtight seal under which the solder can flow. The flux also has another very important function to perform in assisting the cleaning process. All fluxes are slightly corrosive when hot, some more so than others. Zinc chloride (" killed spirits ") is the best flux for most metals, but as it is very corrosive, even when cold, and difficult to remove it must be prohibited for all electrical work. There are, of course, a number of proprietary fluxes sold which are excellent for radio joints, but the finished connection should be cleaned with a rag damped with methylated spirits. By far the best and safest flux is pure resin, although it is more difficult to use and needs greater care if *dry joints* are to be avoided. Resin, being a solid at all normal temperatures and insoluble in water, is safe to use since there is no fear of the flux causing corrosion. It is only a very mild cleaning agent when hot, therefore all parts to be soldered must be scraped scrupulously clean, otherwise the solder will not flow under the flux. Watch the blob of hot solder flowing off the iron. If it forms like a globule of water on a greasy plate then the joint is not clean enough and must be scraped again. The solder should flow in a thin even film over the hot metal ; the thinner the solder flows the better the joint will be.

Solder and Resin

Solder is sold in various grades from a very coarse type containing about three parts of lead to one part of tin which is used for plumbing, to very fine blow-pipe solders containing one part of lead to four parts of tin. Fortunately the makers of electric soldering irons, which are now in almost universal use, have produced a very satisfactory resin cored solder which should always be used with these irons. In addition to the resin in the solder a small tin of resin should be kept handy on the bench. Resin can be bought at most chemists' shops, but only the best pale straw-coloured lump resin should be purchased. Refuse the powdered resin since it is often of inferior quality. A pound costing about 8d. should last a year under normal amateur conditions.

Soldering Hints

In order to produce a good soldered joint certain conditions must be fulfilled.

1. All parts to be soldered must be absolutely clean.
2. Some suitable flux, preferably pure resin, must be used to assist in cleaning and to prevent oxidisation of the parts to be soldered.

World Radio History

3. All the parts to be soldered and the solder itself must be heated to a temperature slightly higher than the melting point of the solder.
4. The heat must be applied long enough for the solder to run into all the crevices of the joint.
5. The soldering iron must have the point properly tinned in order to convey the heat from the iron to the joint.
6. A class of solder suitable for the job must be used.
7. The soldered joint must be kept perfectly still until the solder has had time to solidify.
8. All surplus flux, particularly if a paste or fluid, must be carefully removed when the joint is cold.

Cleaning

This sounds very simple, but it is where most beginners go astray. Cleaning does not mean polishing with a metal polish, it means mechanically scraping with a proper scraper (it is not unknown for a beginner to try cleaning parts to be soldered with a metal polish !). The most useful cleaning tool is a small three-cornered scraper which can either be purchased from a tool dealer or made from a 4" dead smooth single-ended triangular saw file. Grind the teeth away for 1½" on all three sides until the end forms a point. The grinding should be done on a wet grindstone, finally finishing the edges off on an oilstone. Do not use excessive pressure when grinding towards the point, or the heat of grinding will draw the temper as indicated by the point going blue in colour. Files are tempered to what is known as "dead hard," since they are required to cut all other metals ; for the same reason we require our scraper to be dead hard. If, in grinding, the temper is "drawn" it will become soft and will require resharpening too often. Under no circumstances should a high speed carborundum type of wheel be used, as it is almost certain to soften the tool. Besides its use as a scraper this tool makes a good pricker for wood screws, the tapering triangular hole formed, giving an excellent start for the thread.

Tinning the Iron

A soldering iron is useless until the point has been tinned, because it is only through the tinning that the heat can be conveyed from the iron to the joint. The film of oxidised copper and dirt which inevitably forms on an untinned iron acts as an efficient insulation to the heat. To tin the iron, heat it until it will just melt the solder, file one face clean and, before it has had time to discolour, rub it in a small heap of resin and bits of solder in a tin lid. Repeat the process with the other faces of the iron till the point is completely covered with solder for about ¾" up. Once an iron has been properly tinned it should hardly ever need retinning provided it is not overheated and resin is used exclusively as the flux. The surplus resin which finds its way on to the bit burns, to form a black scale, which can be wiped off with a cloth, leaving a bright tinned surface underneath. An excellent way of tinning a gas or coal heated iron is to have a tin containing scraps of solder and salammoniac into which the hot iron is plunged. This method should not be used indoors since the fumes are most objectionable, also the iron must be nearly red-hot, so it is useless for an electric iron. With the salammoniac method there is no need to clean the iron at all, just plunge the hot iron into the mixture and the salammoniac will do the cleaning. Some of the paste fluxes have the disadvantage that they attack the solder on the iron, making frequent retinning essential, but with resin this should never be necessary.

Making a Soldered Joint

Let us now proceed to solder a so-called "tinned soldering tag" to a wire. If any attempt is made to make use of this so-called "tinning" the result is most likely to be a perfect specimen of a dry joint ! Treat the tinning as a dirty surface and scrape it away until the metal is laid bare underneath. It is not enough to produce a few streaks of brass, scrape till the whole of the part to be soldered shows clean brass. Pick up a small piece of solder on the iron, plunge it into the tin of resin and transfer the iron quickly to the soldering tag. The resin will run down the tag followed by a film of solder which should appear as though it wants to meet the brass of the tag. If it behaves like a spot of water on a greasy plate then the tag is not clean. Never touch anything which has just been cleaned for soldering, as the grease from the hand is quite enough to prevent the solder running properly. Now having cleaned and tinned both sides of the soldering tag make the end of the wire into a small hook, put it through the hole in the tag and nip it up with a pair of pliers to make a mechanical joint. Pick up a small piece of solder and some resin on the iron and transfer them quickly to the joint. After the solder has run all through the joint hold the iron underneath to drain off the surplus solder. It is a common fallacy to imagine that the strength of a soldered joint depends upon the amount of solder used. It does not. A good soldered joint should have the parts to be joined, in as close a contact as possible with just sufficient solder left to prevent them moving. That is why it is always best to make a mechanical joint first. Curiously enough, although the tinning on many components is often of a very doubtful quality, tinned copper wire takes solder readily without much cleaning. It is as well to pull the wire through a clean cloth to remove the surface dirt and straighten the wire. If the wire is very old or dirty then pull it through a piece of emery cloth or glass paper.

A very common method of soldering is to lay the wire on top of the tag (uncleaned of course), smear them both with flux, drop a large blob of solder on with the iron and wait until it sticks. This class of joint gets exactly what it deserves—trouble at a very early date. A light jerk would pull the joint apart, for the solder has not been given a fair chance to adhere to either the tag or the wire. The foundation of all good soldered joints should be a sound *mechanical* joint as a beginning.

DESIGN AND LAYOUT

Like everything else in this life designing a piece of radio apparatus is a compromise between many factors, and to obtain the most successful result it is necessary to strike a balance between

World Radio History

them. Radio circuits become more and more complicated every year until the average amateur despairs of ever keeping pace with developments and buys his apparatus ready made, losing all the joy of designing and building.

Modern circuit diagrams may be complicated, but they can be resolved into a number of simple sections, each one performing its own function with respect to the remainder. Thus, to take the case of a four-valve broadcast type of superheterodyne receiver, the circuit might be a frequency changer, an I.F., a double-diode pentode and a full-wave rectifier. Draw out the basic circuit and it appears quite simple. Now add A.V.C., a tone control, coil switching for four wavebands, a gramophone pick-up and switching for an external speaker, and we have a formidable circuit diagram, but, knowing the functions of the various parts, we can dissect it easily. The various sets of coils round the frequency changer valve tell us that the receiver is intended to work on a number of wavebands, the gramophone pick-up and switching for the external speaker are obvious, but it might take longer to find the reason for the tone control and A.V.C. components.

The reverse process takes place when we start to design our own apparatus. We know what we want and we know, or should know, a good deal about the functions of the various components. Given a fairly good working knowledge of modern radio apparatus there is no reason why the home-made set should not compare very favourably with the purchased article, particularly transmitters.

The Basic Circuit and Components

In starting to build a new set the first thing necessary is to draw out the basic circuit diagram. Start with a block diagram—that is, show each valve as a square connected to the next square by the appropriate coupling symbol. Then add the type numbers of the valves, their filament, anode and screen voltages, and currents which it is estimated that they will require. From this sketch the full circuit diagram can be drawn and the power supplies estimated. Now comes the problem of fixing the sizes of the various components, such as grid-leaks, coupling condensers, screen-dropping resistances or potential dividers and by-pass condensers. Some can be calculated from Ohm's Law, but in the case of screen-dropping resistances in transmitters where the current cannot be predicted accurately, resistors with an adjustable tap are advisable.

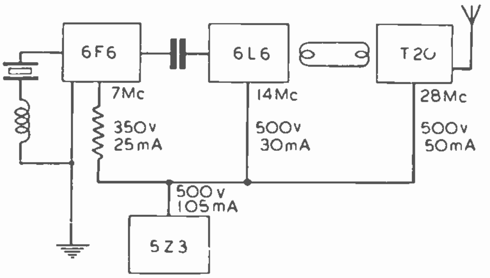


Fig. 1.
When commencing to lay out a job start with a block diagram.

By-pass condenser values are often the cause of confusion. The by-pass condenser is intended to remove the R.F. component in a circuit, leaving only the D.C., hence it should have a very low impedance to the frequency of the R.F. This naturally implies the largest capacity possible, but unfortunately all condensers have an inductive reactance besides the capacitative reactance, and this inductive reactance increases with the capacity. If too large a capacity were to be used then the inductive reactance would predominate, causing the impedance to rise, thus defeating the object of the condenser. A very interesting article describing some tests on by-pass condensers for 56 Mc appeared in *The Wireless World* dated September 29th, 1933, where it was shown that the most suitable size for this frequency is ·0003 μF. For other frequencies the size should vary approximately inversely as the square of the frequency. This must be taken as a rough rule only and for lower frequencies the values can vary within relatively wide limits.

Transmitter grid-leaks also vary in value, but should be higher if the valve is used as a frequency doubler than if operated as a straight amplifier. Here the value depends upon the valve and the amount of drive available, and is best determined finally by experiment.

Transmitter coupling condensers can usually be taken as about ·0001 μF, although some designers use up to ·001 μF.

When considering tuning circuit L/C ratios it should be borne in mind that the capacity is the capacity of the whole circuit, including the valve, valve base, connecting wires, coil-holder, etc., and not just the capacity of the tuning condenser. This can make a considerable difference on 14 Mc and higher frequencies, where the stray capacities are apt to be large. Instead of calculating the capacity required it is better to design the inductance from a reliable formula such as " Radio Data Charts " by R. T. Beatty, M.A., B.E., D.Sc., and published by *The Wireless World*, or from the Abac given in Chapter 24. This will ensure that the L/C ratio is correct. In badly designed transmitters it is frequently impossible to make them operate above 14 Mc, when the only cure is a complete rebuild, using more suitable components.

Before discussing actual layout it must be pointed out that components are not selected to work as one item by themselves, but as a part of the whole set. Thus a grid-coupling condenser in a speech amplifier must be considered in relation to the anode resistance and the grid-leak, which in turn depend upon the types of valves to be used, these in their turn being selected according to the gain required. Considerable latitude is usually permissible for most components, but in cases of doubt it is instructive to consult all the literature available dealing with the instrument under consideration, and to tabulate the values specified, taking careful note of the operating conditions.

Having settled upon the design of the set, draw out the full circuit in ink, adding the component

World Radio History

values in red ink so that they can be seen easily. From this drawing an accurate estimate of the cost can be obtained, not forgetting such items as valveholders, stand-off insulators, dials, knobs, terminal blocks, etc.

Layout

Now comes the important matter of the actual layout, on which success or failure so often depends. A word of sound advice—it pays to devote considerable time and care in determining the best position for every component. All too frequently the parts are grouped to give a nice symmetrical panel layout irrespective of the arrangement inside. A neat panel can accompany a sound electrical design, but the chassis should receive first consideration.

If all the components are to hand, spread them out on a sheet of drawing paper or piece of board slightly larger than the estimated chassis size. If the chassis is intended for a rack then mark two parallel lines to represent the ends. Play a game of chess with the components until all grid and plate leads are short, valves and condensers are out of the fields of coils, and R.F. chokes are in "safe" positions. It will be necessary to play this game for the top of the chassis and also for the under side, remembering that the latter will be of the opposite hand. This sounds very simple, but neither the first nor the second attempt is likely to be satisfactory. Light a pipe and sit down to consider the result, then sweep all the parts to one side and do it again without trying to remember the previous arrangement. It is surprising how many arrangements can be found, most of which appear quite good but usually have one or more bad points. Curing one poor arrangement often leads to other undesirable features, but it should be possible to obtain what is wanted with a little patience. If all the parts are not available use small objects of similar size like match boxes, wire spools or coins to represent the missing parts. Strong brown paper templates cut out to size are very useful, especially for the panel layout.

Before disturbing the "chess game," make a scale drawing, either full size or on squared paper, showing the positions of the large holes for valveholders, dials, meters, coil-holders, switches, outlines of transformers, valves, etc. Wiring holes should not be shown or the drawing will become too confusing. Coupling condensers, small resistors and by-pass condensers can be ignored, but they should not be forgotten.

To do the job properly two drawings should be prepared, first a plan showing all the components in outline, and second a complete drilling plan, but these demand a certain amount of draughting skill. Celluloid stencils for 1-watt resistors, paper tubular condensers and R.F. chokes are easily cut with a sharp knife, and these will be found very useful in drawing out a complicated circuit. By using them it is possible to see at a glance whether or not an item will fit without drawing it.

Do not attempt to decide upon the chassis size or to drill a single hole until the drawing is complete, otherwise it may be found that some vital component has been forgotten. Remember, it is very difficult to alter a metal chassis.

Stencil Cutting

To assist those who wish to make stencils, basic outlines of some popular components are given in Fig. 2. Suitable thin, clear celluloid sheet can be obtained from a coachbuilder. Mark the outline with a sharp scriber, drill the corner holes with a twist drill rotated between the thumb and first finger, cut the straight lines with a sharp penknife, and finish off with a small smooth file. In the drawing the wire leads have been omitted from the resistors, since these leads can be bent easily to any shape, but they have been shown on the R.F. choke.

Wiring Up

Although, strictly speaking, wiring a set pertains to the actual construction rather than to the design, the positions of the various wires must not be overlooked on the drawing. It is as well to start with the less important leads, such as heater or filament, screen and suppressor-grid connections. These should be laid flat along the under side of the chassis, if possible in the corners, where the capacity to the chassis will have no effect, leaving all the available room "up in the air" for the "hot" grid and plate leads. These latter should be as short and as direct as it is possible to make them. Further, they should have no more insulation, other than air, than is absolutely necessary. If insulation is essential, such as when passing through a panel, see that it is ample and of a suitable type if the conductor is to carry high frequencies. Small porcelain stand-off insulators make excellent feed-through insulators if a hole is cut in the panel slightly larger than that in the base of the insulator, so that there is no chance of the wire touching the panel or chassis.

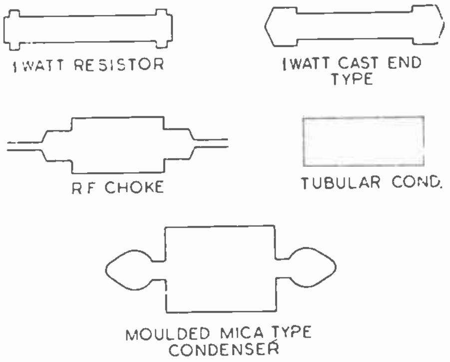


Fig. 2.
Stencil outlines for small components.

Circuit Details

An oscillatory circuit comprises only the coil and condenser, consequently it is very important that the connecting wires should not be smaller in cross-sectional area than that of the coil, otherwise the

World Radio History

connections will introduce undesirable resistance into the circuit. The lead from the anode of the valve can be of thin rubber-covered flex, since it only carries the D.C. (plus the flick impulses) and not the very high oscillating currents of the tuned circuit. Further, if the anode lead is made the same size as the connecting wires, then it will impose an undue strain on the anode cap of the valve if a top anode valve is used.

It is very bad practice to wrap the connecting wires of the tuned circuit round the condenser terminals. Use soldering tags of ample size and see that the soldered joint is well done. Wires that are wrapped round terminals only present a line contact and will come loose in time, whereas a soldering tag which is properly tightened up will never work loose unless there is excessive vibration.

R.F. Chokes

R.F. chokes should be placed outside the field of inductance and well away from each other, otherwise they are liable to cause magnetic coupling between two circuits, a fault which they are intended to prevent. If a choke has to be located near to a coil then see that it is at the centre and that their axes are at right angles. In modern practice with the coil mounted on top of the chassis the choke is best placed underneath, where the chassis will act as an efficient screen.

Push-Pull R.F. Circuits

In order to function with the maximum efficiency, a push-pull R.F. circuit must be arranged symmetrically, both with respect to earth and also with respect to the two halves of the circuit. This point is often overlooked, and the majority of push-pull amplifiers are far from symmetrical. Draw a pencil line along the chassis and treat this as the datum point from which all components should be set off at equal distances both vertically and horizontally. The result will be a more efficient and a better-looking set.

Condensers

In transmitters, small-sized mica moulded condensers can be suspended from the wiring, if care is taken to see that they are not liable to vibrate, but by-pass condensers are best screwed to the chassis. When metal-cased condensers are used for R.F. coupling they are best mounted on two small porcelain stand-off insulators, otherwise the capacity of the case to earth will by-pass a considerable proportion of the current. Small ceramic type condensers are particularly efficient at high frequencies and are excellent for coupling purposes. Curiously enough, they are not so efficient as mica at low frequencies so should not be used in audio amplifiers.

Ceramic condensers can be obtained in capacities up to about ·001 μF with a test voltage of 1,500 volts A.C., so they should be quite capable of withstanding a working voltage of 500 volts. Either moulded mica or tubular paper condensers are quite suitable for screen by-pass purposes. Remember to keep all coupling condensers well away from the chassis or other connections. At least 1″ spacing should be considered the bare minimum.

Resistors

Resistors should never be used in any circuit carrying an R.F. current without either a series R.F. choke or a by-pass condenser, or both, to divert the R.F. component away from the resistor.

Transmitter grid-leaks should have a good choke in series on the grid side, otherwise the resistor will form a low impedance parallel path for the driving voltage, resulting in most of it being wasted. Further, the grid-leak will overheat and possibly fail.

Switches

All switches have some resistance, usually considerably greater than that of the connecting wire, and unless there is ample surface contact the losses will be very high indeed, resulting in low efficiency. Switch contacts will always oxidize, due to the moist atmosphere, and this oxide is a poor conductor, but if the switch is operated regularly the contacts will keep fairly clean. The insulation should be specially designed for high-frequency work, otherwise this will introduce further losses.

Small toggle switches which are designed as mains switches to carry about 3 amperes at 250 volts are quite unsuitable for R.F. purposes. The contacts are much too small, the insulation is unsuitable, and the capacity to earth is grossly excessive. Only the best switches, specially designed for the job, should be used.

ALUMINIUM CHASSIS WORK

In the days when wood baseboards and ebonite panels were the fashion, construction was a simple matter, but with the modern all-metal vogue many amateurs have been compelled either to buy their chassis ready-made or else make the best of wood. Now for a production job the manufacturer uses plated steel, but this material is hardly suitable for home construction, because all the holes are punched and the edges bent with big power presses. Fortunately, aluminium can be worked fairly easily and is by far the most suitable material for amateur use. As a conductor it ranks second to copper, it is relatively cheap and is not likely to crack when bent; further, it can be cut, drilled and bent easily.

Box-type Construction

A box-type chassis can be cut out of one single sheet and bent, or the sides can be cut separate from the deck and joined with $\frac{3}{8}$″ by $\frac{1}{16}$″ angle brass and 6 B.A. screws. The former method is quicker, cheaper and easier, but it is not possible to get square edges where the metal is bent, not that this is a disadvantage. Fixing the sides with angle brass is a wearisome task, but for a first-class job there is nothing to equal it.

For chassis up to 18″ square, which is large enough for most purposes, $\frac{1}{16}$″ sheet aluminium is the best thickness to use. If there are any screening partitions these can be made from 20 S.W.G. sheet to save weight and expense, but if there are no screening partitions it is often advisable to fit a strengthening rib in a large chassis.

Front panels can also be cut from $\frac{1}{16}$″ sheet, but they look better if they are made $\frac{1}{8}$″ thick. Do not attempt to bend a long side in a vice, or the

World Radio History

result will show all too plainly that it has been bent a little at a time. Two pieces of hardwood (oak, beech, walnut or hard mahogany), 3" by 2" and 6" longer than the total length of the unbent sheet, make excellent clamps for bending. The wood should be planed straight and square on all edges and the panel clamped between them, using a ⅜" Whitworth bolt at either end. Ordinary carriage bolts with wing nuts and washers are ideal, since the square under the head prevents the heads from turning. Prior to drilling the holes for these bolts make sure that the top faces of the two pieces of wood are flush.

Before attempting to bend the chassis it should be marked out and all the larger holes drilled, as it is not always easy to cut large holes after bending; furthermore, it is frequently possible to fit an extra clamping bolt through one or more of the chassis holes. If this is not possible, then a stiff clamp must be fixed across the centre to keep the two hardwood battens up to the aluminium.

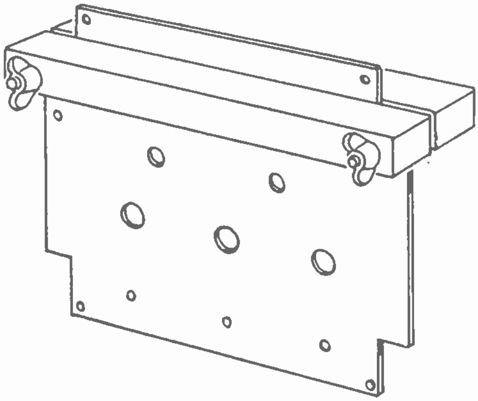


Fig. 3.
An aluminium chassis, drilled and clamped for bending.

Bending the first two sides is easy, but considerable ingenuity has frequently to be exercised in order to bend the remaining two sides. Cut two more pieces of hardwood the length of the last two sides to be bent and clamp these through two holes in the chassis. If no holes, or only one, are available then the hardwood pieces will have to be gripped in a stout vice. The best tool for bending is a rubber hammer, since it will leave no marks, although an ordinary steel hammer can be used, provided the face is not marked and great care is taken to see that all blows are struck true. The marks left by a steel hammer can be considerably reduced afterwards, but this demands some skill. Having clamped the aluminium sheet tightly at the line where it is to be bent, start by bending the flap all along through an angle of about 20°. Carry on bending it a little at a time until it is square with the deck, using light blows of the hammer. A little at a time and light blows, is the golden rule for a good job.

Working Aluminium

When drilling, tapping, sawing or filing aluminium always use turpentine as a lubricant since, if any attempt is made to work it dry, the swarf will clog the tool, causing drills and taps to break in the work. Engineering text-books suggest rubbing the file with a block of chalk to prevent the filings from adhering, but lubricating the file with turpentine works better. The filings can be brushed out of the teeth with ease, whilst if a dead smooth file is used the finish will be like glass. For small holes up to ⅜" or even ½" diameter, ordinary twist drills can be used, but a small pilot hole of about ⅛" should always be drilled first, otherwise the large drill is liable to wander. Holes from ⅜" to 1½" can be cut with an ordinary old-fashioned type of joiner's centre bit.

Very large holes for meters and dials are best cut with a fretsaw and metal cutting blade; even an ordinary wood fret-saw blade will cut aluminium, but the teeth are rather too widely spaced. A tank cutter is another useful tool for cutting meter holes, but the ¼" twist drill centre should be replaced with a short length of steel rod, otherwise the flutes of the drill are liable to open out the centre hole, causing the cutter to wander.

Use a wood chisel to remove the spew from the underside of a drilled hole, taking care that the back of the tool is kept flat against the panel, otherwise the corner of the chisel will leave a deep, ugly scratch.

When cleaning a hole inside a chassis the bevel of the chisel must be kept flat against the chassis. This treatment is rather hard on a good tool, but a cheap chisel costing about 6d. can be bought and kept for the job. Select a chisel with a flat back, otherwise it will have to be ground down on an oil stone, which is a long, tedious job. Small inaccessible holes can be cleaned with a larger-sized drill, which is better than a countersink bit, since it cuts the spew away instead of bending it down, as the countersink has a tendency to do. Never leave the spew in any hole through which a wire will pass. It is advisable to protect all such holes with an ebonite bush or rubber grommet.

Finishing and Polishing

As supplied, sheet aluminium has a highly polished surface, but it is almost impossible to obtain it without scratches. Further, this polished surface is very easily marked, so that it is hardly suitable for a finished panel. Matt finished aluminium has a beautiful appearance, and it is nothing short of a crime to paint it. The commercial way of producing the matt surface is to dip the panel in a hot strong solution of caustic soda, but as this method necessitates a large vat or bath it is rarely possible for home use.

The wavy lines, or what is called "watering," often seen on an exhibition motor-car chassis, are produced with a flat scraper, but it requires considerable skill to attain the necessary wrist action. A mechanical method for obtaining the matt appearance of the caustic soda treatment makes use of a stiff wire scratch brush revolving in a jeweller's polishing head. The panel is held up to the rotating brush and moved quickly backwards and forwards until the surface skin on the aluminium

World Radio History

is scratched away. The brush must be kept rotating in the same direction and great care must be taken when working near the edges of the panel, otherwise the brush will throw the panel across the room.

When the panel has been evenly scratched all over it should be painted with a thin coat of transparent cellulose lacquer and all the surplus lacquer wiped away with a cloth, well moistened with a mixture of amyl acetate and acetone. This apparently removes the lacquer, but actually a very thin film is left which is quite sufficient to prevent the panel from marking. It also smooths down the roughness and washes away the aluminium dust.

TOOLS AND THEIR USES

The amateur workshop varies from a corner of the sole table in lodgings to a large separate room with a bench, lathe, drilling machine and innumerable hand tools. The range of equipment naturally depends upon the space available, but it is surprising how much work can be accomplished with even a small box of tools.

Choosing Tools

Before describing the various tools and their uses, there is one rule which applies when purchasing any tool, and that is, buy the best that can be afforded. Many tools can be bought for a price varying from 6d. to more than a pound, and to the novice the difference in outward appearance is so slight that he is tempted to buy many cheap tools rather than a few first-class ones. Wood saws are an excellent example. The cheaper types may cut wood for a time, but they usually require "driving," whereas a good saw should cut with practically its own weight. If it binds, the cheap saw will probably buckle, while the blade itself may be too soft to keep a cutting edge, or too hard and crack. A good workman cannot do good work with a bad tool, whilst the beginner has no chance to improve.

Wood Saws

Wood saws can be divided into many categories. For example, the "rip" saw used for cutting along the grain, the "crosscut" saw for working across the grain, and the "panel" saw all come within the handsaw class, and all have long, thin, tapering blades varying from 20″ to 28″ in length. The only practical difference between them is in the pitch of the teeth, therefore a handsaw about 26″ long, with 6½ teeth per inch (or, as it is called in the trade, 6½ points), will do all our work. "Dovetail" and "tenon" saws are smaller, with rectangular blades ranging from 8″ to 16″ long, and made with a steel or brass back to stiffen the blade. These are used for making fine cuts across the grain, such as dovetails or tenons for joining two pieces of wood. They have much finer teeth than those in the handsaw class, as they have to make a cleaner cut without tearing the fibre. Brass-backed types are the more expensive, but a good steel-backed saw is an excellent tool. For amateur radio work a steel-cutting hacksaw will do most of the jobs which require the use of a wood tool.

Like all other tools, saws will not give of their best unless they are well looked after. Keep the blade clean and polished, smearing it with a film of vaseline after it is used. A rusty saw is an abomination.

When using a saw hold it with the last three fingers and thumb, the first finger being extended along the handle, pointing towards the end of the blade, in order to guide and control its operation. Maintain a steady, even motion of about 65 strokes per minute for a handsaw, and a little faster for a tenon saw. Don't try to saw fast. Saws need sharpening from time to time and, as this is an expert's job, it is as well to let a good joiner do it.

The two horns at the end of the handle are placed there so that pressure may be brought to bear on either the heel or toe of the saw.

Metal Saws

The "hacksaw" is the universal metal-cutting saw in the amateur workshop. The replaceable blades can be obtained in lengths from 8″ to 12″, and with varying numbers of teeth. Special fine-tooth double-edged blades are made for cutting tubes. The coarse blades, with 14 or 18 teeth per inch, can be used for ebonite or bakelite, but the medium blades, with about 22 teeth per inch, are best for most metals except thin sheet, when fine blades with 32 teeth per inch should be used. As a general rule harder metals demand the finer blade.

A "fretsaw" is a particularly useful tool, especially when used with metal blades for cutting out dial and meter holes. When operated properly the surrounding metal is not marked.

Another handy tool not often seen in an amateur workshop is a jeweller's "slitting" saw, which is like a miniature brass-backed tenon saw having a very thin blade about 4″ long with correspondingly fine teeth. The blades are replaceable and cost about 4d. each. Yet another useful jeweller's tool is the "piercing" saw. This is a small rigid fretsaw which takes material up to about 4″ inside the frame. Incidentally, both these tools are excellent for cutting screws in inaccessible positions.

When replacing saw blades, remember that hacksaw blades must have the teeth pointing *towards the tip of the saw,* whereas the teeth of fretsaw blades should point *towards the handle,* in order to keep the work pressed on to the cutting table.

Hammers

Hammers vary slightly in hardness: the softer types are inclined to mark on the face, a disadvantage when sheet metal has to be flattened, since the hammer then marks the material, whilst the very hard types are liable to chip or split. There is an old trick for testing the hardness of a pair of hammers by taking one in each hand and hitting them together to see which is marked. The latter is discarded as being soft.

Hammers are sold according to the weight of the head, a useful size being a 1-lb. "ball pane." Ball pane refers to the knob, and this is used for riveting.

When using a hammer, grip the shaft at the end and let the head follow through like a golf club keeping the wrist loose and supple.

World Radio History

Files

A file is one of the simplest tools and, without doubt, the most difficult to use skilfully.

Good files are cheap; therefore there is no excuse for buying inferior ones. Hand-made files are considered superior to those made by machine, since the former type has a very slight irregularity in the teeth which makes it cut better; but, naturally, they are slightly more expensive. Files are sold in lengths from about 14″ to 4″ long and in various cuts. These cuts are defined as rough, middle, bastard, second cut, smooth and dead smooth. The shapes also differ, being parallel or taper, and in cross-section they may be flat, three-square or triangular, round or rat-tailed, knife, half-round, or square. When one edge is left uncut the file is said to be "safe-edged."

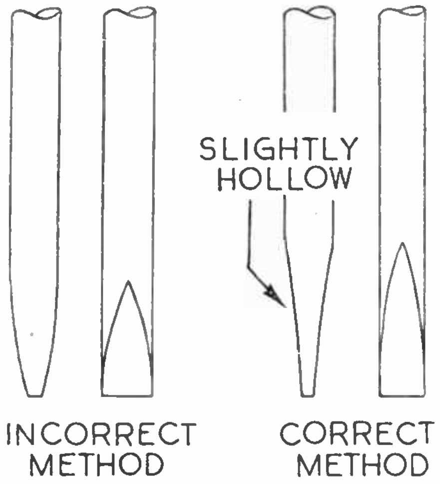


Fig. 4.
The right and the wrong way of grinding the tip of a screwdriver blade.

There is available a very useful set of files which are sold on a card and called needle files. These are particularly handy for small jobs.

File handles are always sold separately, and no file (except a needle file) should ever be used without a handle, since there is always a danger of the file slipping and causing serious injury. To fix a file handle, drill a small hole in the centre to give the tang (or pointed end) a start, place the tang in the hole and bring the file handle down on to the bench with a smart smack so that it drives its own way into the handle. Do this two or three times until the handle is secure. Never hammer a file into its handle because there is a danger of the file splitting. Further, never heat the tang, as this will inevitably draw the temper and ruin the file.

In using a file, grasp the handle firmly in the right hand, with the thumb on top, and let the left hand rest on the tip to guide it. As the file proceeds across the work in the forward cutting direction, pressure must be eased off the left hand and transferred to the right hand. Draw the file back with the minimum of pressure. Always clean a file with a wire file brush after, and often during, work, in order to remove the filings which stick in the teeth. Filings which are firmly lodged in the teeth can be removed with the corner of a piece of tinplate. It is useless to expect a clogged file to cut; even if it does, the work will be badly scratched.

Files should be used first on copper and brass, then when they are too dull to cut brass they can be used on iron and steel, but if they are used on steel first they will be next to useless for brass. A dull file is quite satisfactory for aluminium. Ebonite has a certain amount of semi-abrasive material in its composition and plays havoc with files and drills, so that "elderly" files only should be used. Aluminium has a habit of sticking in the file teeth, but if it is lubricated with turpentine there will be much less difficulty in removing the filings. Unfortunately, turpentine oxidises in contact with the air, so it is as well to keep one or two special files for this material, rubbing them as dry as possible after use.

Screwdrivers

Screwdrivers call for little comment, but the tip is of importance if the screw heads are to remain undamaged. The tip should fit the screw head properly, so that the turning moment is evenly distributed. As these are relatively cheap tools it pays to buy a number of different sizes, including a ratchet type. The blade can be sharpened with a smooth file, care being taken to see that the end is square and the tip nearly parallel. If the tip is filed to too great an angle it will tend to jump out of the screw, damaging the sawcut. On the other hand, if it is filed too thin it will be weak and liable to break under force. (See Fig. 4.)

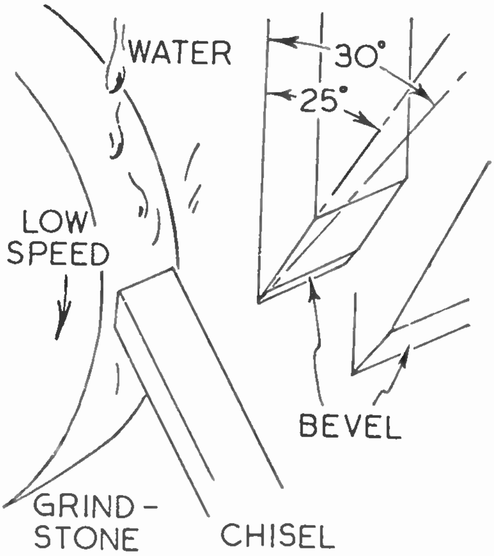


Fig. 5.
The method of grinding and sharpening a wood chisel.

World Radio History

Wood Chisels and Gouges

Wood is not used a great deal in radio work to-day, but it is just as well to have one or two chisels handy and to know how to look after them. Once again it pays to buy only the best, and to take care of them. There is no tool which gets quite so much ill-treatment as a wood chisel. The cutting edge must be kept sharp and the back of the chisel must be ground flat and *kept flat*, otherwise it will be impossible to pare wood.

Most amateurs avoid sharpening chisels, yet it is not difficult even if it demands some skill. If a chisel is badly chipped, the first step is to grind out the chips on a *wet* grindstone until the edge is square and true. (See Fig. 5.)

Never attempt to grind wood tools on a high-speed carborundum type of wheel, since the grinding produces intense local heat which destroys the temper of the tool. The water on a wet grindstone keeps the tool cool, preserving the temper. Having removed the chipped edge, grind the bevel evenly until there is the thinnest hair line of untouched metal at the very tip of the tool. Now give the bevel of the chisel about a dozen rubs along the whole length of a *Washita* oil stone which has been covered with a film of thin, non-drying oil, holding the chisel at a slightly greater angle than was used for grinding. If the finger is now run down the blade the edge should feel as though it has been rubbed over. This is called the " feather edge " and must be removed by rubbing the *back* of the chisel three or four times along the oil stone, taking great care to keep the chisel flat on the stone. Some of this feather edge will have vanished, but the remainder will be felt on the bevel side. To remove all traces, and also to give the final, lasting cutting edge, the chisel must be stropped on the palm of the left hand. Hold the chisel in the right hand and draw the blade across the palm of the left hand, first the bevel side and then the back.

Planes

Wooden planes are practically obsolete and have been replaced by adjustable steel planes, which are easier to use, especially in inexpert hands. A British-made steel smoothing plane with a 2½" blade is about the most useful size for general use because it is heavy enough for large jobs, yet not too clumsy for small work. Plane irons are sharpened in exactly the same way as chisels, but the edge should be very slightly rounded so that the corners of the blade only just touch the wood without marking it. Don't try to take a heavy cut, especially when finishing hard woods. " The lighter the cut the better the finish " is a good adage to adopt. When finishing a board always plane " with " the grain, otherwise the fibres will be torn out, leaving a very rough surface. With some woods, particularly mahogany, the grain is apt to run in different directions in the same piece, in which case it is necessary to plane first one way and then the other. This demands skill.

To make a steel plane work easily rub a wax candle along the bottom to act as a lubricant. In the same way wooden planes should be rubbed on a pad soaked in linseed oil. To preserve wooden planes and make them work sweetly, a joiner first removes the iron, plugs up the mouth bottom and then fills the rest of the mouth with linseed oil till the plane body will absorb no more oil.

Twist Drills and Bits

Twist drills are made of either carbon steel or high-speed steel. The former are much more common and are usually supplied unless high-speed drills are specified. The latter, as their name implies, are designed to run at high speeds, but they have the further advantage that they are harder and will retain their cutting edge much longer than the other types. Naturally, being better, they are the more expensive.

Twist drills can be purchased in fractional inch sizes, advancing by $\frac{1}{64}$", or in a numbered and lettered series, starting with the finest, No. 80 (·0135") to No. 1 (·288"), and starting again with the letter " A " (·234") to " Z " (·413"). The most useful set is from No. 1 to No. 60, which can be purchased in carbon steel on a stand complete for about 20s. High-speed drills cost more than twice this price.

The sharpening of twist drills is best done on a small high-speed carborundum type of wheel. Although this task is not difficult, it is far from simple to describe or to follow. In large machine shops, twist drills are ground on a special machine made for the job, but they can be ground on an ordinary wheel grinder. The three R.H. sketches (Fig. 6) will probably give a clearer idea of the various angles of the cutting edge. The chief angle is the cutting edge, and this has been found from practice to be 59°. The minor angle called the " back rake," need only be sufficient to prevent the tool from rubbing, about 4° is ample ; a greater angle will weaken the tool. The third angle is obtained automatically but the centre of the line "X" *must* coincide accurately with the centre line of the drill, otherwise the drill will tend to make a larger hole than intended. Hold the drill up to the side of the wheel as shown in the L.H. sketches (Fig. 6) and rotate it slowly for about ¼ turn, taking great care not to let the other cutting lip come into contact with the wheel. Grind slightly more off the back than the cutting edge in order to produce the back rake. Grind a little off one cutting lip, then do a little to the other until the drill is sharp and ground central.

Sharpening twist drills is not difficult with a treadle-operated wheel, but is next to impossible single-handed with a hand-driven grinder. An old sewing machine treadle and a jeweller's polishing head make an excellent cheap grinding equipment, whilst, if a fairly stout polishing head is selected, it can be used for innumerable operations quite beyond the intentions of the maker.

Wood-working bits are of many types, the two most useful being centre bits costing about 6d. each, which are satisfactory for shallow holes, and twist bits costing about 1s. 6d. each, which will drill long holes true. An adjustable bit costing about 7s. 6d. will drill any size from ½" to 1½", and this can often be made to replace a series of cheaper bits and is therefore a good investment.

Hand Drills

If there is one tool with which Great Britain would appear to take second place to the U.S.A.

World Radio History

it is the hand-drill. American drills are neater and better finished, yet quite strong enough for light work. One of the best known is the *Goodall-Pratt* No. 5½. Although rather expensive, it has two speeds, will take up to ⅜" in the chuck and has a useful amount of leverage in both the large gear-wheel and handle. The *Millers Falls Company* make an excellent range of smaller drills.

The brace for the wood bits should have a ratchet, since this is invaluable for working in confined spaces. Square shank twist drills can be obtained to fit the brace and are particularly useful for sizes over ⅜". A screwdriver bit to fit the brace is very handy for persuading stubborn screws to move. Few screws can resist such an instrument; they either turn or break.

A small hand-operated drilling machine is useful for the larger workshop, as jobs can be done with it which would be quite outside the scope of a hand-drill, particularly if the machine takes up to ⅜" or even ½" drills.

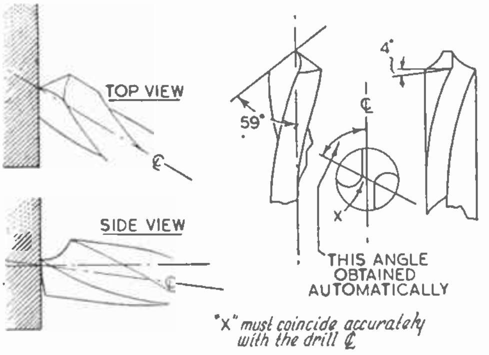


Fig. 6.

Illustrates at right the angles of the cutting edge of a twist drill. The left-hand sketches show method of grinding.

Reamers

Reamers, or rimers, are used in engineering practice to produce more truly circular holes than can be obtained by drilling. The hole produced by an ordinary twist drill is far from circular, and it is customary to drill out the hole slightly smaller than required and then to insert a parallel reamer. These reamers are similar in appearance to twist drills, except that there are five or more flutes which twist very slightly and in the opposite direction to a drill. The cutting is of course done by the flutes and not by the point, which is blunt. Parallel reamers can be obtained in sizes from about ⅛" in diameter up to 1½" or over, the prices ranging from a few shillings to a few pounds. For the amateur constructor they are a luxury tool, but a ¼" parallel reamer can be very useful for cleaning out condenser bearings.

Taper reamers are much more useful and are intended for tapering a hole to take a taper pin. Both parallel and taper reamers have a square head so that they can be rotated with a tap-wrench, but the taper reamers can also be obtained with a square head to fit a joiner's brace. They are only made in the smaller sizes and cost 3s. or 4s. each. A set of three or four reamers taking from ⅛" to ½" are invaluable for enlarging holes in sheet metal. The fact that the hole is taper is of no consequence, as the material is rarely thicker than ⅛".

Broaches

Broaches are a cheap form of taper reamer, and are made in smaller sizes than reamers. They are taper pieces of steel with five flats ground as cutting edges instead of the flutes of the reamer. Broaches cost but a few pence and can be obtained as small as $\frac{1}{64}$" diameter.

Pliers, Metal Shears and Spanners

A good selection of pliers are very useful, but these can be accumulated over a period. One good type is the long-snouted pliers, which are invaluable for picking nuts out of a mass of wiring. A pair of heavy, insulated 7" square-nosed pliers, a pair of 6" side cutters and a pair of 4½" round-nosed pliers would do to commence with.

Metal shears are frequently dispensed with in favour of the household scissors, but this is hardly fair to the scissors! Buy a pair of shears not less than 9" long with straight blades. There are some fancy shears with curved blades but these are best left alone, and smaller shears are not powerful enough. When using shears see that the cutting face of the bottom blade lies flat along the piece of the sheet which is being cut. The waste piece will then curl away nicely, leaving a straight, true edge.

Spanners, not pliers, should be used for tightening nuts. B.A. box spanners can be obtained in sets of three to take nuts from 1 B.A. to 6 B.A., whilst a set of five double-ended B.A. steel spanners costs about 2s.

Vices

The choice of a vice depends upon the kind of bench available. A good stout bench demands a 7" quick-release joiner's vice and a 4" engineer's parallel vice, preferably on a swivel mounting. For the temporary workshop there is nothing to equal a *Record Imp* vice, which can be clamped on to a table when required.

Vice jaws are serrated in order to hold the work firmly, but for small delicate work a pair of clams should be put over the jaws to protect the work. These clams can be made from two pieces of sheet brass each about 2" long and the width of the jaw. Grip the two pieces of brass in the jaws about the half-way line, bend one over the moving jaw and the other over the fixed jaw, hammering them down to the contour of the jaw. Clams can also be made from sheet lead in the same way and are also made of fibre, but these latter need special clips made to fit over the jaws. Vices for light work should be fixed at a height so that the operator's elbow comes on a level with the top of the jaw, but this demands a very high bench. Vices for heavy work should be slightly lower, so that more pressure can be brought to bear on the tool.

World Radio History

Taps and Dies

Taps and dies are probably a refinement, except for the inveterate constructor, but there is no doubt that a much better and neater finish can be given to a set if components are fitted with screws tapped into the panel or chassis instead of the inevitable nut and screw. Tapping holes takes longer, but the result is well worth the time spent. To hold properly, the length of the tapped hole should be at least equal to the diameter of the screw, but for very light work a $\frac{1}{16}$" aluminium panel will stand a No. 6 B.A. thread quite safely.

All B.A. dies are made in the $\frac{13}{16}$" diameter "button" type, which is a standard size. Taps are made in three types—taper, second and bottom. A taper and second or bottom of each size are quite sufficient for all radio work. The taper is used to start the thread, which is then finished off with the second or bottom tap.

Taps should be used in an adjustable tap wrench, but for light work they can be used in a drilling machine or even a hand-drill if care is taken not to strain the tap. Since taps are tempered very hard in order to be able to cut hard material, they are very brittle and snap under the slightest bending. When tapping thick material, they must not be rotated but given half a turn, then a slight move back to dislodge the swarf, then half a turn and another slight turn back.

Rules, Squares and Scribers

When buying steel rules choose those of the rustless variety, as they are much easier to read after they have been in use for some time. Get accustomed to working in metric dimensions as well as in inches. It is only a matter of practice, but once the method becomes familiar it will be found more convenient than the awkward fractional scale. If it is remembered that 1" equals approximately 2·54 cm. and that 4" is very nearly 10 cm., conversion from one to the other will be easy.

For marking out it is essential to have some means of drawing lines at right-angles, and a proper engineer's steel square with a 5" blade is a convenient tool to start with. Quite a good square can be bought for about 3s. 6d., which is accurate enough for most work. A large joiner's square with a 12" blade is handy for marking off panels and chassis.

A pocket scriber, a pair of spring dividers and, possibly, a pair of outside calipers are about all the marking-out tools required. The calipers and dividers should be of the nut adjustable type, since they are easier to use than the old-fashioned friction model. A micrometer reading up to 1" is a luxury which few will want, but is essential for crystal grinding.

Oil Stones

It is necessary to have some means of sharpening wood tools, and there is a considerable range of abrasive stones to choose from, some natural stone and others synthetic. A *Washita* oil stone is the best for giving the final finish to a tool, whilst a double-faced *Carborundum* stone with one coarse and one medium side can be made to do much of the rough grinding which should be done on a wet grindstone. Carborundum is probably the sharpest cutting material known, but the finish from an oil stone lasts longer.

Always see that the stone has a film of thin non-drying oil on it when it is in use and wipe this off after use to prevent the accumulation of dirt. Keep the stone in a tight-fitting box, preferably of wood. Plane irons should be sharpened along the whole length of the stone, but small chisels should only be sharpened at the ends in order that they should not wear grooves and hollows in the stone.

HARDENING AND TEMPERING

Silver steel is a high-grade of carbon steel which is much used for making small hand tools. It does not contain silver, the designation being given to it because of the highly-polished finish of the ground bar. Silver steel is sold in square and circular bars 12" long in sizes varying from $\frac{1}{16}$" to 1", the sizes being true to ·0005", the pre-war price of the $\frac{1}{4}$" diam. size being about 6d. per foot.

As supplied, silver steel is soft and easily cut with a file, drill or hacksaw, but before it can be used as a cutting tool it must be hardened and tempered. Softening (or annealing), hardening and tempering are all heat processes. If steel is heated to a dull cherry red and allowed to cool very slowly, as, for instance, when covered with ashes, it will be very soft, but if the cherry red steel is plunged into cold water the steel will be very hard, yet too brittle to be of any use as a cutting tool (except as a scraper). To make the tool fit to cut, some of the hardness must be "let out," and this process is called "tempering."

Different classes of tools require different degrees of hardness, and fortunately it is possible to tell this hardness by the colour of the oxide scale which forms when the tool is being heated for tempering.

As an example, let us assume we have made a special screwdriver and wish to harden and temper it. Table 1 tells us that the colour for a screwdriver should be dark blue. Having forged and ground it to shape we should first harden it by heating the tip to a bright cherry red and plunging it into cold water. As we only require the tip to be hard, only that part should be heated. There will be sufficient metal in the body of the blade to take the stress without hardening. If we now try to file the tip we shall find that the file slips over without cutting, showing that the tip is very hard, but if we were to use it in this state it would break at the first attempt, consequently it must be tempered. Take a piece of emery cloth and polish the tip. Now hold the screwdriver blade a few inches above a medium gas ring or bunsen burner so that the tip of the flame (but not the flame itself) plays on the body and watch for the colours forming on the polished steel. First comes a very light straw colour, which deepens to a light brown, then to a purple brown, light purple, dark purple, and finally a dark blue. Just *before* the correct colour is reached the screwdriver must be plunged into cold water as quickly as possible before any more heat can reach the tip and soften it further. All this process takes less time to do than it does to read, and with a little practice is quite easy. If the tool is found to be too soft, it can be hardened and tempered again, but this should not be done too often, otherwise the steel will spoil.

World Radio History

Forging and Grinding Tools

Small flat drills, screwdrivers and flat scrapers can be forged in any kitchen fire; the only tools required for forging are a hammer (about 1-lb.), a block of iron and a pair of large but old pliers to hold the work. Heat the steel to a dull red and with a few deft blows hammer it out to a little larger than the required size. Any superfluous metal can be removed with a carborundum or emery wheel.

Hardness	Colour	Use
Very hard	Cherry red	For preliminary hardening only
Soft	Pale blue	Too soft for any practical purpose
Elastic	Dark blue	Springs. Screwdrivers, circular saws (metal), wood chisels.
	Dark purple	Cold chisels (metal), axes
	Light purple	Wood drills and bits
	Yellow purple	Plane irons, metal drills
	Brown yellow	Gouges, reamers, punches
Hard	Dark straw	Taps and screw-cutting dies
	Medium straw	Machine tools
	Light straw	
	Very pale straw	Hammer faces and scrapers for brass

Table 1*
Tempering table showing relationship between hardness and colour

It should be remembered that the group of materials called "mild steel" are hardly true steels at all, but are more nearly iron. Mild steel cannot be hardened in the same way that a tool steel can be treated, although heating has some effect on mild steel.

Treatment of Other Materials

The heat treatment of silver steel has already been mentioned, but it is not always realised that the non-ferrous metals such as brass, bronze, copper and aluminium can have their physical characteristics altered by heat treatment. Briefly, to harden steel, it is heated and cooled rapidly, whilst to soften or anneal it the heating is carried out slowly. The non-ferrous metals can be softened by heating and cooling, but the speed of cooling has not the same effect on their ultimate hardness as it has on steel. The only way to increase the hardness of the non-ferrous metals is to "cold work" them, and in the case of sheet metal this is achieved by rolling the sheets cold. In the same way hard-drawn wire and tubes are drawn through dies whilst cold. If they are ordered "soft," then the metal is heated in a furnace and allowed to cool. Brass, copper and bronze can be heated to a dull red, but great care must be taken not to overheat aluminium (or its alloys), as its melting point is below a visible red heat.

The action of rolling a sheet of metal imparts what is called a "grain," and if the hard metal is to be bent it must be bent across this grain, otherwise it is almost sure to crack. As the grain runs lengthwise down the sheet it can be considered as parallel to the minute scratch lines which are to be found on a sheet of hard rolled metal. If in doubt cut a strip of metal and try bending it in two places at right angles, when it will be almost sure to crack along the grain.

Brass and bronze should be cut without any lubricant, and the drilling speed can be fast. Copper should be drilled carefully, as the swarf is inclined to stick to the drill, causing it to bind and break. A special lubricant is usually used for cutting copper, but as a makeshift a thick oil can be used. Turpentine is the best lubricant for aluminium, but it leaves a sticky resinous deposit which is difficult to remove, and for work where this deposit cannot be tolerated paraffin oil should be used as a substitute. Alternatively thin sewing machine oil can be tried.

SCREWS AND SCREW THREADS

There are many types of screw threads in use to-day, but the only one most likely to be needed for radio work is the British Association (B.A.) thread. This thread is numbered from 0 to 10, the largest (No. 0 B.A.) being slightly under ¼" in diameter, whilst the smallest in common use (No. 10 B.A.) is ·067" in diameter. For most radio work Nos. 2, 4 and 6 are quite sufficient, but some component manufacturers use the odd sizes, particularly No. 5 B.A. Table 2 gives a list of the B.A. numbers from 0 to 10 B.A. with the clearing and tapping drills. In certain cases two drills are specified for the tapping size, and the choice depends upon the material to be tapped.

Metal Screws

Metal screws are of two types, rolled thread and cut thread. Rolled threads are much cheaper to produce, but whilst they are fairly satisfactory for light work their appearance cannot be compared with a good cut thread screw. Rolled thread

B.A. No.	Clearing Drill	Tapping Drill
0	¼"	9 or 10
1	2 or 3	18 or 19
2	10 or 11	25 or 26
3	18 or 19	30 or 31
4	26 or 27	33 or 34
5	29 or 30	39 or 40
6	32 or 33	44
7	38 or 39	48
8	42 or 43	51
9	46 or 47	53
10	49 or 50	55

Table 2.
B.A. sizes and drills

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* *Taken from "A Text-Book of Mechanical Engineering," by Wilfrid J. Lineham—Chapman & Hall, 1918.*

World Radio History

screws are never found in first-class radio or electrical instruments and should be avoided. As their name implies, cut thread screws are turned out of the solid bar in an automatic machine. The threads are clean and sharp, giving a better grip to the nut, whilst the head looks more attractive.

Metal screw heads are of various types, such as cheese head, countersunk head, round head and raised head. Each has its own particular use. The hole for the head of a countersunk screw must be countersunk, yet how often are screw heads seen sticking up above a panel, when a few minutes' work with a countersinking drill would have imparted a finish to the job.

Where countersinking is impracticable, a cheese-headed screw looks more workmanlike than a round head. Round-headed screws should be used very sparingly; in fact, they can nearly always be replaced with advantage by the cheese-headed variety. Round-headed screws are rarely used in engineering work for the reason that they have a weak head and the saw cut is very liable to be damaged by the screwdriver slipping when tightening.

Needless to say, brass (plain or plated) is the only permissible material for radio screws and nuts. Steel screws are stronger, but suffer from the serious disadvantage that they rust. When rustless steel screws become available for amateur use at reasonable prices, the brass types will become a thing of the past. Nickel, or preferably chromium-plated, screws look better than brass on an aluminium panel, but where no plated screws are available brass screws with their heads thinly tinned make a very good substitute.

Nuts

Nuts are also of two types, those stamped from a sheet of metal, usually brass, and those turned from solid hexagon bar. Stamped nuts should be avoided at all costs. Nuts are made in two thicknesses, described in the trade as half nuts and full nuts. In engineering practice half nuts are used to lock a full nut where vibration is anticipated, and the half nut is always run on first. In radio practice half nuts are sometimes used alone, usually when there is insufficient room for a full nut.

There is a right and a wrong way to put on a full nut. One side of the nut has the tops of the edges turned off, and this side is always the outside. Again, following engineering practice, a washer should be placed under the nut to prevent the edges from biting into and marking the article being gripped. B.A. spanners, both box type and double-ended flat steel, are very cheap, and there is no excuse for tightening nuts with a pair of pliers. Pliers are not intended for tightening nuts and only cause damage, thereby making a job look unsightly. Where nuts are liable to work loose or are subject to vibration, spring washers, either of the helical or serrated tooth type, should be used instead of plain washers. Do not use both spring and plain washers, as the latter will defeat the whole object of the former.

When it is desired to make a connection to a screw passing through ebonite or a similar insulator it is not advisable to place a soldering tag between the nut and the ebonite. Put a washer and half nut on first, follow with the soldering tag, and finally use a full nut to grip the soldering tag. If the soldering tag is gripped between the nut and ebonite, there is always the risk of the ebonite shrinking, thus allowing the soldering tag to work loose.

Wood Screws

It would take many pages to describe all the types of wood screws which are manufactured, but for amateur purposes only steel and brass screws with either countersunk, round or raised heads need be considered. Wood screw diameters are denoted by numbers starting with No. 1 (which has a diameter of $\frac{1}{16}$″), advancing in steps of $\frac{1}{64}$″. The length increases by $\frac{1}{8}$″ in the smaller sizes and $\frac{1}{4}$″ or $\frac{1}{2}$″ in the layer lengths. Countersunk screws are measured overall, whilst round-head screws are measured from under the head. Chromium, nickel-plated and japanned screws are easily obtained in all the usual sizes. Screws are made in smaller sizes than No. 1, but these are very seldom used in amateur radio work.

Rivets

Although in commercial radio practice nuts and screws are giving place to rivets, they are almost unknown in amateur circles. Rivets are strong, easy to use, very cheap, and they impart a workmanlike appearance to any set. Small rivets ($\frac{1}{16}$″, $\frac{3}{32}$″ or $\frac{1}{8}$″ diameter) can be purchased from most model-makers in steel, copper and aluminium with round or countersunk heads. Naturally the material used for the rivet should be the same as that of the materials to be joined. The two plates should be clamped together and the holes drilled and countersunk on the outer sides. The rivets should then be inserted one at a time and the surplus lengths cut off with a pair of end-cutters, leaving sufficient of the rivet projecting above the panel to fill the countersink hole. Commence riveting with the ball of a light ball-peen hammer and finishing off with the flat face, taking great care never to strike the sheet itself. When using steel rivets it is not advisable to countersink the sheets to make the finished rivets lie flush; steel rivets are best left with a round head on each side. The most successful use for rivets is in building chassis and metal cases, whilst screws and nuts are to be preferred for fixing components.

World Radio History

Chapter Four

RADIO RECEIVERS

Sensitivity — Selectivity — Signal to Noise Ratio — Detection— Reaction — Amplification — Straight Receivers — Superheterodyne Receivers—Frequency Changing—I.F. and R.F. Selectivity—Choice of I.F.—A.V.C.—Single Signal Reception—Signal Strength Meters —Noise Suppression—Superhet Converters—Super-regenerative Receivers—Construction.

THE choice and design of any receiver will depend upon the duties which it is expected to perform and in turn this performance can be most conveniently expressed as a combination of certain properties which a receiver must possess in varying degrees. The principal properties are set out in the following paragraphs.

GENERAL REQUIREMENTS

Sensitivity

The main object of a receiver is to detect incoming radio frequency signals picked up by an aerial, and to reproduce them in an audible form, through a loud-speaker or head-telephones. Some receivers will be able to detect relatively weak signals, whilst others will only respond to those of greater strength. Their ability in this respect is defined as the "sensitivity" of the receiver. Sensitivity is usually expressed as the input between the aerial and earth terminals which is required to produce a standard power output to the speaker. In the case of broadcast and similar types of receivers the accepted standard of sensitivity is defined as the input (in micro-volts) required to produce an output of 50 milli-watts into the most suitable load. The frequency at which the test is made must be specified, whilst the test signal is assumed to be modulated to a depth of 30 per cent. by a pure tone of 400 c.p.s. frequency. The definition is thus purely arbitrary, and serves merely as a standard of comparison between receivers. It will be noticed that the measure of the sensitivity of a receiver does not take account of the aerial to which it is connected.

In the case of communication receivers designed to be used with head-telephones, a lower output level is required, and the standard is frequently taken as 5 milli-watts, or in some cases 2 milli-watts. In practice, a power input of 4 milli-watts to telephones usually represents as strong a signal as can comfortably be tolerated. A typical sensitivity figure for a four-valve broadcast receiver, or a simple type of amateur receiver would be 30 micro-volts. A sensitivity of 2 or 3 micro-volts is good, whilst the most highly developed communication receivers may reach a figure of less than one micro-volt.

These figures relate to telephony. In the case of telegraphy it is a little more difficult to obtain accurate results, but sensitivity will usually be higher.

Selectivity

A very sensitive receiver may be able to receive weak signals well, but it may not equally be able to separate them from others on adjacent frequencies. The degree of ability to do this is referred to as the "selectivity" of the receiver, and is of particular importance under the congested conditions of amateur operation. Selectivity although not easily defined in a few words, will generally be expressed as the number of kilocycles through which a receiver can be tuned in order to pass across a particular transmission, or alternatively as the "band-width" of the circuits employed. Differences of opinion exist, however, as to the point at which a signal is regarded as tuned out. In some cases this is taken as a reduction in power or voltage output by a certain factor, such as 30 dB; and in others as a reduction to inaudibility, which will imply at least 60 dB. The factor is perhaps best illustrated in the form of curves, which show how the output to the telephones varies with frequency. Further references to this matter will be made later in the chapter.

Many important effects connected with selectivity depend upon the fact that the band-width occupied by a transmission, and hence the separation necessary between adjacent transmissions to avoid interference, is independent of the actual carrier frequency. Thus for example, a frequency band some 10 kilocycles wide will be occupied by a typical telephony transmission, no matter whether the carrier frequency be 1·7 Mc or 30 Mc. However, the *proportional* band width will be very different in the two cases, being about 0·6 per cent. in the former case and 0·03 per cent. in the latter. The selectivity of resonant circuits is related to this proportional change, and tends to be greater at low than at high signal frequencies.

Selectivity cannot be further studied without a knowledge of the behaviour of a simple resonant circuit.

World Radio History

When a coil is tuned by a condenser to resonance with the applied R.F. voltage, a current flows around the circuit. This current depends on the applied voltage and the R.F. resistance of the coil and condenser. Obviously the lower this resistance the greater the current at the resonance frequency, and at the same time the smaller, compared with the resonant current, will be the current at any frequency other than the resonant one. The ratio of the current at the resonance frequency to the current at some other frequency gives a measure of the selectivity of the circuit. In practice the resistance of the coil and condenser determines the selectivity, and then the current in the coil and the voltage across it. Obviously the most selective circuit will provide the most voltage to apply to the grid of a valve and at the same time rid or reduce the input of any undesirable frequency (*i.e.*, interference) in proportion. This resistance can be reduced to a fairly low value by good coil and condenser design, but a practical limit is reached after which resort must be made to other methods.

If a small voltage be injected into such a circuit, at its resonant frequency, a larger voltage will be built up across the terminals of the coil or condenser. The ratio of this voltage, to that which is induced, depends upon the resistance of the circuit, and is a measure of both efficiency and selectivity.

In early text books this ratio was termed the "magnification" of the circuit but in recent years the symbol "Q" has taken its place. The "Q" of a circuit is defined as the ratio :—

$$\frac{\omega L}{R} \quad \text{or} \quad \frac{1}{\omega CR}$$

where L, C and R are the inductance, capacity, and resistance of the circuit, and ω is 2π times the frequency.

Signal to Noise Ratio

Perhaps the most important property of a receiver from the amateur point of view is the ratio of signal strength to background noise. It is well known that when telephones are used very weak signals can be heard ; but such signals cannot be understood unless they predominate over the extraneous noise with which they are inevitably accompanied. It is not essential therefore that the sensitivity of a receiver be extremely high provided it has a quiet background.

Received noise is of two types, first that which originates outside the receiver and is picked up at the same time as the signals ; and secondly, that which originates within the receiver itself.

External noise, which may be due to atmospherics, interference, electrical machinery or power lines, is largely beyond the operator's control, and can only be minimised by improved aerial design, or by increased selectivity. The latter point, which is often overlooked, can best be appreciated if it is realised that such noise is usually of no definite frequency, but is more or less uniformly distributed over the spectrum. If therefore, the band-width of a receiver is greater than that absolutely necessary to pass the wanted signals, additional noise will be picked up without any corresponding increase in the latter. Crystal filters are of the utmost value in this direction. In addition, certain types of noise can be minimised by using noise-suppression circuits to be described later.

Internal noise is of a more serious nature, and can be divided into two classes, avoidable and inevitable noise. Avoidable noise may include such sources of trouble as A.C. mains hum, microphonic or faulty valves, bad insulation of components or wiring, and excessive hiss from a beat-oscillator. All defects of this kind can be overcome by proper care in design and construction. Inevitable noise which is the all-important limiting factor in receiver performance arises principally from two causes. The first of these is internal noise generated by the first valve of the receiver, and mainly due to irregularities in cathode emission (termed the "Shot effect.") The second is noise produced by the irregular flow of electrons within the first tuned circuit of the receiver (termed "Thompson effect," or simply "circuit noise.") Both are important mainly in the first stage only, for here signals are at their weakest, whilst later in the receiver they will have been amplified to a level at which noise represents a much smaller proportion of the whole. Valve noise can be reduced by improvements in design, and the recent aligned-grid construction has helped materially in this respect. Circuit noise is basic however, and at present no method for its complete elimination is known.

The Osram Z62 is an indirectly heated pentode with a high slope and designed for use in short-wave receivers or wide-band amplifiers. The short seal gives improved performance up to 60 Mc.

Reproduction and other Factors

In the case of broadcast receivers, and those intended chiefly for telephony reception, the quality of reproduction is a factor of importance. A fair idea of performance in this respect can be obtained from a curve showing power delivered to the speaker for a constant input at frequencies throughout the musical scale.

Communication under amateur conditions, which is frequently conducted by telegraphic means, seldom calls for exceptional quality of reproduction however, so that further discussion is unnecessary at this point. Similar remarks apply to perfection of automatic volume control action, a factor frequently specified in the broadcast case.

World Radio History

More important is the general question of stability, both of electrical performance and mechanical adjustment. A good receiver should be easily tuned to the desired frequency, and free from mechanical defects such as backlash of the tuning dial, which frequently mar a sound electrical design. Primary electrical requirements are that the receiver should retain its adjustment in all respects, should be capable of accurate readjustment to any desired frequency, and reasonably free from the distressing tendency for the tuning to "drift" as the valves warm up after switching on. A number of other points of this nature will be commented upon later in the chapter.

STRAIGHT RECEIVERS

Detection

The primary necessity of any receiver is the provision of some form of rectifier, commonly termed the "detector," by which the incoming R.F. oscillations (which are at frequencies much too high for direct audibility) are converted into a pulsating (or modulated) direct current, able to actuate the telephones. Early receivers comprised little more than a detector, and prior to the introduction of the valve, such devices as the coherer, the magnetic detector and the crystal detector were the only types known. To-day the crystal detector is still in limited use for local broadcast reception, whilst in amateur equipment it finds a place, together with the more modern *Westector,* in field strength meters and monitors.

The diode valve became recognised soon after its introduction as a more reliable detector than any of those which proceeded it. Subsequently it passed out of general use in favour of the triode on account of the better sensitivity thus obtainable; but in recent years diode detection has once again become common. To-day however, the diode is chosen mainly because of its freedom from distortion, and its ability to rectify large signal voltages without overload when used as part of a receiver circuit in which ample sensitivity is already provided by a number of amplifying stages.

Detection by a triode or other multi-electrode valve is the basis of the simplest receivers, and single-valve circuits of this kind have proved invaluable throughout the earlier years of the amateur movement.

In Chapter 2 it was explained that a triode detector can be regarded theoretically as a diode rectifier (formed by grid and cathode only) followed by an amplifying stage, provided by the grid and anode of the same valve. A triode is thus no more sensitive inherently than any of the earlier detector arrangements, followed by a very moderate degree of amplification. The utility of a *triode* detector in the reception of weak signals is entirely explained by the process of reaction.

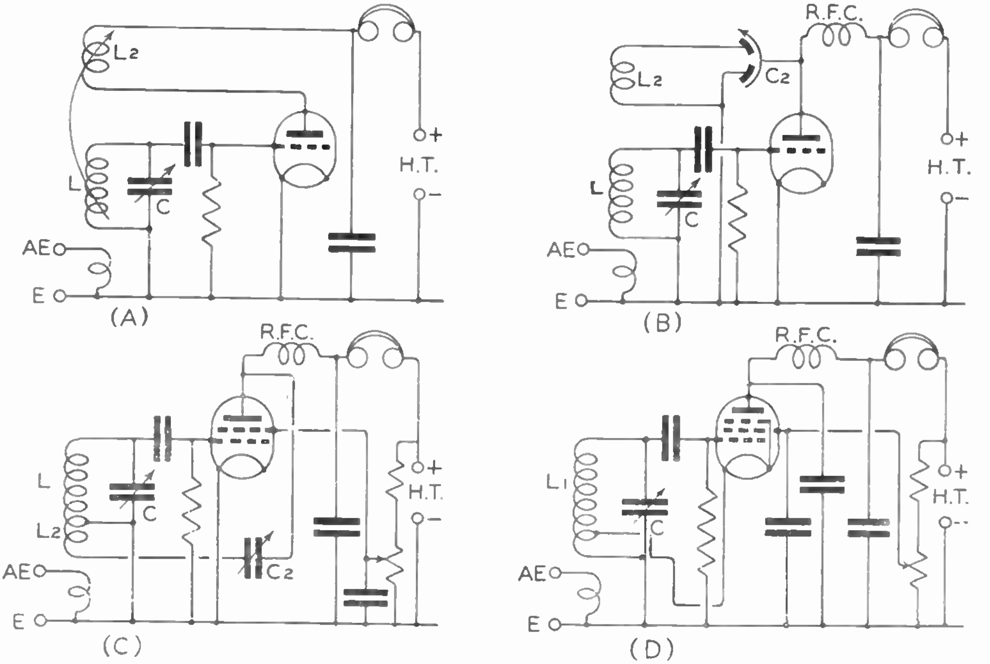


Fig. 1.

Four typical circuits for obtaining reaction. (a) Employs the swinging-coil L_2 as originally used at low frequencies; in (b) this is replaced by a fixed coil and variable reaction condenser C_2. A Hartley circuit renders (c) more suitable for the higher frequencies, whilst (d) illustrates cathode coupling, with reaction controlled by variation of screen voltage.

World Radio History

Reaction

The rectifying action of any detector is never perfect, so that in the case of the triode there will always be a proportion of unrectified R.F. potential upon the grid. Since the valve is an amplifier, there will be a larger R.F. potential present in the anode circuit, a part of which can be transferred back to the grid circuit in the correct phase to reinforce the original signals. The classical method for achieving this is to insert a " reaction coil " into the anode circuit as shown in Fig. 1 (*a*), and to couple it magnetically to the grid circuit inductance. By so doing, the total grid potentials are increased, an effect which not only increases the apparent amplification and sensitivity of the detector, but which has the same effect as lowering the resistance of the tuned grid circuit. Selectivity is therefore assisted at the same time. If the amount of amplified energy fed back in this manner be sufficiently increased, a point will be reached at which the circuit resistance becomes zero, in other words the entire circuit losses can be regarded as cancelled. Both grid potential and selectivity should then be infinitely great, but as explained in Chapter 6, the practical result of the effect takes the form of continuous oscillation at the frequency of the tuned grid circuit.

Provided the working conditions of the detector have been suitably chosen however, a very considerable improvement in sensitivity and selectivity can usefully be obtained before oscillation commences, whilst the latter condition is useful for the reception of telegraphic signals by the " autodyne " beat method.

Reaction can be regarded as the introduction of negative resistance into the grid circuit, which as the feedback coupling is increased, progressively counteracts the positive resistance of that circuit, a useful formula relates the grid voltage Vg produced by a reaction coupling K, if the original signal voltage reaching the grid was V. It is :

$$Vg = V\left(\frac{1}{1-K}\right)$$

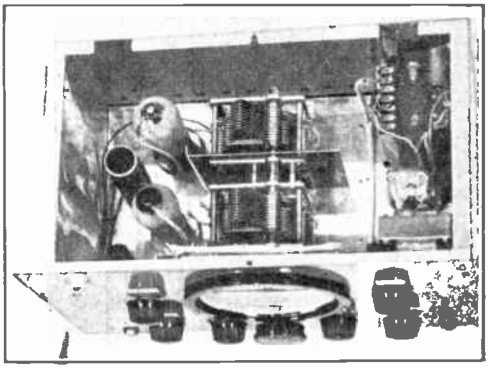
Since the performance of the triode detector depends so much upon the adjustment of reaction, it is not surprising that many circuit variations have been introduced for the purpose of improved control. The circuit of Fig. 1 (*a*) is satisfactory at comparatively low frequencies, but suffers from the defect that movement of the reaction coil (to vary magnetic coupling with the grid coil) varies the mutual inductance and residual capacities affecting the latter, thereby causing changes in tuning. These effects become serious at higher frequencies. The effect due to the movement of the reaction coil can be overcome by the arrangement shown in Fig. 1 (*b*), where the magnetic coupling remains fixed, and the energy fed to the coil is controlled by the differential reaction condenser C_2. This circuit is popular for the reception of broadcast and the lower amateur frequencies ; but there are good reasons for preferring an arrangement in which no variation of inductance or capacity occurs.

Improved high frequency performance can be obtained by the adoption of the series Hartley circuit shown in Fig. 1 (*c*). The use of a single tapped coil leads to closer coupling and readier reaction, whilst both the inductance and feedback condenser may be fixed, reaction being controlled by some expedient such as variation of the anode or screen voltage. As an example of modern practice, Fig. 1 (*d*) shows a circuit which takes advantage of the high mutual conductance of modern screen-grid or pentode valves. Here the cathode of an indirectly heated valve is taken to a tapping on the grid coil and, because the cathode circuit also forms part of the effective anode circuit, it provides reaction coupling. Reaction can be controlled by varying the amplification of the stage, such as by the screen potentiometer illustrated, or by variation of grid bias or anode voltage. The stability of such a circuit, and its freedom from effects upon tuning are markedly superior to the original prototype of Fig. 1 (*a*).

Amplification

Whilst single valve receivers making use of a detector stage only, have given outstanding service to the amateur, it is more usual to add further stages of amplification. These can be added either before or after the detector. The former is termed radio frequency or signal frequency amplification, and the latter low frequency or audio frequency amplification. The two methods have distinctly different properties, which it is important to understand.

Of the several methods of detection outlined in Chapter 2, the leaky-grid system is the one in most general use. It is chosen because of high sensitivity to weak signals, and because it is particularly suited to smooth control of reaction. However, even the grid detector is not linear in action, but for small signal voltages it shows an approximately square-law response. This implies that the rectified output falls off rapidly in the case of weak signals, and in extreme cases will fall below the level of the valve



A 4-Valve All-Wave Straight Receiver for A.C. mains. The R.F. stage and the detector are pentodes, followed by a triode resistance-coupled to an output pentode. Complete coverage from 11·5 to 2,500 metres in seven ranges is effected by tandem connection of two sets of four-way coil switches. The stators of the two-gang condensers are each divided into a large and a small section, the latter only being connected when any of the three high-frequency ranges are in use : the large sections are switched in for the other ranges. Controls are provided for R.F. gain, A.F. gain, reaction and tone, besides the combined fast and slow tuning control. A description of this receiver appeared in the *T. & R. Bulletin* dated November, 1941, but this issue is not now available.

World Radio History

noise. Low frequency amplification following the detector acts entirely to increase the strength of the rectified signals produced by it, and can do nothing to make audible signals which were initially too weak for effective detection. Its use will not therefore increase the sensitivity of the receiver unless the incoming signals already exceed a certain limit of strength. A single A.F. stage is generally desirable in a receiver designed for head-phone use, whilst a second stage may be added when it is desired to employ a loud-speaker.

Radio frequency amplification on the other hand does not materially assist the loudness of the stronger signals, but by increasing the strength of weak signals before detection, enables them to be effectively rectified. It thus increases the actual sensitivity of the receiver to which it is fitted. In order to couple an R.F. amplifier effectively to the detector, or R.F. stages to one another, a circuit tuned to the incoming signals is nearly always provided. The selectivity of this circuit will be added to that of the reacting detector, so that the selectivity of the whole combination will be improved. In special circumstances an R.F. stage may be coupled for purposes of isolation by an untuned circuit, the most common device being an R.F. choke. In this case it gives no additional selectivity, and only little amplification at high frequencies. In the most typical amateur application an untuned stage is used to isolate the detector from the loading of an aerial, the variations of which may lead to irregular reaction control, and " blind spots."

Typical Designs for Straight Receivers

Since space limitations will not permit of a complete discussion of all the details involved in receiver design, the most important will be outlined by describing a few typical complete receivers. The term " straight receiver " denotes a circuit which contains only R.F. amplification, a detector stage, and A.F. amplification, as opposed to more elaborate designs. The circuit diagram of a simple and compact two-valve receiver specially designed for a kit bag is shown in Fig. 2, whilst Fig. 3 conveys a clear conception of the structural layout. Radio frequency amplification has been omitted from this receiver in the interest of size and weight, thus it is particularly necessary to provide an efficient detector. For this reason an R.F. pentode has been chosen. The aerial is connected *via* the variable condenser C_1 to a plug-in coil L_2. By the adjustment of C_1 the aerial loading can be so arranged as to permit of smooth reaction, whilst coupling can be reduced to deal with strong signals, or provide increased selectivity. This is an important feature when aerials of varying size and type are to be used. The main inductance L_2 is tuned by C_2 and C_3, the former being of relatively large capacity for the general coverage of wave bands, and the latter of smaller capacity for band-spread purposes. The coupling of the reaction winding L_1 is fixed approximately for each coil, and the fixed condenser C_5 acts as a stopper for the anode voltage. Reaction is controlled by variation of screen voltage through R_2, R_4 and R_5. The condenser C_9 by-passes the screen for R.F.

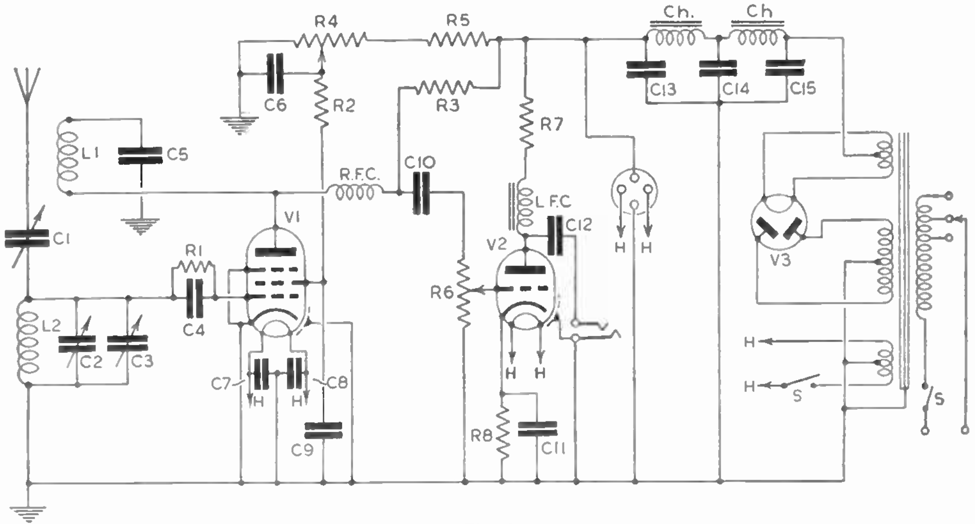


Fig. 2
Circuit diagram of a Portable Two-Valve Receiver suitable for a kit bag.

C_1	65 $\mu\mu$F, Eddystone 978.	$R_{2,3}$	100,000 ohms.
C_2	100 $\mu\mu$F, Eddystone 900/100.	R_4	50,000 ohms potentiometer.
C_3	22.5 $\mu\mu$F, Eddystone 900/20.	R_5	25,000 ohms.
$C_{4,5}$	100 $\mu\mu$F.	R_6	.5 megohm, potentiometer.
C_6	.1 μF, Tubular.	R_7	50,000 ohms.
$C_{7,8,9}$	.01 μF, Tubular.	R_8	2,000 ohms.
C_{10}	.05 μF, Tubular.	V_1	Type 6J7.
$C_{11,12}$	2 μF.	V_2	Type 6C5.
$C_{13,14}$	8 μF × 16 μF.	V_3	Type 80.
C_{15}	12 μF.	CH	Smoothing choke 10-20 H, 30 mA
R_1	1 megohm.	LFC	Low frequency choke

Transformer, 200-240 volts input, 200-0-200 volts, 20 mA, 6.3 volts, 1 amp.; 5 volts, 2 amps. output.

World Radio History

potentials, whilst the large condenser C_6 is provided mainly to prevent noise when the potentiometer R_4 is adjusted. An R.F. choke serves to keep excessive R.F. potentials from the L.F. stage, V_2, and the coupling between the detector and the first A.F. amplifier is by means of resistance capacity coupling, the coupling resistance being R_3 and the condenser C_{10}. The potentiometer R_6 across the grid circuit of the first A.F. amplifier acts as a volume control.

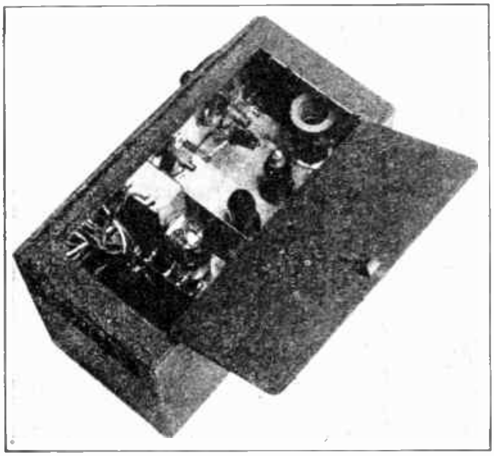


Fig. 3.
Interior view of the Portable Receiver shown diagrammatically in Fig. 2.

The anode of V_2 is fed through the resistance R_7 which limits the anode current and also the audible output to a comfortable level. The choke L.F.C. ensures an ample anode load, and the potentials set up across it are transferred to the telephone jack through the blocking condenser C_{12}, which prevents the H.T. voltage from reaching the 'phones. By this arrangement one terminal of the 'phones can be earthed, so that risk of shock is minimised. The cathode resistance R_8 provides bias for V_2, and is by-passed by C_{11} so that a low-impedance path exists, and degeneration is avoided.

The receiver is fitted with a simple A.C. mains power supply unit of a type explained in Chapter 9. A plug and socket H, enables the receiver to be fed from batteries when this is more convenient. The switch S opens the heater circuit for battery operation.

Fig. 4 shows the circuit diagram of a more complete four-valve straight receiver (employing an R.F. stage), designed to operate a loud-speaker. This can be regarded as the best combination for all-round fixed-station use. A second R.F. stage, exactly similar in connections to that shown, is sometimes added, but very careful screening will be necessary if the best results are to be obtained, since stray reaction effects can easily lead to instability, or difficulties in handling. For these reasons a single stage is more general in amateur practice. An untuned or choke-coupled stage can however be added without difficulty between the aerial and the tuned R.F. stage of Fig. 4, and has much to recommend it.

Reviewing the features of this circuit it will be noticed that the aerial is coupled inductively by the coil L_1 to the grid coil L_2 of the R.F. stage. A variable coupling is no longer necessary, since the effects of aerial damping on the behaviour of the detector are overcome by the isolating action of the R.F. stage itself.

L_2 is tuned with a variable condenser C_1 to the required frequency. The incoming signal set up across L_2 C_1 is amplified in the valve, and the amplified output appears across the primary of the R.F. transformer L_3. The choke (RFC_1) prevents the R.F. from being by-passed *via* the H.T. circuit, and the condenser C_3 adjusts the extent of coupling between the valve anode and L_3. The screen of the valve is by-passed to earth *via* C_2. The secondary of the R.F. transformer L_5 is tuned by C_5 and C_6, C_6 being the main tuning and C_5 the fine tuning condenser. The second valve acts as a leaky-grid detector, C_7 R_2 being the grid condenser and leak. The coupling between the R.F. amplifier and L_3 is made adjustable in order to prevent the valve damping the coil too heavily and also to give good selectivity. The winding L_4 and reaction condenser C_4 are also intended to improve both the selectivity and sensitivity of the circuit.

Reaction to the detector valve is applied through a variable condenser C_4 and the coil L_4 coupled to L_5. The amount of feedback is controlled by altering the amplification of the valve. The potentiometer R_1 varies the screen voltage, and reaction is obtained by utilising the screen as an anode; the condenser C_4 controlling the amount of reaction in addition to R_1. For the reception of c.w. signals the detector valve is allowed just to oscillate by increasing reaction, and the tuning altered to give an audio beat or note with the incoming carrier. Under these conditions the detector is operating in its most sensitive and selective state.

The first A.F. stage is coupled in a manner similar to that of the simple receiver of Fig. 2, and the anode of the first A.F. amplifier is coupled to the second A.F. amplifier or output valve through an A.F. transformer. The anode of the first A.F. valve may also supply signals to headphones connected between C_{11} and earth. The condenser C_{12} by-passes any R.F. that may have escaped RFC_3 and reached the A.F. transformer. The grid bias for the output valve is obtained by inserting a resistance R_6 in series with the negative H.T. lead; this system obviates the necessity for using a separate grid bias battery. It will be noticed that Fig. 4 shows the use of directly heated or battery type valves, and that the choice of biasing arrangements is therefore limited.

In the case of a mains-operated straight receiver the circuit may be similar to the one described above in all respects except that grid bias may be obtained by the system known as auto-bias, which consists of placing a resistance between the cathode of the valve and earth as shown in Fig. 2. The bias is obtained by virtue of the voltage drop across the resistance caused by the anode current passing through it. This results in the cathode becoming positive with respect to the earth, and as the grid is connected in effect to earth, the grid is negative with respect to the cathode. The resistance should be shunted with a condenser to prevent audio voltages being developed across it: a suitable value is 25 µF.

World Radio History

Grid bias for R.F. amplifiers can also be obtained in the same way ; if a variable μ valve is used the grid bias may be varied by making the resistance variable and so varying the amplification. For R.F. operation the value of the shunting condenser may be about 0·1 μF, or even less.

SUPERHETERODYNE RECEIVERS

The performance of straight receivers falls short of the ideal in certain respects, notably those of selectivity, and high sensitivity to modulated signals. The selectivity obtainable from a single resonant circuit, even with critical reaction, is hardly adequate for the crowded amateur wave-bands of pre-war days, and is quite inadequate to reject the signals from powerful local stations on adjacent wave-lengths. To do this effectively a number of circuits in " cascade " is necessary, and to obtain these, with high sensitivity in addition, would demand the use of several R.F. stages. Such an arrangement would be very difficult to adjust and stabilise, whilst it is almost impossible to obtain the full benefit from a number of circuits, when all must be re-tuned for every change in frequency. The circuits can hardly be kept " in line " with the necessary accuracy, whilst even if this were achieved, selectivity is not constant, but falls off with increasing signal frequency as has been explained earlier.

Frequency Changing

The superheterodyne receiver differs from the T.R.F. receiver in that the signal or carrier is amplified at the original signal frequency, and is then changed to another frequency and further amplified before being rectified in the detector and applied to the audio amplifier. The second frequency is known as the " intermediate frequency " (I.F.) and the amplifier working at this frequency as the " I.F. amplifier." The reason for this arrangement is that by changing the frequency it is possible to choose an I.F. such that the amplification and selectivity are just what is required ; also as this frequency, is fixed by the design, once the initial adjustments have been made, no further tuning of this amplifier is necessary, and the principal defects of the straight receiver are avoided. In the interests of selectivity, a comparatively low I.F. is generally chosen.

The process of frequency changing is analogous to modulation in a transmitter, or to heterodyne reception in the straight receiver, in fact, the valve in which it occurs was at one time invariably termed the " first detector," and the true detector which rectifies the I.F. signals to feed the L.F. stages was called the " second detector." The latter term is still used, but the former is now universally replaced by the name " frequency changer."

Suppose that a straight detector be receiving c.w. in the oscillating condition. If the grid circuit be detuned " x " kilocycles from the incoming signals, a beat note of " x " kilocycles pitch will be heard. If this detuning be increased, " x " will also increase until it enters the radio-frequency region when it can be amplified by tuned stages following the detector. This note " x " has now become the I.F. of a superheterodyne receiver ; and the detector an " autodyne " frequency changer stage. The autodyne system was originally used in some practical receivers, but as it was found inefficient to detune the detector grid circuit so far from the signal frequency, the method was replaced in time. In modern receivers a separate oscillator is provided to produce the necessary beat note.

Superficially a non-linear or detector type of valve seems necessary to effect frequency changing, but recent work has shown that similar effects can be obtained with less attendant difficulties if a linear valve be employed, and the electron stream " modulated " by the beating oscillator. Modern frequency changers as described in Chapter 2, employ this " multiplicative " principle in many cases. The original separate oscillator is retained in some advanced arrangements, but in the interests of

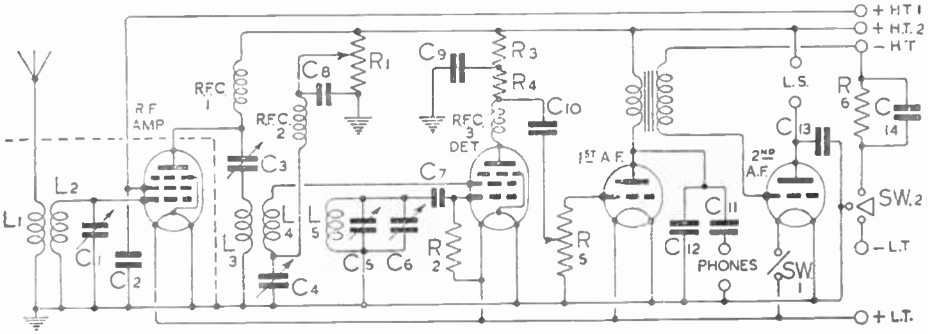


Fig. 4.

Circuit of a Four-Valve Receiver.

$C_{1, 6}$	150 μμF, Special J.B.	R_1	250,000 ohms, potentiometer.
$C_{3, 4}$	200 μμF, Eddystone 957.	R_2	3 megohms.
$C_{2, 8, 11, 14}$	1 μF.	R_3	20,000 ohms.
C_5	22.5 μμF, Eddystone 900/20.	R_4	30,000 ohms.
C_7	100 μμF.	R_5	1 megohm, potentiometer.
C_9	.5 μF.	R_6	450 ohms.
$C_{10, 13}$	.006 μF.	$V_{1, 2}$	Type 210, SPT.
C_{12}	100 μμF.	V_3	Type HL2.
$RFC_{1, 2, 3}$	Short-wave chokes,	V_4	Type PM2A.

World Radio History

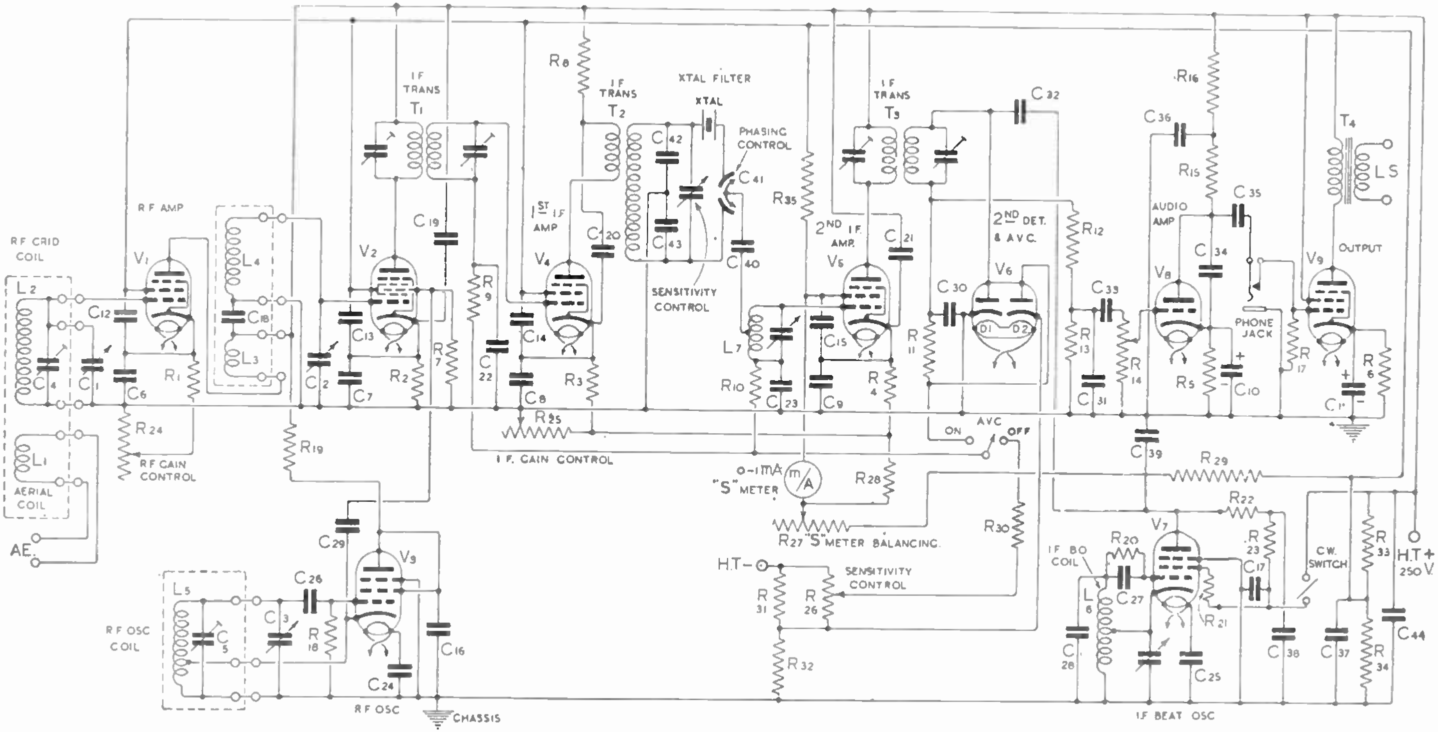


Fig. 5. Circuit diagram of a composite 10-valve communication receiver illustrating the general principles and points found in contemporary designs.

Condensers.

$C_{1, 2, 3}$	Ganged.
$C_{4, 5}$	Coil trimmer or band set.
$C_{6, 7, 8, 9}$	Cathode decoupling, 0.1 μF.
$C_{10, 11}$	Cathode decoupling, 25 μF.
$C_{12, 13, 14, 15}$	Screen decoupling, 0.1 μF.
$C_{16, 17}$	Screen decoupling, .01 μF.
C_{18}	Anode decoupling, 0.01 μF.
$C_{19, 20, 21}$	Anode decoupling, 0.1 μF.
$C_{22, 23}$	A.V.C. decoupling, .01 μF.
$C_{24, 25}$	Heater by-pass, 0.1 μF.
$C_{26, 27}$	R.F. and I.F. Osc. grid, .0001 μF.
C_{28}	I.F.B.O. lumped tuning, .0005 μF.
C_{29}	R.F. Osc. coupling, .0001 μF.
$C_{30, 31}$	I.F. by-pass, .0001 μF.
C_{32}	I.F.B.O. coupling, 2-5 μμF.
C_{33}	Audio coupling, .01 μF.
C_{34}	I.F. decoupling, .0002 μF.
C_{35}	Audio coupling, .01 μF.
C_{36}	Audio decoupling, 4 μF.
C_{37}	Screen decoupling, 8 μF.
C_{38}	I.F.B.O. decoupling, .001 μF.
C_{39}	I.F.B.O. filter, .0003 μF.
C_{40}	Crystal filter coupling, 10 μμF.
C_{41}	Differential phasing.
$C_{42, 43}$	Crystal bridge, .00015 μF.
C_{44}	Smoothing, 8 μF.

Resistances.

$R_{1, 2, 3, 4}$	Auto bias, 300ohms.
R_5	Auto bias, 3,000ohms.
R_6	Auto bias, 240ohms.
R_7	F.C. oscillator grid leak, 50,000ohms.
R_8	Decoupling, 1,000ohms.
$R_{9, 10}$	A.V.C. decoupling, 250,000ohms.
R_{11}	A.V.C. coupling, 2 megohms.
R_{12}	Audio diode load, 30,000ohms.
R_{13}	Audio diode load, 250,000ohms.
R_{14}	A.F. volume control, 500,000ohms.
R_{15}	Anode resistance, 200,000ohms.
R_{16}	Anode decoupling, 50,000ohms.
R_{17}	Grid leak, 500,000ohms.
R_{18}	Oscillator grid leak, 50,000ohms.
R_{19}	Oscillator anode resistance, 10,000ohms.
R_{20}	I.F.B.O. grid leak, 100,000ohms.
R_{21}	I.F.B.O. screen dropping, 50,000ohms.
$R_{22, 23}$	I.F.B.O. anode, 10,000ohms.
R_{24}	R.F. gain control, 10,000ohms.
R_{25}	I.F. gain control, 10,000ohms.
R_{26}	Sensitivity control, 100,000ohms.
R_{27}	" S " meter bridge, 1,000ohms.
R_{28}	" S " meter bridge, 60,000ohms.
R_{29}	" S " meter bridge, 2,000ohms.
R_{30}	Sensitivity control decoupling, 100,000ohms.
R_{31}	Sensitivity control bias, 300ohms.
R_{32}	Delay volts bias, 30 ohms.
R_{33}	Screen potentiometer, 3,000ohms.
R_{34}	Screen potentiometer, 2,000ohms.
R_{35}	Second I.F. screen decoupling, 2,000ohms.

Suitable valves (A.C. operation).

	Osram.	American Type.
V_1	KTW63	6K7G
V_2	X64	6L7G
V_3	KTZ63	6J7G
V_4	KTW63	6K7G
V_5	KTW63	6K7G
V_6	D63	6H6G
V_7	KTZ63	6J7G
V_8	H63	6C5G
V_9	KT63	6V6G

World Radio History

economy it is more usual to combine the oscillator and mixer electrodes into a dual valve, such as the triode-hexode, and to inter-connect them internally.

When both signal and oscillator frequencies are applied to a mixer valve, it is found that in the anode or output circuit both carriers appear, as well as the sum and difference of the two carrier frequencies. For example, assume a signal carrier of 1,000 kc. If the local oscillator is adjusted to 1,500 kc, then in the output of the frequency changer there are present 1,000 kc, 1,500 kc, 2,500 kc, and 500 kc. If the output circuit is tuned to, say, 500 kc and the I.F. amplifier is also tuned to 500 kc, the 500 kc beat will be amplified. If the original 1,000 kc signal was modulated, then the 500 kc beat will also be modulated. If the output of the I.F. amplifier is detected, the modulation will be audible in the detector output. If the I.F. amplifier has sufficient selectivity all other frequencies present in the frequency changer output, except the I.F., will be rejected.

Obviously, the I.F. may be higher or lower than the signal frequency, depending on whether the sum or difference frequency is used. For example, commercial " all wave " receivers usually employ an I.F. of 465 kc, in which case on long waves the signal frequency is lower than the I.F. and on other wavebands the signal frequency is higher than the I.F.

Ganged Circuits

The local oscillator frequency is adjusted as part of the process of tuning the receiver so that for all radio-frequencies the sum or difference in frequency, as the case may be, between it and the signal carrier is equal to the I.F. The condenser adjusting the oscillator frequency is usually ganged to those tuning the R.F. amplifier or aerial circuit, but it is necessary to arrange that the change in oscillator frequency during tuning occurs at a different rate from the R.F. circuits in order that the sum or difference I.F. remains constant. This result is accomplished either by using specially shaped vanes for the oscillator section of the gang condenser or by placing a " padding condenser," in series with the oscillator tuning condenser, and suitably modifying the oscillator inductance.

Coils

In the majority of amateur-built superheterodyne receivers the coils for each wave-band are of the interchangeable plug-in type, thus simplifying construction and making the individual lining-up of each band comparatively easy. Commercial practice favours the more convenient arrangement of wave-change switching, whereby the coils for each band, together with their associated trimming and padding condensers, are brought into circuit by ganged switches. These employ a number of " wafers," each carrying a switch assembly of up to six positions. One wafer is provided for the oscillator, and one for each R.F. circuit. Insulation for normal use has generally been bakelite, but ceramic switches are now obtainable, and are much preferable at high frequencies. It is usual to provide switch contacts which short-circuit all the coils not actually in use, so that they cannot give rise to undesirable absorption effects, and can safely be mounted in close proximity to each other.

I.F. Selectivity

The selectivity of a superheterodyne depends on both the R.F. and I.F. circuits although it is usual for the bulk of the selectivity to be in the I.F. amplifier because this is of fixed frequency and therefore remains constant once it has been adjusted. I.F. selectivity is obtained by using efficient coils or I.F. transformers of high Q, usually wound with stranded wire (Litz) and fitted in some cases with air dielectric trimmers instead of mica. For telephony reception the coils may be arranged for a band-pass, that is to say, the two coils forming the I.F. transformer may be tuned to slightly different frequencies in order to transform the sharp peak of the resonance curve into a narrow flat-topped peak. Where extreme selectivity is required reaction may be applied to the I.F. amplifier in the same way as in a T.R.F. detector. Another method is to employ quartz crystals in the I.F. amplifier. Such is the increasing importance of this method for obtaining exceptional selectivity that a chapter on crystal filters has been included in this edition.

R.F. Selectivity

R.F. selectivity or " preselection " must be of a reasonably high order otherwise two objectionable types of interference may be present. The first, known as " second channel " interference, is due to the fact that there are always two R.F. frequencies that can beat with the local oscillator and give the required I.F. As an example, if the I.F. of a receiver is 500 kc and the signal being received is 14,000 kc, then the local oscillator will be tuned to 14,500 kc, but if there is an interfering signal on 15,000 kc that will also beat and give a 500 kc I.F., so that it is necessary in this case that the R.F. tuned circuits should be able to reject the 15,000 kc signal adequately.

The second type of interference is less common, but can take place with strong local signals when an interfering signal gets through the R.F. circuits and beats with the harmonic of the local oscillator. In this case a signal on 28,500 or 29,500 kc could beat with twice the local oscillator frequency (29,000 kc) and give 500 kc. Another probable cause of interference is when a signal at I.F. arriving on the aerial reaches the I.F. tuned circuits. This rarely occurs when there is more than one R.F. tuning circuit but when it does it can be cured by fitting a rejector, tuned to the I.F., in the aerial circuit.

Choice of I.F.

The requirements of selectivity and second-channel rejection combine to influence the choice of an I.F. in practical receivers. A low I.F. is always helpful in obtaining good selectivity from a minimum number of circuits, but since a higher frequency is useful in eliminating second-channel, a compromise is usually reached. Short-wave superheterodynes have an I.F. around 450/500 kc in order that when the receiver is tuned to say 20 Mc the ratio is not exceedingly large. Superheterodynes especially designed for communication purposes may have an I.F. of 465 kc or in the latest types about 1,600 kc and those for use on the 56 Mc band may with advantage have an I.F. as high as 4 Mc since in this special case very high selectivity is actually undesirable.

World Radio History

A Typical Circuit

It is proposed now to follow through the circuit of a typical 10-valve communication receiver and consider the functions of the various component parts. Fig. 5 shows the circuit of such a receiver, which although not of any particular make incorporates features from several in order to illustrate various details which will be described. No power supply is shown, but the receiver may be considered as either A.C. or A.C./D.C. operated. In any event the power supply follows normal practice.

The specification for such a receiver would include one R.F. amplifier or pre-selector, a two-valve frequency changer, two I.F. amplifying stages with crystal filter, a diode 2nd detector, delayed A.V.C. with noise suppression, two A.F. stages, a c.w. beat oscillator, a signal strength meter and H.T. rectifier (not included in the schematic).

Plug-in coils are shown in order to simplify the circuit diagram. These coils L_1, L_2, L_3, L_4 and L_5 may in fact be mounted as one unit and plugged in altogether or they may be separate or alternatively connected by means of ganged switches as required. Generally plug-in coils (however arranged) are more efficient than ganged-switched coils, even if they are considerably less convenient.

The condensers C_1, C_2 and C_3 are ganged together and form the main tuning control. Their size determines whether a rotation of the dial covers a wide waveband or merely one narrow waveband such as an amateur allocation. The condensers C_4 and C_5 act as trimmers only where the gang condenser is intended to cover a large tuning range. Where only a coverage of one amateur band is required they are supplemented by a fixed condenser in parallel; in this case there will be a condenser also across L_4 (not shown in the diagram). It will be evident that once these condensers are adjusted for each set of tuning coils, the correct waveband coverage will be fixed and the coils will all be aligned, so that trimming condensers on the actual gang condenser are unnecessary. No padding condensers are shown in the frequency changer oscillator circuit L_5 C_3, because for most amateur purposes it is only required to cover one band with each coil. When a padding condenser is used it is connected in series with the lead from the fixed high voltage vanes of the gang condenser to the end of the oscillator coil, or in series with the " earthy " end of the coil, depending on the type of oscillator circuit.

L_1, is the aerial coupling coil, L_2 is the tuned grid coil, the band being set by C_1 and tuned by C_1.

The R.F. amplifier valve V_1 is a variable μ R.F. pentode. Grid bias is obtained automatically in the cathode lead, R_1 being a fixed and R_{24} a variable resistance which acts as R.F. gain control, a necessary feature where there may be strong local signals liable to overload the frequency changer thereby causing distortion or cross-modulation interference. The condenser C_6 by-passes R.F. in the cathode circuit to earth and C_{12} decouples the screen circuit. The R.F. amplifier is coupled to the frequency changer by an R.F. transformer L_3, L_4 and is tuned by C_2, whilst C_{18} decouples the anode H.T. supply.

The frequency changer or mixer valve V_2 is of the electron mixing type and bias is obtained by R_2 decoupled by C_7. C_{13} and C_{19} are the screen and anode decoupling condensers respectively.

The R.F. oscillator valve V_3 is an R.F. pentode connected as an electron-coupled oscillator, the coil L_5 having the cathode tapped one-third of the way up the coil, band set by C_5 and tuned by C_3. The grid condenser C_{26} and leak R_{18} provide grid bias (for explanation see Chapter 2). The supplies are decoupled by R_{19} and C_{16}. The condenser C_{24} from the heater to earth prevents modulation hum and spurious signals being picked up from the heater supply or mains. An electron-coupled type of oscillator is used in order to obtain good frequency stability; a more complete description of this circuit may be found in Chapter 6. The output of the oscillator is taken *via* C_{29} to the injection grid of the frequency changer V_2. The resistance R_7 is fitted in order not to leave this grid open from a D.C. point of view. The output is taken from the cathode of V_3 rather than from the grid so that any effect around V_2 shall not pull the oscillator frequency. The mixer valve must not load the oscillator circuit heavily as this would cause frequency drift. Cathode connection also gives a better signal to noise ratio.

A.V.C.

Due to the generally higher sensitivity of superheterodynes over T.R.F. receivers, stations suffering from fading are more often receivable. A method of overcoming this fading known as " automatic volume control " (A.V.C.) is employed, in which case the detector valve after the I.F. amplifier is a diode. The rectified I.F. carrier (which appears as a D.C. current in the diode load), depends for its amplitude on the strength of the I.F. carrier and of course originally on the signal from the aerial. This D.C. is applied as grid bias to the I.F. amplifier valves and sometimes to the R.F. amplifier and frequency changer as well, in such a way that an increase in signal strength increases the grid bias and hence lowers the amplification. In this way the output remains nearly constant over wide ranges of aerial input.

In some cases a small fixed voltage is arranged to be in opposition to the A.V.C. voltage so that no drop in amplification occurs until this voltage is overcome. This is done in order that no A.V.C. action occurs on weak signals and the arrangement is known as " delayed A.V.C. " In other cases where exceptionally full A.V.C. is required, the A.V.C. voltage is amplified in a valve before application as grid bias and is then known as " amplified A.V.C. " For delayed A.V.C. a double-diode valve is used, one diode being employed for audio and the other for A.V.C. as it is undesirable to insert a delay voltage in the audio circuit.

I.F. Stages

Reverting to the details of Fig. 5, the output of the mixer valve is coupled to the 1st I.F. amplifier valve V_4, *via* the I.F. transformer T_1, both windings being tuned to the I.F. by means of small trimmer condensers. The valve V_4 is a variable μ R.F. pentode with grid bias obtained by the cathode resistance R_3 and the variable resistance R_{25} which it shares in common with the 2nd I.F. amplifier valve V_5. This resistance acts as the I.F. gain control. The grid of V_4 may also obtain bias from the A.V.C. line *via* the decoupling circuit R_9 and C_{22}. The anode and screen supply is decoupled with C_{20} and C_{14} and the cathode with C_8. The reason C_{22} is made small and R_9 large is to give adequate decoupling to audio-frequencies which may be present on the A.V.C. line and yet not give too long a time constant which would prevent the grid bias from following rapid fading.

The output of the 1st I.F. amplifier is fed into the 2nd I.F. transformer T_2 and thence *via* the crystal filter to V_5 the 2nd I.F. amplifier. The explanation of this part of the receiver is referred to in Chapter 5, in which its design is discussed in detail. The components making up the filter will be easily recognised from the description there given. The circuit shown in Fig. 5 is designed to work with a low impedance type of crystal, so that a step-down input transformer T_2 and step-up output coil L_7 are shown.

The second I.F. stage V_5 is of the same type and similarly connected to V_4. It is coupled to the detector V_6 by a third I.F. transformer T_3.

V_6 is a double-diode, the first diode D_1 being connected across the I.F. transformer secondary. C_{30} is the I.F. by-pass condenser having a value such that the audio-frequencies set up across R_{12}, R_{13} are not shunted away. The A.F. output is set up across the potential divider comprising R_{12} and R_{13}. The voltage across R_{13} passes *via* C_{33} to the volume control R_{14}.

V_8 is a triode, resistance capacity coupled, by R_{15}, C_{35} and R_{17} to the output valve V_9. R_5 and C_{10} provide cathode bias for V_8 and R_6, C_{11} the auto-bias for V_9. R_{16}, C_{36}, which form a decoupling circuit in the H.T. to V_8, prevent A.F. instability. A jack for headphones is fitted so that they may be used instead of the output valve and loud-speaker. C_{34} is an additional I.F. by-pass condenser in case any I.F. has reached the anode of V_8; it also removes some of the hiss due to excessive high-frequency response or valve noise introduced earlier in the receiver.

The A.V.C. applied to the I.F. valves, providing the appropriate switch is operated, is the D.C. voltage set up by rectification of the I.F. carrier across R_{12} and R_{13}, fed to the A.V.C. line through R_{11}. When no signal is being received a D.C. bias (which is the drop across R_{32}) is supplied to the A.V.C. line *via* the diode D_2 which has a negligible resistance compared with the return path R_{11}, R_{12} and R_{13} to earth. The voltage applied by R_{32} is quite small, being of the order of 2 volts. This voltage is applied also to D_1 through R_{11}, which is non-conductive in this direction and as a consequence is inoperative as it has a delay voltage on it. As a result of this, no signals are rectified by D_1, until the I.F. voltage applied exceeds the delay voltage. This voltage corresponds to weak signals equal to or less than the noise level. When strong R.F. signals are tuned in, the D.C. voltage rectified by D_1 exceeds the delay voltage and an A.V.C. voltage appears across R_{12} and R_{13} together with audible signals. This A.V.C. voltage is not by-passed by D_2 because its anode is now negative with respect to its cathode. This system is known as delayed A.V.C. with audio noise suppression or muting. In practice when a fixed negative bias (R_{32}) is provided to the A.V.C. line the cathodes of the controlled valves (in this case the 1st and 2nd I.F. valves) would be returned to earth and no auto-bias or manual I.F. gain (R_{25}) provided. Both systems are shown in order to cover prevailing methods.

When the A.V.C. is switched off the A.V.C. line is connected *via* R_{30} to the control R_{26} which is a sensitivity control. This control provides a negative bias by virtue of the drop across R_{31} and R_{32} in series with the negative H.T. lead. For reasons mentioned above R_{26} is not required when the I.F. gain control R_{25} is used.

Beat Oscillator

In order to receive c.w. signals a further separate oscillator is coupled to the detector input after the I.F. amplifier, and adjusted so that it beats with the I.F. to give an audible frequency. It is necessary that care should be taken in the design so that no output of this I.F. beat oscillator feeds back to the input of the I.F. amplifier, otherwise overloading may result. In any case the voltage of this oscillator and the voltage of the average I.F. signal should be of the same order for the best results. The I.F. beat oscillator valve V_7 is an R.F. pentode used in an electron-coupled oscillator circuit similar to that employed in the R.F. oscillator V_3, the coil L_8 being tapped one-third of the way up, tuned by a fixed condenser C_{28} and a small condenser just capable of tuning the oscillator through an audible beat with the I.F. R_{20} and C_{27} are the grid condenser and leak, R_{22}, R_{23} and C_{38} form a decoupling circuit as do R_{21} and C_{17} for the screen supply. The condenser C_{39} is to attenuate the output to a small value suitable for applying to the 2nd detector through C_{32}. The elaborate filtering is necessary in order to prevent any portion of the I.F. beat oscillator output being picked up in parts of the receiver other than where it is injected into the 2nd detector.

There are two ways of tuning the I.F. beat oscillator; the first is to tune in the signal so that the carrier falls near the centre of the I.F. band width, setting the oscillator say 1,000 cycles different either side so that an audible beat note of 1,000 cycles is obtained. The other method is to arrange the tuning so that an interfering signal is well down the I.F. resonance curve and the wanted signal is in the centre of the curve. This system is known as Single Signal Reception.

Single Signal Reception

Fig. 6 which gives a graphical illustration of this interesting method of adjustment shows that when the selectivity curve (dotted) is broad, the beat note will be heard over several kilocycles on either side of zero beat, whereas when selectivity is high, only one part of the beat note range will be audible, separation of c.w. signals is thus much improved. The use of crystal filters is most desirable, and in fact nearly essential for a fully satisfactory single signal response.

Signal Strength Meter

The last detail of importance shown in Fig. 5 is the " S " meter which is fitted in order that the signal strength of stations may be read with fair accuracy. This meter is connected in the screen supply to the 2nd I.F. valve. The resistances R_{27}, R_{28}, R_{29} and R_{35} form a bridge circuit. The bridge is formed by the ratio arms R_{35}; R_{27} and R_{29} in

World Radio History

series ; the known resistance R_{28} ; and an unknown resistance which is the effective screen to cathode resistance of the valve V_5. The meter is placed across the junction of R_{35} and the screen, and the junction of R_{28} and R_{29}, assuming that R_{27} is at its minimum value. When the screen current through the valve equals the current through R_{28}, and when R_{27} and R_{28} equal R_{35} then the meter should read zero. As the screen current is reduced by A.V.C. the bridge becomes unbalanced and the meter will give a reading. The meter is calibrated in " S " units. As there are small variations between valves the resistance R_{27} is adjusted to compensate for this variation. If the variation is large it may be necessary to modify the value of R_{29} slightly.

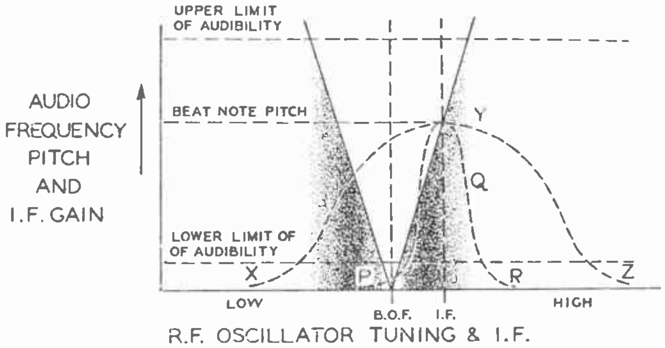


Fig. 6.

Sketch illustrating how the beat note is audible over its full range of pitch when selectivity is low (curve XYZ), but only over a limited pitch when selectivity is high (curve P, Q and R).

After initially balancing the meter to zero, it is brought back to zero each time with no signal applied and the A.V.C. off by means of the I.F. gain control R_{25} ; the R.F. gain control being set at some predetermined value. This procedure ensures that the receiver is adjusted to a definite sensitivity, a condition necessary to ensure consistent and accurate results.

In some cases the " S " meter bridge is connected in the anode circuit of the 2nd I.F. valve instead of in the screen. In this event the bridge is fed from the H.T. line instead of the screen supply and the resistance R_{28} requires to be about 35,000 ohms instead of 60,000 ohms. This method of connection makes the " S " meter considerably more sensitive and it could be used for a receiver having many A.V.C. controlled stages where the current change per valve is less.

The resistances R_{33} and R_{31} form a fixed potentiometer in order to reduce the 250 volts H.T. to 100 volts for the screen supply. The decoupling condenser is C_{37}.

Noise Suppression

A very desirable additional feature, particularly in receivers used at the higher frequencies where man-made static is common, is some form of noise suppression circuit. Several methods of overcoming local noise have been developed in recent years, one, which is a form of A.V.C., comprises a circuit so arranged that any noise peaks having an amplitude appreciably greater than that of the required signal, cause the receiver to become virtually " dead " during the duration of the noise peak. The effect is that instead of the noise appearing in the output being louder than the signal, the signal is cut off momentarily during the noise. It has been found that for certain types of interference (such as is caused by static and motor cars), which consist of short duration peaks of high intensity, a receiver can be operated at a readability that would be impossible with a suppression circuit. In practice the I.F. amplifier is split into two channels one dealing with the signal I.F. only and the other with the noise I.F. only. The latter is constructed to have a very short time constant, and may consist of an I.F. stage feeding a diode, fitted with a low valve of load resistance and a very small by-pass condenser. The potentials developed by noise impulses across this resistance are applied to the suppressor grid of a stage forming part of the main I.F. system, and when the noise voltage materially exceeds the delay voltage, serves to cut off the amplification of that stage. Since the noise suppression channel acts more quickly than the main detector system of the receiver, the latter is interrupted before the noise is heard.

The suppression system described above is somewhat elaborate, but a number of much simpler systems can also prove very useful. A circuit of particular value in c.w. reception is known commercially as an " audio limiter." In its most usual form one A.F. stage is replaced by a pentode operated with greatly reduced anode or screen voltage, so that saturation occurs at the normal level of the audio signals. It is thus impossible for any signal or noise potentials to exceed the saturation value, and undesirable peaks are entirely suppressed. Unfortunately the system is much less suited to telephony because the limiter valve introduces objectional distortion.

Noise Limiters

A second popular form of suppressor is the diode noise limiter, a typical circuit of which is shown in Fig. 7. In this arrangement a diode is shunted across the A.F. input and a delay voltage is supplied in such

World Radio History

a way that the diode is non-conducting at low signal levels, but when the signal or noise has a value greater than the delay voltage it conducts and acts as a shunt on the audio input. D_1 in the illustration is a 2nd detector diode, R_1 the diode load, D_2 the noise limiter. The delay voltage is adjusted across R_2. A battery is shown but this voltage can be obtained by any other means. The double pole switch S.S. disconnects the battery and the anode of D_2 when the limiter is not required.

The operation is as follows: when the voltage across R_1 reaches a value such that the cathode voltage of D_2 is more negative than the anode voltage as set by R_2, D_2 becomes conductive and shunts R_1; hence the A.F. input. This circuit is also useful for c.w. reception in that if the signal is adjusted so that the limiter is in operation the output signal will remain at the same level even if the incoming signal fades.

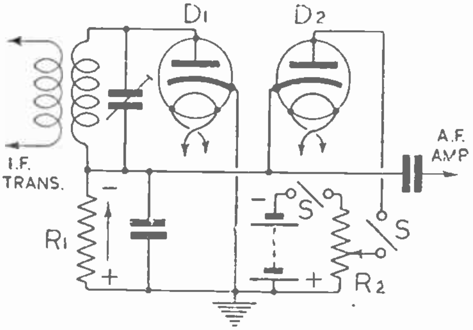


Fig. 7.
Noise limiting diode detector circuit.

Noise suppressor or limiter devices can be fitted to most existing receivers without difficulty, but it must be borne in mind that they cannot prevent noise peaks from overloading previous circuits and they will not reduce the noise peaks to a lower value than that of the signal. Several specialised circuit arrangements of the general nature described have been advocated from time to time, and these are believed to operate with varying success. As a rule, however, it is not entirely sufficient to employ a single diode limiter. More perfect suppression is possible if two diodes are connected in push-pull, thereby limiting both the positive and negative half-cycles of the audio signals.

The Superheterodyne Converter

It will have been noticed that the I.F. detector and L.F. stages of Fig. 5 have very much in common with a straight receiver, in fact, they can be regarded as a special form of straight circuit adapted to receive only one frequency (the I.F.), and modified to take full advantage of the convenience of fixed tuning adjustments. The possibility thus becomes evident of converting a straight receiver into a superheterodyne by placing between it and the aerial a converter unit containing a frequency changing stage, preceded perhaps by an R.F. preselector. The circuit of such a unit will be substantially the same as that of the first two stages of Fig. 5; the first I.F. transformer T_1 being either coupled to the aerial terminal of the straight receiver, or replaced by a choke-condenser coupling. Thus the aerial terminal of Fig. 2 could be taken directly to the frequency changer anode, C_1 forming the coupling condenser, and L_2, C_2 a tuned grid coupling circuit, although it would be more satisfactory to employ a receiver having at least one R.F. stage rather than the simple design illustrated.

A superheterodyne converter may contain its own power supply, or it may derive H.T. and L.T. from the receiver with which it is used, generally through a plug and socket connection. The straight receiver will of course be tuned to a frequency suited to I.F. use, and depending as already explained upon the order of signal frequency to be dealt with. As a rule this will lie between 1,500 and 150 kc, being one at which the receiver performs at its best, and one upon which no powerful local signals are encountered.

The converter is particularly useful in providing ultra-high frequency reception from a straight receiver, which may then be operated at from 2 to 10 Mc in order to minimise second channel effects. A further feature of the arrangement is that a very useful vernier tuning adjustment is provided by slightly varying that of the straight receiver, and thus changing the effective I.F. instead of the oscillation setting.

Double Superheterodyne Receivers

A superheterodyne converter can also be used to proceed an existing superheterodyne receiver, when a double-superheterodyne combination results. This arrangement has certain useful properties which lead to its adoption in certain commercial cases, and it is becoming of interest also in amateur circles. By this system the frequency is twice changed, and the compromise represented by the choice of I.F. in most receivers can be avoided. For example, the frequency may first be changed to a relatively high I.F., such as 2 Mc, in order to overcome second channel effects. It may then be changed to a low frequency, such as 465 kc or less, at which figure selectivity can be readily obtained and crystal filters incorporated. As a further valuable feature, a very perfect form of band-spread tuning can be achieved by varying the first I.F. over a range of perhaps 500 or 1,000 kc. This is possible since only a few circuits of moderate selectivity need be controlled; and their calibration will be independent of the actual incoming signal frequency. Interesting as the double-superheterodyne can be however, it may also contain pitfalls which render it suitable only to the advanced experimenter.

SUPER-REGENERATIVE RECEIVERS

This form of receiver employs a special type of detector and in general is used only for ultra-short wave reception. As mentioned earlier, when a detector valve with reaction is used and the reaction increased above a certain point, oscillation sets in, and on a telephony signal there is an audible whistle or beat with the carrier. Therefore it is normally necessary to have the detector just off its oscillating point to receive telephony. If the reaction could be increased so as to pass beyond the oscillating condition without an audible beat, the sensitivity would be far higher.

This result is achieved in super-regenerative receivers by introducing into the detector another

World Radio History

voltage at a supersonic frequency (above audibility) in such a way that oscillation ceases every half cycle of the supersonic frequency. This frequency is known as the "quenching frequency." The quenching frequency is injected into either the grid or anode of the detector valve and is generated in a separate valve, or in certain cases in the same valve. Due to the fact that a valve does not cease functioning instantly when the grid voltage is increased or the anode voltage is lowered, it is necessary that the quenching frequency should not be too high otherwise the oscillation of the detector may not have time to stop during a half-cycle of the quenching frequency. Conversely the frequency should not be too low otherwise it will be audible as a high-pitched whistle. The voltage injected must be enough to reduce the detector oscillation to zero each negative half-cycle. A quenching frequency of between 10 and 100 kc is suitable for a signal frequency of around 40–60 Mc.

The features of super-regeneration are extremely high sensitivity from a simple type of receiver (which rapidly increases as frequency is raised), and a very effective A.V.C. action inherent in the functioning of the system. Its major drawbacks are very poor selectivity, and relatively high background noise levels, which however, decrease when a carrier is tuned in. C.W. signals produce no beat-note in the receiver, and cannot therefore be read unless either the reaction is reduced to the ordinary regenerative condition, or a weak external beat-oscillator is employed. As a result of these features the circuit is of little use until the ultra-high frequencies are reached, when its low selectivity is of less importance. Because of its low cost, weight and size, this type of receiver has been widely used to receive self-excited transmissions, but it is now being gradually displaced in amateur circles by more advanced types.

RECEIVER CONSTRUCTION

The baseboard and panel method of construction is suitable for simple two or three valve T.R.F. receivers or experimental layouts but is less adaptable to those employing more than one R.F. stage or for superheterodynes where a metal chassis or separately screened stages are most desirable. A chassis should be of rigid construction and braced where necessary, the front panel being made of metal or metal-backed wood. This also should be rigid otherwise microphony and unstable c.w. signals will result. It is necessary where the baseboard layout is used to screen the R.F. stage from the detector. This form of construction is shown in the receiver illustrated in Fig. 8. In some cases the receiver is contained in one or more metal boxes for screening purposes.

When a very high gain is required each stage may be contained in a separate metal box secured to the chassis. These boxes should be insulated from one another except where earthed to the chassis. Unless each stage is screened from the next, it is essential to use either metallised valves or valve cans, in which event the coils should also be in cans. A good rule is that the can should have a diameter equal to twice that of the coil diameter and clear the ends of the coil by at least one half a coil diameter.

Earthing

All grid and anode leads should be short, whilst screened leads should be used sparingly as they increase stray capacities, and losses tend to become high. Earthing always represents a problem and it is advised that one of the two following methods be used (*a*) run an earth bus bar of copper strip or several 14 s.w.g. wires in parallel down the centre of the baseboard or chassis and solder each earth

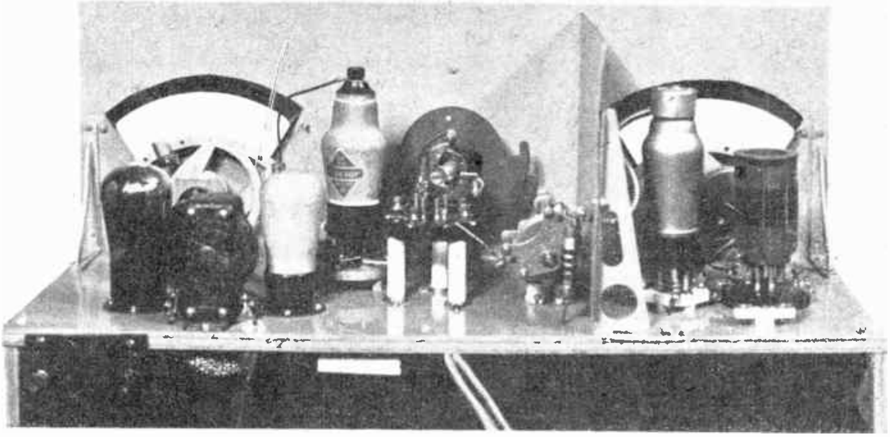


Fig. 8.

Rear view of the Four-Valve Receiver (Fig. 4), showing layout of components. The right-hand section contains the R.F. amplifier. The detector valve is mounted in the centre. The R.F. transformer L_3 L_4 L_5 is removed. The aerial coil L_1 L_2 is plugged into position on right-hand side.

point to it by the shortest possible lead; (*b*) fit a fair-sized tag to the baseboard or chassis adjacent to each valve. To this tag connect all the earth returns associated with that valve or stage, *i.e.*, anode, screen, cathode and grid or A.V.C. by-pass, etc. This method prevents circulating currents in an earth lead (or the chassis itself) common to more than one stage. In high gain amplifiers either R.F. or I.F. instability may be caused by coupling in the heater wiring and therefore where practicable it is often advantageous to earth one side of each heater at the valve socket directly on to the chassis.

Layout

The question of the best layout to use depends very much on the type of receiver and construction adopted, consequently no standard layout exists. The information given here must therefore be limited to mentioning some precautions to be taken.

In the case of a simple T.R.F. receiver of baseboard or screening box construction, the illustrations give a good idea of usual practice. It is principally in multi-valve receivers where layout becomes all important. The first general axiom is to arrange matters so that the output stages are as far removed as possible from the aerial or input circuits, or in a superheterodyne from the frequency changer, in order to prevent instability of I.F. feedback or I.F. harmonics causing patches of mush in one or more of the bands. In superheterodyne receivers the I.F. beat oscillator should also be as far removed as possible from the frequency changer or early I.F. stages, otherwise the I.F. amplifier may be overloaded by stray radiation from the I.F. beat oscillator.

It is unwise to mount a mains transformer near an A.F. transformer, a 1st audio amplifier, an iron cored I.F. transformer or a leaky grid detector, otherwise audio or modulation hum may result.

Valves whose grids are connected to the ganged tuning condensers should be located close to these condensers and a wave change switch if used, must be adjacent in order to keep the R.F. leads short. The I.F. valves in a superheterodyne should be located close to the I.F. transformers for the same reason.

The A.F. volume control should be kept clear of any mains or heater leads unless the control is in an earthed metal case.

Valves

For battery-operated T.R.F. receivers, R.F. pentodes are the most suitable for R.F. and detector stages but small triodes or pentodes are satisfactory for output stages. Modern valves which use the same voltage for both screen and anode are more convenient as they obviate the necessity for taps on the H.T. battery.

In the case of mains-operated T.R.F. receivers the same types of valve remove the necessity for a screen potientiometer. It is preferable to use a valve having a top grid connection for a leaky grid detector in order to reduce hum.

The recently introduced beam tetrode output valves, such as the KT66, can be freely recommended, as their high gain and efficiency are well suited to the amateur-built receiver.

For superheterodyne receivers the R.F. and I.F. stages should be operated with R.F. pentodes, whilst the frequency changer may be either a two valve arrangement as in Fig. 5 or a combined valve such as a triode hexode. This latter valve is more convenient to use, takes up less space and is in modern types quite suitable for use down to the 56 Mc band. Where a two valve set is employed a triode or a pentode oscillator may be used. It is useful to remember that most pentodes may be used as triodes by strapping the anode and screen. The second detector is almost invariably a diode in modern superheterodyne construction.

Negative feedback has been found very useful in generally cleaning up the performance of A.F. systems, and is fast becoming a universal technique where good quality from simple equipment is desired. Negative feedback may be added to a two stage amplifier simply by removing the by-pass condenser across the cathode biasing resistor of the first stage, as at C_{10} in Fig. 5. A resistance in the order of 100,000 ohms may then be joined in series with a 1 or 0·1 μF. H.T. blocking condenser, from the anode of the second (or output) stage directly to the cathode of the preceding stage. Feedback is increased by reducing the value of this resistance, and as this is done, gain will be lowered, but distortion and virtually all defects in the amplifier will be largely eliminated. Feedback can be easily cut in or out of circuit by a switch, according to whether high gain or high quality are desired.

Aerials

In concluding this necessarily brief survey of receiver design it should be stressed that a receiver can only perform at its best when connected to an efficient aerial. It is in general preferable to employ a simple receiver together with a thoroughly effective aerial system, than to expect a highly developed receiver to make up for the defects of a yard or two of badly insulated wire. Well designed aerials, if possible of directional types, result in greatly improved signal to noise ratio; and their properties are very fully dealt with in other chapters of this handbook.

* * *

Circuit Descriptions

The receivers depicted in Figs. 2, 3, 4 and 8 have been described in past issues of the *T. & R. Bulletin*, but all such issues are now out of print. The circuit of Fig. 5 does not represent a receiver which has been constructed. It is, however, intended to show the chief features of modern communications type receivers.

Technical Enquiries

Under present conditions the Radio Society of Great Britain is unable to answer technical questions or provide information regarding circuits described in this publication.

Descriptions of receivers are frequently published in the *R.S.G.B. Bulletin*, issued monthly to members of the Society.

World Radio History

Chapter Five

CRYSTAL BAND-PASS FILTERS

Choice of I.F.—Early Crystal Filter Developments—Operation of Quartz Resonators—Action of Single Crystal Filters—Variable Selectivity—Double Crystal Band-Pass—Telegraphy Filters—Telephony Filters—Impedance Matching—Choice of Receiver—Construction—Switching.

IT is doubtful whether any superheterodyne communication receiver can be regarded as complete or fully up to date unless it incorporates the extremely high selectivity which is obtainable through the use of Quartz Crystal Filters. Whilst other methods for obtaining high selectivity are known, and may be useful in particular cases, few can compare with the crystal either in simplicity or performance. These facts make it particularly attractive to the amateur, who is faced with the necessity of listening to signals on crowded wave-bands, and who requires a receiver at the same time which is highly selective and free from constructional complications.

Choice of an Intermediate Frequency

Since the Quartz Crystal is a component that can only be used at a fixed frequency, it is not adaptable to straight receiver design. A crystal filter must form part of the I.F. system of a superheterodyne, and it will therefore be helpful to discuss the choice of a suitable frequency. This choice is well known to be a compromise in the majority of cases. The use of a low I.F., of from 30 to 175 kc, was at one time popular, since good selectivity is then possible through the effect of a number of ordinary tuned circuits, arranged as I.F. intervalve coupling transformers. At such low intermediate frequencies however, second-channel or image interference will be prominent. The two oscillator frequencies which will bring in any given signal differ by twice the I.F. They are thus not widely different, and cannot readily be separated by a reasonable number of tuned R.F. circuits preceding the frequency changer. As the congestion of wave-bands increased, second channel interference led to the abandonment of low intermediate frequencies in favour of higher values.

An I.F. in the region of 465 kc has come to be widely used to-day, because it offers an acceptable compromise between the demands of selectivity and image rejection, and is suitable for both broadcast and communication receivers. Higher frequencies, of from 1,600 kc to 10 Mc are occasionally used, mainly in the design of ultra-high frequency and television receivers where selectivity need not be high. It is good practice to raise the I.F. in rough proportion to the incoming signal frequency, thereby retaining the same order of image rejection. Quartz crystals can be manufactured for use at these higher frequencies, and may provide in the future the first satisfactory method for attaining selectivity when these are employed. At the present stage of development however, 465 kc represents the best all-round choice, since both crystals and other components are readily obtainable, therefore all descriptions in the remainder of this chapter will assume that an I.F. in that neighbourhood is used.

Early Crystal Filter Developments

Crystal filters in use to-day are of two very distinct types, the single-peaked, and the band-pass. The former is the well-known " crystal gate " or single-crystal filter, whilst the second is of more recent origin, and employs two or more similar crystals in a " push-pull " form of circuit. A study of the single-crystal system is both useful in itself, and necessary to an understanding of the more effective double-crystal arrangement, therefore its origin provides a convenient starting point for this chapter.

During 1929, Dr. J. Robinson, in searching for a very sharply peaked selective device, with which to test his Stenode theory of reception, introduced the quartz crystal resonator into radio receivers, and the circuit which he developed is used in many of the better class amateur and commercial receivers. Whilst unquestionably a British invention (it was described by Dr. J. Robinson during his American lecture tour in 1930), the advantages of the device in relieving amateur band congestion were first realised by American engineers and amateurs. The excellent work of James Lamb in developing the practical applications of the circuit is well known, and has given rise to an impression that it actually originated on the other side of the Atlantic.

The Operation of Quartz Crystal Resonators

A quartz crystal can be regarded as a device able to introduce into an I.F. amplifier a much higher

World Radio History

Q than is normally possible. Whilst the Q of crystals varies considerably according to type, a figure of 20,000 is not unusual. Recent work shows that the Q of a specific type may actually increase with frequency. It can, therefore, be stated that a crystal offers an excellent method for overcoming the limitations of a high I.F.

Through the use of quartz crystals for transmission purposes the theory of their operation is fairly well known. However, in order to follow through the present discussion it is helpful to remember that a crystal is found to behave like a series tuned circuit of very high Q. Fig. 1 gives the equivalent electrical circuit assigned to it in the classical researches of the late Dr. Dye. Here L, C, and R, represent the effective inductance, capacity and resistance of the crystal as a resonator. C_2 represents the unavoidable parallel capacity of the holder and of the small condenser formed by the piece of quartz between its electrodes. C_3 represents the capacity of the air gap, which when used acts in series with the crystal. In some publications the capacity C_2 is shown divided into several parts, but as any combination of capacities can be expressed as a single resulting capacity, the various components which make up C_2 and C_3 can be combined into a single capacity, termed C_4. This is still more reasonable because in many of the cases to be considered no air gap is used, thus the capacity C_3 can be regarded as short circuited.

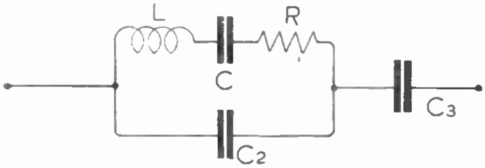


Fig. 1.

The equivalent electrical circuit of a quartz crystal resonator.

If a crystal is used to couple two valves, say in place of the coupling condenser in the familiar tuned-anode arrangement, it would be by-passed to some extent by the capacity C_4. Several methods of balancing this effect will come to mind, and one or two are illustrated by the dotted lines in Fig. 2.

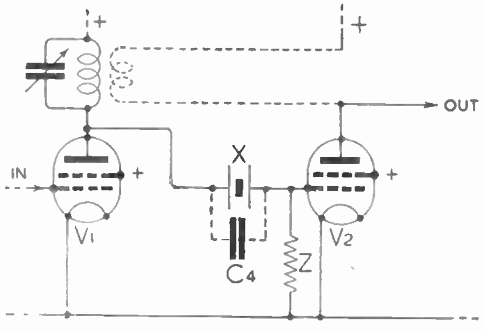


Fig. 2.

Simple arrangement for coupling a valve amplifier by means of a quartz resonator. Two methods for neutralising the capacity of the holder are shown.

For example, a reaction coil from the anode of V_2 could be coupled back to the tuned anode circuit. Since a phase change of about 90° occurs both in C_4 and in V_2, the reaction coil can be used to feed back energy in the opposite phase to that leaking through C_4, which could neutralise its effect at the output from V_2. On the same lines of argument, a small neutralising condenser could be connected from the anode of V_2 to that of V_1, and in the same way this would compensate for the leakage. Practically, however, these arrangements have proved somewhat less convenient than the usual "Crystal Gate" circuit, which in its simplest form is shown in Figs. 3 (*a*) and 3 (*b*).

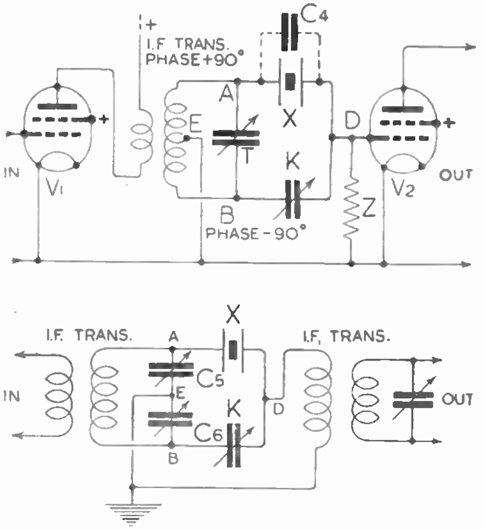


Fig. 3.

Two forms of crystal filter circuit.

(A) Employing a centre-tapped input transformer.

(B) Obtaining a similar result by the use of two equal condensers having their common connection earthed.

The Action of the Single Crystal Filter

The action of this filter must be carefully reviewed, because the whole of the later explanations depend upon it. The filter commences with an ordinary I.F. transformer (Fig. 3 (*a*)) having a secondary winding AB, centre tapped at E. In many receivers a step-down ratio is used here to match the low impedance of certain crystals, but this detail can be ignored for the moment. Whilst an actual centre tapping is probably the most efficient arrangement, and is almost essential in the band-pass arrangements to be described later, it is not always possible to obtain an exact centre point on a coil. An alternative arrangement is the use of two condensers of equal value as shown in Fig. 3 (*b*). This is common practice in commercial receivers, and frequently the condensers are replaced by a two-gang variable by which the input circuit can be detuned, thus varying the effective selectivity as described later in the chapter.

World Radio History

When an R.F. current is induced into any tuned circuit the potential is in opposite phase at the two ends of the circuit relative to its centre point. Thus A and B are in opposite phase. Therefore, energy passing from A through the crystal X to the valve grid at D will be initially in opposite phase to that reaching the same point through the balancing or phasing condenser K. Considering a frequency well outside the resonance curve of the crystal, the latter will behave as a small condenser of almost the value C_4. A phase change of about 90° will occur in this condenser and also in K, but since these two changes are the same, they do not prevent energy from A and B being in opposite phase at D. If K is now adjusted to equal the value of C_4, equal and opposite potentials reach D, producing no resultant effect at the grid. This is termed the condition of balance, where the stray capacities of the crystal and its holder are neutralised by K. Under this condition the resonance curve of the filter will be that of the series circuit L, C, and R, in Fig. 1.

Another way of considering the filter is to regard it as a conventional A.C. bridge network. This circuit is balanced when K equals C_4 as it can be assumed that the reactance of the crystal itself when out of resonance is infinite. On approaching resonance, the crystal reactance falls until it becomes a pure resistance at the resonant frequency. The balance of the bridge will then be destroyed and a voltage will reach the output at D. This argument makes it clear that it is quite permissible to speak of C_4 as being balanced by the condenser K.

The explanation for the increased selectivity and high Q of a crystal will be found in the actual values of L, C, and R. For example, with a typical 465 kc X-cut bar crystal, L may be as high as 16 henrys, and C, a fraction of a micro-micro-farad, whilst R will be very much lower than the R.F. resistance of any 16 henry coil encountered in practice. The precise value of R, which is greatly influenced by the crystal holder, may lie between the limits of 3,000 to 20,000 ohms, but 15,000 ohms may be taken as typical for the type of crystal mentioned. Now Q is given by the expression

$$\frac{\omega L}{R},$$

which for any particular frequency ω, increases with the ratio of L to R. But L is extremely high for the crystal, and since the total resistance of the circuit is low, a very high Q figure will result.

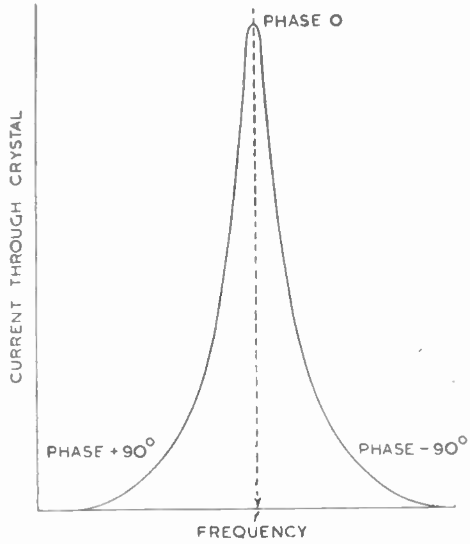


Fig. 4.

The type of response curve given by a quartz crystal coupling circuit (such as that shown in Fig. 3) when the capacity of the holder is balanced.

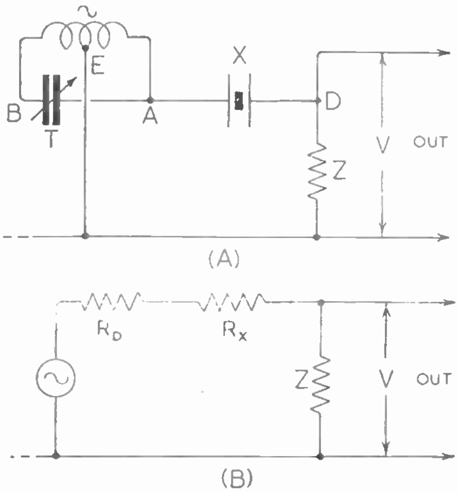


Fig. 5.

(A) A simplified equivalent circuit of Fig. 3 when in the balanced condition.

(B) The resistance potentiometer to which a crystal coupling corresponds at the resonant frequency of the crystal.

Variable Selectivity

When the stray capacity of a single crystal has been balanced a symmetrical, sharply peaked resonance curve of the form sketched in Fig. 4 should be obtained. It may be thought that the shape of this curve should depend entirely on the properties of the crystal used but in practice however the curve which matters is that of the voltage measured across Z. It is found that the shape and steepness of the latter curve is very much affected, both by the nature of the load impedance Z and by the input circuit AB. Advantage is taken of these effects to produce the variable selectivity crystal filters found in most communication receivers. Since these effects are also most helpful when band-pass arrangements are considered it will be worth while to examine them a little more closely at the present juncture.

To simplify matters, let it be assumed that the parallel capacity C_4 has been balanced by the phasing condenser K. The bottom half of the bridge can now be neglected, and the effective circuit can be re-drawn as in Fig. 5 (*a*). At or near resonance

World Radio History

the circuit resembles a simple potentiometer, consisting of half the winding of the input transformer (E A) in series with the crystal X, and the load Z, the output voltage being tapped off across Z at the point D. This can be further simplified by drawing it as shown in Fig. 5 (*b*) where the input coil has been replaced by a source of alternating voltage (representing the signal voltage induced in it by the primary winding of this transformer) in series with a resistance R_D, which represents the dynamic resistance of the input coil. For frequencies quite near to resonance, R_D can be treated as a pure resistance. If Z is also a tuned circuit, the same remarks will apply, whilst at resonance (the point at which a single crystal is generally used) the crystal itself also behaves as a resistance, which will be denoted by R_X.

The whole circuit thus resembles three simple resistances in series. At frequencies well outside resonance, R_X becomes extremely high (possibly as much as 100 megohms) therefore very little energy reaches D. This may be very simply expressed by the formula:

$$\text{Output voltage, } V = \frac{Z}{Z + R_D + R_X}$$

which however, holds exactly only for resonance.

When R_X is very large this expression becomes very small. The actual voltage is almost proportional to Z, thus the most interference from neighbouring signals will be obtained when Z is large, and a better cut-off when it is reduced. At resonance R_X falls to a few thousand ohms, but however small it becomes the voltage across Z will still be limited by R_D. Thus, for the sharpest curve and highest peak voltage, R_D should also be low. It will not be difficult to see that when R_D is large, that is to say an input circuit of high dynamic resistance, the variations of the crystal are somewhat "masked" by the large fixed value of R_D, and the response curve is therefore flatter and less selective.

This argument shows clearly that the performance of the filter depends on both R_D and Z. It is usual to reduce R_D by detuning the input coil AB. This lowers its impedance and sharpens the resulting curve. For greater band-widths AB is brought into tune, increasing R_D up to a limit depending upon the Q of the coil, and widening the curve. Similar results can be obtained by varying Z, although perhaps less conveniently, and in some recently published circuits this improvement is shown. The several modifications that are found in actual crystal filters are intended to improve the impedance matching at resonance, such as by using a step-up transformer at Z to increase the voltage passed on to the next valve, in the manner shown in Fig. 3 (*b*).

Looking at the formula it will be obvious that the largest output voltage will occur when Z is high, but this condition unfortunately leads to very poor selectivity, therefore it is not wise to increase Z much beyond the value of $R_D + R_X$ at resonance. This means that Z may often be a good deal lower than the input resistance of the valve which follows. Therefore to match the resistance $R_D + R_X$ to the valve it may be very useful to employ a step-up ratio. To complete the system, it may also be useful to choose a step-down ratio for the input transformer which feeds the crystal, if the latter be a low impedance type, such as the "Y cut" plate often encountered in American commercial receivers. Such step-down ratios are common in these sets, and failure to obtain good results can often be traced to this cause. Many British firms recommend "X-cut" bar crystals, which have a high resonant impedance, and are therefore simpler to use, since no step-down ratio is necessary. Substituted in a commercial receiver such crystals will often appear "dead," on account of incorrect matching by the circuit. They are however, ideal for band-pass arrangements.

To sum up these variable selectivity effects it may be said, that if high selectivity is required from a crystal, the input and output circuits must be kept fairly low in impedance (or resistance); whilst to reduce this selectivity and make the Q of the crystal *appear* less, it is only necessary to raise these impedances to high values.

The Phasing Condenser

There is one other effect, very familiar to crystal gate users, which is produced by varying the phasing or balancing condenser, K in Fig. 3 (*a*). So far it has been assumed that this condenser was set to balance the bridge, in order that the effect of stray capacity across the crystal can be neglected, and the symmetrical curve of Fig. 4 obtained. If now the condenser be varied slightly, the curve becomes unsymmetrical, and takes the form sketched in Fig. 6. A point of "zero" response occurs near one side of the crystal frequency f, whilst the other side of the curve is raised somewhat. If there is nothing to modify this effect, such as for example an out-of-line I.F. circuit, then the increase in response at O should be the same as the depression at P. The position of P relative to f can be varied at will by adjusting the phasing condenser

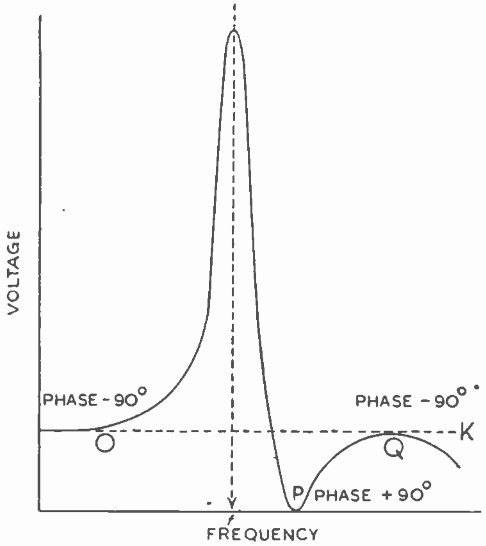


Fig. 6.

The type of response curve given by a crystal coupling circuit when the, balancing or phasing condenser, is varied.

World Radio History

K, whilst if this be varied to the other side of its balancing setting, the point P moves to the other side of f. The user of a crystal filter can therefore adjust K to obtain a zero beat response on any one interfering carrier frequency such as a telegraphic signal. In doing so, however, a penalty must be paid, because the response at most other frequencies has been increased, possibly bringing in fresh interference. It will be shown later how a band-pass circuit reduces this trouble.

A different method for obtaining the same effect as that of varying K, is to leave this fixed, and to displace the centre tapping of the input coil. A popular method is to vary the two condensers C_5 and C_6 of Fig. 3 (*b*) so that one increases as the other decreases by an equal capacity such as by mounting them " back to back " on one shaft. The combined capacity varies little, so that detuning is not noticeable but the voltages reaching V_2 through X and K respectively, are rendered unequal. To do this may be more convenient than the provision of a small variable condenser K, while because the spindle of the two condensers can be earthed, that of the small condenser K cannot. This scheme is less convenient for variable selectivity, and it is probable that the exact circuit of Fig. 3 (*a*) is the easiest from which to obtain perfect performance in receivers of amateur construction.

The production of the zero point P can be very easily explained for the crystal behaves in exactly the same way as any other tuned circuit of high Q. In particular, it shares the property of all such circuits, in that if a current be induced into it the voltage across the circuit is in phase with that current at resonance. This is another way of stating that the circuit behaves as a pure resistance to the frequency to which it is tuned. As the applied frequency is changed towards a lower value however, the circuit tends to become capacitive, or to behave similarly to a condenser, and the voltage leads the current in phase. By the time the " skirts " of the resonance curve are reached, this phase change approaches 90°, as the voltage and current are practically out of phase with each other. In just the same way, if the applied frequency is raised, the circuit becomes inductive and the voltage lags behind the current. These facts are expressed in Fig. 4, where if the phase of the voltage relative to the current (which is taken as fixed in phase, for reference) be regarded as zero at resonance, it will be very nearly + 90° out of phase towards the left of the curve, and nearly — 90° to the right.

Now if the phasing condenser K be changed from its balance setting, some voltage through it will reach the output point D. Since a condenser introduces a phase change of + 90°, the voltage reaching D will be 90° in advance of that at B. That is to say, it will be in the same phase as that through the crystal over all frequencies to the right of the resonance curve of Fig. 4. To the left of the curve therefore the voltages will be in opposite phase, and at some point between the peak and zero they must be equal and opposite, giving rise to the zero point P. Since the position of P depends upon the actual magnitude of the voltage reaching the output through K, its position will change as K is varied. If K be made less than the balancing value, voltage will predominate at the output through the crystal capacity, C_4, of Fig. 3 (*a*). This is derived from the point A, and is thus initially in opposite phase to that which has been discussed. It therefore results in a zero point on the other side of the resonance curve, in fact as shown in Fig. 6.

This very simple way of regarding the effect was introduced by Dr. Robinson when he first patented the crystal gate in about 1929, and it has proved adequate to explain all the facts which have so far come to light in the use of crystal circuits. It is interesting to note that as resonance is approached, the phase changes are no longer sensibly 90°, but of some lesser value, and a perfect cancellation at P becomes impossible. This fact is noticeable in practice, it being impossible to balance out an interfering signal which is less than a few hundred cycles from the crystal frequency. Notice also that the point P is due to a form of bridge balance effect, so that a perfect zero will not occur if there is an unbalance of power-factor, such as might occur if the condenser K has high losses, or any other component was of poor quality. It is thus important to construct crystal filters on low-loss lines.

If in practice it is found the response at P, when removed a few kilocycles from resonance, is excessive, and that the trouble is not due to poor screening between input and output circuits, then it may be accounted for by lack of power-factor balance. The connection of a high variable resistance across the side of the bridge (either across K or the crystal) whichever has the lower losses may be found to improve the zero point, and it is often possible to reach very high values of rejection. As a rule the reduction of a signal at P will not be absolute, but in the order of — 60 dB. It can however be raised almost indefinitely through the addition of a resistance balance to the bridge. This component will, however, need to be as carefully screened as the rest of the filter, if first-class results are desired.

The effect described above, by which a more or less zero response is obtained at P, has been termed " anti-resonance." It will be seen however, that it is in fact a balancing, and in no sense a resonance effect, so that the expression " anti-resonant point " should be avoided.

The Double-Crystal Band-pass

Suppose two exactly similar crystals are available, but differing in frequency by about the width of band-pass required. Let them be connected in parallel in a circuit such as Fig. 3 (*a*), and the phasing condenser adjusted to compensate for the total parallel capacity of the two crystals and their holders. The circuit will now behave as two complete crystal gates in parallel, and will give a response curve having two sharp peaks. Each curve will have the phase relationships described when considering Fig. 4, and in the region between the two crystal frequencies it is clear that the voltages through one of them will be in opposite phase to those through the other. At the output point D they will therefore be in opposition, and their combined effect will be very low.

This is unfortunately not of great practical use as a band-pass arrangement, but might become so if the phase of one crystal response curve could be completely reversed, so that the phases in the middle region became additive. Fortunately an extremely simple way of doing this exists, and it is surprising

World Radio History

that so many years elapsed before the practical advantages of the arrangement were realised. The second crystal is merely moved to the opposite arm of the bridge, being joined in parallel with the condenser K. It now receives input from the opposite end of the coil AB, which is in opposite phase to that applied to the original crystal, and so delivers an output in reverse phase at D. At first sight it would seem necessary to provide the second crystal, X_2, with its own balancing condenser K_2 in the other arm of the bridge, as shown dotted in Fig. 7, but since the action of these condensers is purely differential, the effect of K_2 would be to reduce the balance setting of K. It can therefore be omitted, K being set to a value that is lower than its original setting by the capacity of K_2. Practically, the two balancing condensers necessary with two similar crystals would tend to be equal, and so K might be omitted; but as small differences in capacity between the two arms of the bridge are generally present, K will be joined across whichever arm has in fact the lowest residual capacity. A good arrangement is to join a fixed condenser of a few micro-micro-farads capacity across one crystal. and a variable condenser of somewhat larger maximum capacity across the other. By varying this condenser it is then an easy matter to introduce a predominance of capacity into either arm as required. It is still permissible to talk of the balance condition, just as when only one crystal is used, for in this condition the response curves of both crystals will be symmetrical.

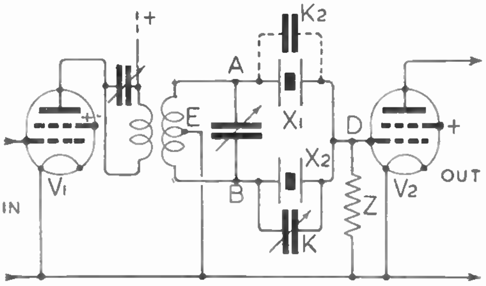


Fig. 7.

Placing a second crystal X_2 in the opposite arm of the bridge as shown above, will produce a band-pass characteristic. ■

It is also possible to vary balance by a differential condenser arrangement as described for the single crystal filter of Fig. 3 (*b*), but this is not recommended under band-pass conditions, as it tends to impair the impedance matching. Centre tapped transformers can now be obtained from manufacturers, and a positive centre tapping will be found much the most reliable type of connection.

The phase conditions are now different since those of one curve have been reversed. Let it be the left-hand curve of Fig. 8. Then in the region between f1 and f2 both crystals will be contributing voltages in the phase + 90°, which will assist each other over most of that region, resulting in a larger output at D than from either crystal alone. At the peaks, each crystal is approximately 90° out of phase with the response due to the other at that frequency, which is in any case comparatively small. There is thus little interaction, the peak voltages being perhaps reduced by a few per cent., and similar conditions occur for the limited region just around each peak frequency, where rapid phase changes are occurring. The resultant curve is of the band-pass form as shown in Fig. 8, and has an effective width slightly greater than the frequency difference between the two crystals. Response is high over the band f1 to f2, but is very low outside this region, where the phases, due to each crystal, remain in opposition. Before considering just how low is the response it is necessary to treat separately the two cases when the difference f2 — f1 is large or small.

Telegraphy Filters

It will be simplest to consider firstly the case when the two crystals are quite near together in frequency, say 300 cycles (0·3 kc.) at an I.F. of about 465 kc. The response curve of Fig. 8 will now become very high and narrow as pictured in Fig. 10, and at the mid-frequency (half-way between f1 and f2) there will be considerable response from both crystals, in approximately additive phase. Thus the central dip between the crystal frequencies will be slight, and no special measures need be taken to eliminate it. Each crystal can now be operated at high effective selectivity, and as was explained when discussing variable selectivity from a single crystal, the load impedance Z of Figs. 3 and 5 can be low in value. In practice a resistance of between 5,000 and 50,000 ohms is suitable, and the simplest possible circuit can be used (Fig. 7) with a resistance in the position Z.

It is important to realise that the slope of the curve outside the crystal frequencies, namely the cut-off slope of the filter, will be greater than that of a single crystal used alone. At any outside point, say near the "skirts" of the curve on the left-hand side, there will be the response of the crystal X_1, just as there would be in an ordinary crystal gate.

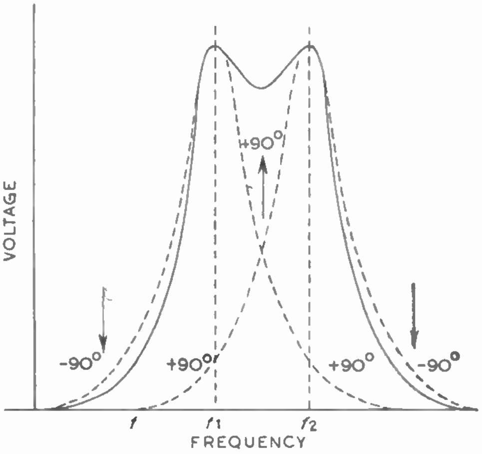


Fig. 8.

The effect upon the resonance curve of moving the second crystal into the opposite arm of the bridge as shown in Fig. 7.

There is, however quite an appreciable response at that point also, from the crystal X_2, which is only a few hundred cycles different in frequency, and this response is in phase opposition to that through X_1. The resulting response must therefore be less than that through either crystal alone, and so the band-pass system is more selective in practice than the simple crystal gate, which it may naturally be expected to supersede.

Balancing the Band-pass Filter

What now will happen if the balancing condenser K of Fig. 7 is varied from the setting which gives the symmetrical curve of Fig. 8? In the case of the single crystal filter it was shown that if the balancing or phasing condenser be increased, a zero point occurs on the high frequency side of the crystal frequency. Now K is connected to act as a balancing condenser for the crystal X_2 in the band-pass circuit, so if it be increased in capacity, a zero point is to be expected on the *high-frequency* side of X_2, as shown at P_2 in Fig. 9. The position of this point can be moved about by the operator to dodge interference just as if he were using a single crystal filter.

But in increasing K something else has occurred. The capacity in the arm of the bridge containing X_1 has been increased, which exactly corresponds to a *reduction* in value of the imaginary balancing capacity K_2 which completes the bridge circuit for that crystal. This introduces a zero point P_1 on the *low-frequency* side of X_1 (because the conditions are the exact reverse of those pertaining at X_2) and therefore falling outside the pass-band on the low frequency side. Two symmetrical zero points thus occur simultaneously, giving the condition shown in Fig. 9. The position of each point will vary with the balancing condenser. Thus it becomes possible to reduce interference on both sides simultaneously. This produces a very real improvement over the single crystal arrangement in which a zero on one side is necessarily accompanied by an increased response on the other, probably bringing in interference from signals on that side of resonance.

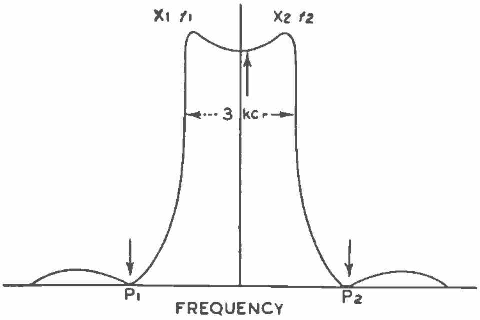


Fig. 9.

The effect of increasing the balancing capacity is to introduce two zero points at P_1 and P_2 at the same time raising the central region.

Advantages of the Band-pass System

It is now possible to appreciate the reasons why a narrow band-pass obtained from a pair of crystals is more useful to the practical amateur than the older form of crystal gate. The latter has been found very valuable for a number of years, but it has certain defects which often prevent its full use, and which are overcome by the band-pass.

First is the question of ease in handling, coupled with tuning drift. The single crystal has a very sharply peaked response, and signals must be tuned in " on the nose " of this curve in order to gain the full benefit from the filter. If it is highly selective, the proportion of detuning permissible is very slight indeed. This means that with the majority of receivers it is a distinctly tricky matter to tune in a signal accurately through the crystal, and in the stress of a DX contest for example, valuable time is often lost. Once the signal has been tuned, however, quite a small trace of oscillator drift in the receiver will lose it again, and this or any other slight disturbance may demand fresh searching at each changeover during a contact. Admittedly these difficulties have been reduced by careful design in the more perfect commercial receivers, but they are seldom entirely absent, particularly in amateur-built equipment.

A second group of difficulties arise at the transmitter. A perfectly stable crystal controlled transmission may be received through a crystal gate receiver satisfactorily, but unfortunately there seems little prospect of all signals coming under this category. Not infrequently a transmission will drift, through gradual heating of the transmitting crystal, and it may become difficult to hold it at the receiver without constant retuning. The position becomes much worse, however, in the case of self-excited transmissions or those possessing a violent chirp, not to mention the numerous rough or modulated notes to be heard on any crowded band. These will often belong to the most sought-after long distance stations, who may perhaps be working under very unfavourable conditions. Such signals can seldom be received at all through a normal crystal gate, but even if selectivity can be broadened to an extent which will deal with them, a considerable residue of interference will also be heard.

The use of a double-crystal band-pass, having an effective width of perhaps half a kilocycle, completely overcomes all but the worst of the difficulties mentioned. The receiver need now only be tuned so that the signal falls *between* the frequencies of the two crystals, and there is a certain amount of latitude in adjustment which makes searching comparatively simple. Drift in either receiver or transmitter is unimportant provided that it does not exceed the width of the pass-band, whilst a chirping or modulated signal will be well received if it does not vary materially by more than the band-width. The increased strength of modulated or unsteady signals in comparison with the single crystal is very striking.

It has been explained that the band-pass filter also gives improved rejection of interference outside the band. An improvement in signal-to-noise ratio may therefore also be expected. Careful measurements have indicated that in this vital matter the band-pass filter shows an improvement of about 20 dB over a typical single crystal filter. The reason for this is indicated in Fig. 10, where the dotted curve represents the type of response to be expected from the latter. The curves are of course drawn on a somewhat wide scale, for if represented in the more usual proportions, they would be so steep and narrow as to be contained with difficulty in the sketch. It is well known that the response of a receiver to untuned noises, such as atmospherics, or ignition interference, will be reduced in proportion as selectivity is increased. The degree is said to be proportional to the square root of the band-width, and the area within the response curve of the receiver provides a measure of its susceptibility to noise from outside sources. Now it will be seen that whereas the single crystal curve is very narrow at the peak, it widens more rapidly than the corresponding band-pass curve, whilst towards the "skirts" it is considerably wider. The total area beneath it will be somewhat greater. Hence whilst the improvement in signal-to-noise ratio on switching in a single crystal filter may be about 40 dB in a typical case, the improvement effected by a band-pass filter some 300 cycles wide has been estimated at 60 dB, showing a 20 dB advantage in favour of the latter. It must, of course, be realised that the above figures are relative, and will not apply exactly to all cases.

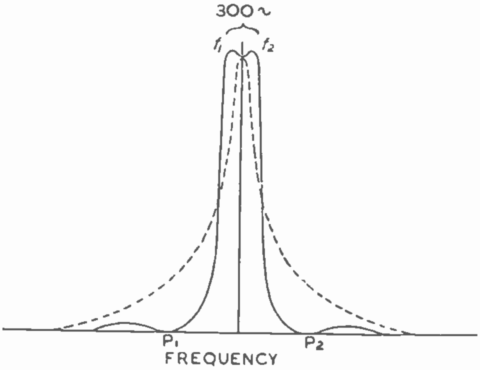


Fig. 10.

A comparison between the response of a narrow band-pass filter and that of a single similar crystal used alone.

In the reception of telegraphy by means of a crystal filter adjusted to maximum selectivity, criticism is often levelled against the unpleasant ringing effect imparted to the signals. This effect is inherent in the single crystal arrangement, and is a manifestation of the exceedingly low damping of the crystal. The same effect can also be obtained from other circuits in which damping is very low, such as a reacting detector adjusted critically just below the oscillation threshold. Here again the band-pass filter provides a solution to the problem, for it is found that when a pair of crystals are used, ringing is almost absent. The probable explanation of this improvement lies in the fact that whereas in the case of a single crystal the carrier wave is carefully adjusted to resonance with the crystal (and is thus ideally placed to excite ringing) in the band-pass arrangement the carrier will normally lie about midway in frequency between the two crystals used. Being a hundred cycles or more away from the resonant frequency of either, it is not able to excite oscillation in them so readily because energy is being applied to the filter at a substantially different frequency from that of either crystal, whilst in the previous case it is applied at the exact crystal frequency. Increasing band-width by the choice of crystals more widely separated in frequency, still further reduces the effect, until at band-widths of several kilocycles ringing cannot be detected.

Telephony Filters

It has been estimated that a sharp 3 kilocycle band-pass will roughly double the number of telephony signals that can comfortably be read during congested periods on the 7 Mc band, in comparison to a typical modern communication receiver which is not fitted with such a filter.

The response of modern receivers is nearly always of the single-peaked variety, being obtained from perhaps four or six I.F. circuits in line. Whilst the width may be effectively a few kilocycles only on weak signals, it will be at least 6 or 7 kilocycles when signals are strong, because the response falls gradually and there are appreciable "skirts" to the curve which enable very strong interfering signals to break through. Probably an attenuation of 1,000 : 1 can be taken as about the figure necessary completely to reduce the strongest interference usually encountered, although even this value will not cope with a 100 watt station only a mile or two away! A typical I.F. amplifier employing six circuits at 465 kc will give this ratio at about 6 kilocycles from resonance, or in a very good receiver, possibly 4 kilocycles, implying an effective band-width in the presence of strong interference of from 8 to 12 kilocycles. The crystal filter will attenuate 1,000 times at 1·5 kilocycles from either edge of the pass-band. Thus, its maximum effective width is 6 kilocycles for 3 kilocycles crystal separation. If the crystals were chosen at 2·5 kilocycles separation, and the balancing condenser used to steepen the cut-off slope, an effective width of as little as 4 kilocycles could be reached.

An example of the practical advantages of this reduction could be found in broadcast reception prior to the war. Consider the separation of Deutschlandsender from Droitwich on the long-wave band. A modern receiver employing six I.F. circuits would separate the German station moderately, but with a considerable residue of sideband splash. At an intermediate point between the two, a mixture of jumbled programmes was heard. Comparing now the performance of a receiver containing only one I.F. stage but incorporating a crystal band-pass filter of 4 kilocycles effective width, used in the single sideband condition. The German programme was found to suffer from perhaps one-third as much splash as in the former case, whilst at a point halfway between the two transmitters no direct programme interference could be heard from either. There was a silent spot, containing nothing but an occasional trace of splash as the sidebands of the two stations heterodyned each other. Under amateur conditions, there would be room for another transmission at that frequency.

There are thus good reasons for the incorporation into a receiver of a band-pass filter similar to that sketched in Figs. 8 and 10, and having a width of from 2·5 to 5 kc. If the receiver be so tuned as to place the incoming carrier centrally in the pass-band, modulation will be reproduced up to some 1,200 or

World Radio History

2,500 cycles, a sufficient limit for intelligible speech. Alternatively the receiver may be so tuned as to place the carrier near to one edge of the band, when the range of reproduction will be doubled. The concave curve shape characteristic of the filter is helpful, since it tends towards crisp reproduction by accentuating the higher speech frequencies ; or in the case of single side-band reception it has the effect of increasing the carrier relative to its side-bands. This is equivalent to a reduction of percentage modulation, and reduces the distortion which normal detectors introduce to a deeply modulated single side-band transmission.

Impedance Matching

To obtain a 3 kilocycle band-pass it is only necessary to modify the telegraphic filter by selecting a pair of crystals differing in frequency by 3 kilocycles instead of a few hundred cycles. Switching from one band-width to another is thus quite easily arranged when desired. If, however, the circuit of Fig. 7 be retained, there will be one serious defect. The central dip between f1 and f2 (Fig. 8) will be excessive, being perhaps 10 or 20 times down in voltage. Fortunately, several simple expedients will overcome this difficulty, the most convenient from the amateur point of view being based on the effects of impedance matching, which were explained when discussing the single crystal filter so that they could be referred to at this point without further explanation. It was there shown that the effective selectivity of a crystal depends upon the input and output load values, and that if these are made high, the response curve is considerably broadened. By taking this step, the response of each crystal at the mid-point of Fig. 8, can be increased until it approaches half the peak response, when the central region becomes level. In practice a slight central dip has been shown to be useful, partly to improve the conditions for single side-band reproduction, and partly because the effect of other I.F. and pre-selecting circuits lined up to the mid-frequency will be to lift the centre. If, therefore, the curve were initially flat, it would become convex in shape through the action of these additional circuits, which must be present in any practical receiver. Impedance matching must not therefore be carried too far. It has also been pointed out that if the balancing condenser be adjusted to bring in zero points near to the sides of the band-pass, as in Fig. 9, the centre will at the same time be raised. The condenser can in fact be regarded as a means for transferring energy from outside to inside the pass-band. Thus unless the initial response is left somewhat concave, the centre will be raised excessively, if the balancing condenser be used to reject interference.

Practically the only alteration necessary to level the response sufficiently, is the substitution of the load resistance shown in Fig. 7 by a tuned circuit as depicted later in Fig. 12. The following valve may with advantage be tapped at a point about one-third the turns up this coil from the earthed end, as shown, in order to prevent it damping the circuit excessively. This tapping is only essential, however, when the filter is followed by a diode or other detector, having a comparatively low impedance. To obtain the best results it is of course necessary that the input and output circuits shall possess high dynamic resistance, since it is upon this factor that the filling-up of the central dip depends. Thus they should be coils of high Q. In practice it is preferable to employ rather high values of inductance tuned by low values of capacity, 2,000 micro-henrys being a good figure for an I.F. of about 465 kc. An air dielectric trimmer is also to be recommended. No great care is necessary over the impedance matching of a 3 kc band-pass and coils having a Q of 150 should be found satisfactory. When desired however, band widths up to 8 or 10 kc can be obtained, but to maintain level response, coils of really excellent Q would be required, and considerable care is necessary in all aspects of the design.

Practical Considerations

Perhaps the simplest case is that of a commercially built receiver which already includes a crystal filter of the ordinary type. If the receiver belongs to the better class of American product, the filter will have been carefully designed and due attention paid to matching the impedance of the crystal used, whilst its efficiency will also be high. Since the whole receiver will have been designed to fit in with a crystal filter, and the necessary reserve of amplification and stability provided, a very successful conversion would be expected.

In order to reap the benefits previously described on telegraphic reception the alteration of an ordinary filter to a band-pass of some 300 cycles should be an easy matter. Here there will be no necessity to depart from the impedance matching arrangements already provided by the makers. It may however be necessary to reconstruct the filter entirely, if a 3 kc filter is decided upon, and to employ high impedance crystals.

The Second Crystal

For c.w. purposes a second crystal of identical type to that in the receiver must be obtained, and differing in frequency by not less than 200 or more than 500 cycles. Very probably the crystal will be found to be a Y or oblique cut plate, and not a bar as has been recommended here, but this may not be important when telegraphy only is considered. The type of crystal used is suited to the circuits provided, and it will be better to obtain one similar to it either from the original makers or from a reputable manufacturer, than to risk the insertion of a pair of new crystals to which the transformers, etc., are not suited. If possible, the original crystal should be sent as a sample, so that a second one may be obtained at the correct frequency difference. Very few amateurs will have equipment of sufficient accuracy to measure the small difference of a few hundred cycles, and this will best be done by the manufacturer.

Having obtained the second crystal (which it should be emphasised *must* be very similar both in performance and holder to the original) it should be connected in parallel with the existing balancing or phasing condenser. When this has been done, however, it will probably be found that the filter will no longer balance, that is to say there will be no point on the scale of the phasing condenser at which selectivity becomes high and background noise diminishes. To restore balance, it will be necessary

World Radio History

to add capacity across the original crystal to compensate for that of the new crystal and its holder. A 5 or 10 μμF cup-type ceramic condenser soldered between the terminals of the original crystal holder will generally be of the right order to correct matters; whilst in a few cases of course the range of adjustment of the phasing condenser may be so large that an additional condenser is unnecessary, the balance point merely changing to a lower point on its scale.

If the differential balancing system of Fig. 3 (*b*) happens to be fitted, it will be necessary to reduce the capacity of K, or to add a few micro-microfarads of capacity across the original crystal, until balance occurs at the original setting of the control knob. In many cases it will be sufficient merely to remove K entirely, relying on the nearly equal capacities of the two crystals and their holders.

Having restored balance, the filter will be ready for use and on tuning through a c.w. signal, the band-pass effect should be easily discernible. There will now be two settings of the tuning dial at which the beat note sharply rises in strength, instead of a single point, as in the original filter. These will be separated by a few hundred cycles, and between them the beat will fall a little in strength. Should it seem to fall excessively, a slightly different adjustment of the phasing condenser is called for. Outside the region bounded by these two peaks, the beat should vanish rapidly. Tuning to say 1 kilocycle outside either peak, it should be possible to reduce signal strength practically to zero. The two extinction points should be symmetrical, and occur substantially at the same setting of the phasing condenser. If they occur at different settings, it means that the two crystals differ excessively in performance, one being perhaps rather a poor specimen in comparison to the other. Should the extinction not be reasonably complete, it means that either the screening of the filter is insufficient, or there is a source of electrical loss present, such as might be caused by poor insulation of wiring, crystal holder or condenser.

Choice of a Suitable Receiver

In the fitting of a band-pass filter to a commercially built receiver there may be little choice of method or of position, and the experimenter is very much in the hands of the original designers. However, some discretion is necessary in deciding whether or not a receiver will repay the alteration; or in the case of an amateur-built receiver, in the choice of a suitable circuit arrangement.

The principal points to consider are whether the receiver has a sufficient reserve of amplification to overcome the slight loss inherent in the filter, which in the case of a 3 kc band-width should average about 6 dB; and whether it has sufficiently fine tuning controls and good oscillator stability to enable full use to be made of the greatly improved selectivity. A 300 cycle c.w. filter should introduce no more loss than the single crystal gate, and whichever type be chosen, stability of tuning is the principal requirement. A telephony filter on the other hand will not demand such fine adjustment, but will demand a better reserve of amplification. This should exceed 6 dB, because owing to the reduced band-width there will be an apparent loss of sensitivity in receiving telephony, due to the attenuation of the higher audio frequencies. In general, crystal filters cannot be recommended as an addition to a receiver which has no R.F. stage, and only one I.F. stage, an exception occurs perhaps where the design is unusually efficient in which case a c.w. filter might be effective. A receiver having one R.F. and one I.F. stage will generally be satisfactory, but whenever possible a second I.F. stage is most desirable. Since the gain provided by two effective I.F. stages is in excess of normal requirements, the filter insertion loss will not be objectionable, and two such stages should invariably be provided in any receiver designed primarily to incorporate these filters.

Position of the Filter

The point in an I.F. amplifier at which the band-pass filter is inserted may depend on many factors, and no stage is altogether unsuitable. In the case of conversions it will probably be decided either by the position of an existing crystal gate, or by the space available on the chassis. When a choice exists, as in the design of a new receiver, it is usually better not to adopt the practice common to single crystal filters of placing this circuit immediately after the frequency changer, for to do so lowers the efficiency at a point where signal-to-noise ratio can be adversely affected. The filter will also work at its best when the signals applied to it are relatively strong, since careful measurements have shown that a slight "threshold effect" occurs in some crystals, and energy is required to overcome slight friction between the crystal and its holder. There are thus good reasons for placing it later in the receiver, and it may either form the coupling between two I.F. stages when two are in use, or it may proceed immediately the second detector. The latter position has been found an easy one from which to obtain correct performance. A word of warning is necessary concerning A.V.C. however. If a double diode be used, the second diode must not be connected to a point in the I.F. system *before* the filter, as is often done to derive A.V.C. from a point at which selectivity is not too great. By so doing the stray capacity (or other coupling) between the two diodes forms a by-pass across the filter, slightly impairing its performance. An entirely separate A.V.C. diode would have to be used in such a case, which however occurs most often in telephony reception, since for c.w. it is not usual to retain the A.V.C. in operation.

Recent tests have shown that the filter will perform particularly well when followed by a detector of the "infinite impedance" type, in which the load resistor is placed in the cathode lead of a triode valve. In this circuit, regeneration can be applied by adjustment of the cathode by-pass condenser. Similarly, the well-known leaky-grid detector with reaction is suitable when A.V.C. can be dispensed with. These detector circuits will very well repay investigation, since they enable regeneration to be applied to the filter output coil, thereby reducing its damping, and making a tapped coil unnecessary. The amplification lost in the filter can be overcome, and a telephony filter easily levelled. A reacting detector probably offers the best solution when only one I.F. stage is in use.

World Radio History

Constructing the Filter

The practical construction of an excellent c.w. filter is simple. The circuit of Fig. 7 should be adopted, or if an input transformer be purchased, the maker's instructions followed. Care should be taken not to obtain a transformer designed for other purposes, in which the inductance of the secondary may be only some 600 or 900 μH, for to use this will lead to a disappointing loss of amplification. It is necessary therefore to specify a component having not less than 1,500 μH, and preferably more than 2,000 μH inductance.

A suitable I.F. transformer can, however, easily be adapted by the ingenious amateur. Firstly, one secondary coil should be removed from a spare transformer and this extra secondary slid on to the dowel which usually supports primary and secondary. If possible the primary winding should be placed centrally on the dowel, and one secondary coil arranged on each side of this, connecting the two in series. The combined inductance of the two secondaries, each of about 600 microhenrys, will give a winding of the desired higher inductance, whilst the junction between them provides the necessary centre tapping, which is taken to the earth-line in the diagrams. Fig. 11 shows a sketch of the rebuilt transformer.

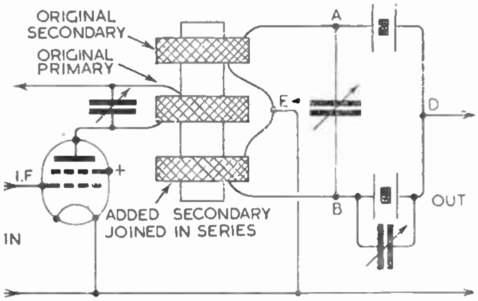


Fig. 11.

A method of adapting an I.F. transformer to filter use by adding a secondary winding from a spare transformer.

It is quite possible to arrange all the components needed for a filter within a single large transformer-can, bearing in mind that the balancing condenser must be well insulated from earth on both sides. A Polysterene bracket or bush forms an excellent mounting. Alternatively, perfectly satisfactory filters have been constructed merely by grouping the necessary components closely beneath the holder of the valve which follows the filter, and supporting them on short leads within the under-chassis wiring. Remember that there must be no stray coupling which might by-pass the filter, destroying much of its performance, whilst the well-known laws of clean and logical layout must be observed.

If the usual I.F. transformer be replaced by the centre-tapped one, the secondary (outer) leads may be taken to the crystals situated immediately beneath the transformer. The balancing condenser should be placed very close to this point and fitted with an insulated extension spindle to the front panel if convenient. The only remaining component, the terminating resistance, may form a grid leak for the following valve, and may be mounted directly upon its holder. The grid lead should be very short, or at least effectively screened. It is an attractive refinement to enclose the filter in a metal box or compartment, which may then be placed above the chassis, although this is seldom essential.

To permit of the filter being cut out for telephony or less selective reception, the vanes of the balancing condenser should be bent over at the tips, so that in the " all-out " position they short-circuit. This procedure effectively removes the filter, restoring the receiver very closely to its normal condition.

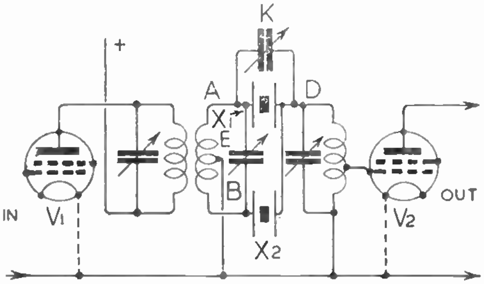


Fig. 12.

By substituting a tuned circuit for the load resistance, the filter circuit shown above becomes suitable for the reception of telephony.

Adjusting the Filter

Although the adjustment of filters has already been mentioned the following additional information may prove helpful. Firstly, the balancing condenser should be shorted, and the receiver put into normal operation. The new I.F. transformer can then be trimmed to resonance, whilst the receiver is tuned to a strong and reliable transmission, such as one of the commercial high-speed telegraph stations. On rotating the balancing condenser, a point should be found at which the signals become weak, or vanish entirely. On rocking the main tuning control, two sharp peaks, corresponding to the two crystal frequencies should be noticeable. Remember that these frequencies *cannot be altered,* and so tuning should next be set to a point intermediate between them, and all I.F. circuits lined up to that mid-frequency. Finally, the tuning should be displaced to a point so that the signals fall well outside the band-width, and the balancing condenser adjusted for either minimum signal response, or perhaps better, for minimum background noise.

Practical Telephony Filters

The 300 cycle c.w. filter just described may with advantage form a first experiment for those of moderate experience. Most remarks concerning it apply to a filter of greater band-width, which should follow the circuit of Fig. 12. Rather more care may, however, be necessary in constructing and adjusting a telephony filter, which however, must not be regarded as beyond the ability of any careful amateur constructor. A very satisfactory band-width for communication telephony is 3 kc, for which a pair of high impedance bar crystals separated by from 2·8 to 3·0 kc should be obtained. It will be necessary to build or purchase an input transformer similar to that already described, and in addition an output coil, which should be tapped, if the filter is to proceed a detector stage. One satisfactory commercial "transformer" comprises only a single 2,000 μH coil, centre-tapped, and provided with an air dielectric trimmer. It may be used either as input or output coil, being connected in the former case as an auto-transformer.

The receiver selected for a telephony filter should possess an ample reserve of amplification, since as has been stated, there will be a drop in sensitivity of about two-fold with the filter in circuit, whilst owing to the narrower audio response band resulting from the increased selectivity, some additional audio gain may be useful. Most adequately designed receivers meet these needs successfully. Somewhat more space is required to accommodate the output coil of Fig. 12, in place of the simple resistance of Fig. 7.

The most vital factors in the performance of the 3 kc (or wider) filters are, thorough screening, and a high quality output circuit. Regeneration applied to this circuit by any of the recognised methods provides a simple and extremely effective means of overcoming any losses which may be present. Should simplicity be particularly desired, it is possible to increase regeneration until oscillation sets in, thus dispensing with a separate B.F.O. A detector stage should follow the filter when these expedients are adopted. In other cases an iron-cored Litz wound coil, tuned by an air dielectric trimmer is to be recommended, not only for efficiency, but to ensure that the circuit remains tuned to a frequency about mid-way between the crystals without frequent "touching-up."

It is possible for an experimenter who prides himself in neat mechanical construction, to build the whole filter into a large coil-can, such as those measuring 2 in. square by 4½ in. high. The input coils are then kept close to the bottom of the can, and the output circuit near to the top, a metal screen being incorporated to divide the can into two screened compartments. Some form of metal chassis will be necessary to support the components within the can. The majority however, will find the use of two cans the simplest solution. Fig. 13 gives an idea of a suitable layout.

Lining-Up Procedure

The adjustment of a telephony filter follows exactly the lines laid down for the narrower c.w circuit. Whilst adjustment on incoming signals is clearly possible, and may be quite simple if the filter is free from any constructional defects, the use of instruments is most helpful, as it enables the response curve to be drawn, and lined up to the most symmetrical condition. A test signal is best provided from some form of *unmodulated* oscillator, or from a signal generator having the usual 400 cycle modulation tone switched off. Testing with modulated waves can be most misleading, since the selectivity of the crystals is sufficient to pick out the side-bands and harmonics of the modulation, thus giving a response curve resembling the Alps! Output from the filter can be observed with the help of any good valve voltmeter, a hard-vacuum cathode ray oscillograph, or simply by measuring the A.V.C. voltage produced by the second detector of the receiver.

Having lined up all I.F. circuits to a frequency mid-way between the crystals, it will be found that the tuning of the output circuit following the crystals will be the most critical. It should be used as the final adjustment for obtaining symmetrical response. Notice that if this circuit is not correctly tuned, but resonates outside the pass-band, the response will resemble two very sharp peaks rather than any form of band-pass filter. Also, if an excessive dip (exceeding about 0·7 of the crystal peak response) occurs at the mid frequency, then the losses of the output coil are probably excessive.

The foregoing remarks assume that the balancing condenser has been set to reject a frequency about 5 kc outside the frequency of either crystal. If it is incorrectly set, very distorted curve shapes are obtained. Should the peak response of one crystal slightly exceed that of the other, they may be evened up by detuning the *input* transformer a little. A difference exceeding 30 per cent, which cannot thus be overcome, suggests faulty crystal matching or mounting. Adjustment of the filter should be found simple after a few minutes experience, provided that the procedure suggested is followed *systematically*, so that confusion does not occur between the effects of the three major adjustments. When correctly aligned and constructed the filter will give a rejection of signals outside the pass-band exceeding 60 dB, whilst it will be found a great convenience in calibrating or lining up the receiver to have the I.F. permanently fixed by the crystals.

Switching of Filters

It has been mentioned that crystal filters can easily be removed from circuit by arranging the balancing condenser to short-circuit at the end of its travel. The effect of the second crystal, which is not shorted, can then be neglected, and the receiver reverts to normal except that there will be a slight loss of stage gain owing to the centre tapping of the filter input transformer. If a high inductance has been used as recommended, the voltage across half the secondary will be nearly as great as that across the whole secondary of a normal I.F. transformer, and so little loss occurs. Two I.F. stages in which crystal filters are used, should not give trouble from instability, since the slightly lowered gain and complete screening help to overcome any tendency to self-oscillation or feedback. It may be still better when space permits to provide an actual shorting switch across one crystal, so that the filter can be cut out without destroying the optimum setting of the balancing condenser. This switch must, however, be a very low loss and low capacity type, having preferably Frequentite or Polystyrene insulation. A toggle switch would not be satisfactory. A telegraphy filter will of course be cut out when receiving telephony. Theoretically there may be no need to cut out a telephony filter, but to do so may be useful when searching the frequency range, receiving high quality broadcast stations, or ultra-short wave transmissions. It has been pointed out that crystal band-pass filters lend themselves readily to the choice of several band-widths, and to conclude this description a few of the easier

World Radio History

methods of switching from one to another will be mentioned.

A very simple scheme applicable to a receiver having two or possibly three I.F. stages, and thus ample gain, is to include a telegraphy filter between, say, the first and second stage, and a telephony filter between the second stage and the detector. Both filters can then be cut out when normal low selectivity is required, and either can be introduced at will when interference conditions demand. In constructing an ambitious receiver of this nature, the constructor should not reject the idea of three I.F. stages as altogether excessive. The additional cost of a third stage is not serious, and if the gain of each is kept under control by a method such as cathode bias adjustment, excellent stability should be achieved. Further all the gain desired will be available when receiving very weak signals through, perhaps, both filters in cascade. If in obtaining the necessary crystals, it is arranged that the c.w. band-pass either falls centrally within the 3 kilocycles telephony filter, or coincides with one edge of it (one crystal of each identical in frequency) the two can be used together in single-signal c.w reception still further to eliminate the unwanted sideband. An attenuation of 140 dB for the unwanted beat note has been measured in this system, which is giving excellent results in certain amateur-built receivers.

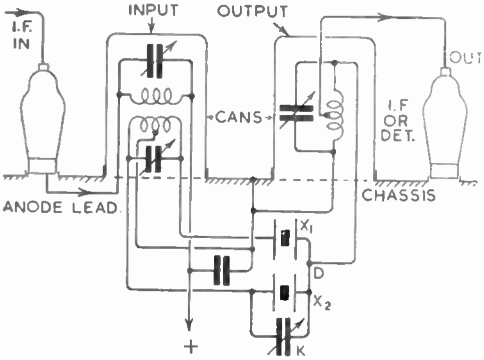


Fig. 13.

Suggested chassis layout for a crystal telephony filter. Input and output coils are mounted in separate cans with their trimmers at the top. Crystals and balancing condenser are placed directly below the chassis, using very short leads. An insulated condenser spindle is extended to the front panel.

Should two or more band-widths be desired from a single filter, they may be attained by the use of three crystals and a single-pole selector switch, as shown in Fig. 14. Crystals are obtained having a separation from X_1 to X_2 of 300 cycles for telegraphy, and from X_1 to X_3 of 3 kilocycles for telephony. Crystal X_1 remains in one arm of the bridge permanently, whilst either X_2 or X_3 (or a short circuit) is introduced into the other arm by means of the switch. This system gives an instant choice of either broad selectivity (the other I.F. circuits alone), 3 kilocycles band-width, or 300 cycles at will, whilst other widths could easily be added through the use of additional crystals and switch contacts. The arrangement has a minor drawback in that the mean I.F. changes slightly on switching over. To avoid this it would be necessary to employ double-pole switching, so that a fresh pair of crystals could be selected for each band. Similarly an elaboration on these lines would enable the output matching impedance to be changed for each band, using a resistance at band-widths of a few hundred cycles, and substituting circuits tuned to the centre of each other band. It is doubtful if any but the exceptional enthusiast will wish to go to these lengths, and no great difficulty should be found in working out suitable switching. The arrangement of Fig. 14 can be recommended, however, to those who wish to make their receiver outstanding in selectivity over any commercially built receiver obtainable at the date of publication of this Handbook.

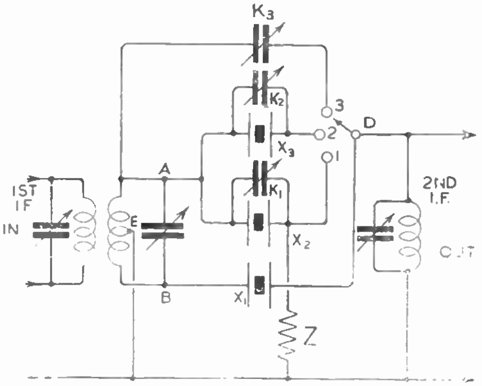


Fig. 14.

A band-pass filter in which a selector switch provides three degrees of selectivity. Position 1,300 cycles; position 2, 3 kilocycles; position 3, low selectivity. The output coil is not tapped as it represents a compromise between the three positions. The condenser K_3 which provides optimum coupling when the filter is cut out, is not essential.

World Radio History

Chapter Six

RADIO TRANSMITTERS

Valve Operation — Power Efficiency — Driving Power — Practical Circuits — Stability — Crystal Control — Electron Coupling — Frequency Multipliers—Power Amplifiers—Couplings—Harmonics—Layout—Typical Designs.

THIS Chapter deals with the generation of stable oscillatory power for the aerial, whilst Chapter 7 will deal with the means of imposing the message on this oscillatory or " carrier " power. Some of the fundamental principles and definitions have already been given in Chapter 1, which should therefore be studied first.

Requirements

The function of a transmitter is to supply power to an aerial at a definite frequency; it must also be possible to convey intelligence by means of the signal radiated. There are two ways of performing the latter function; first by breaking up the signals into the dots and dashes of the morse code; second, by modulating the signals with speech.

The chief requirement is a generator of oscillations. For this purpose the valve has now practically superseded all other methods, and is the only one considered here.

The power which is finally applied to the aerial must represent as high a proportion as possible of the power consumed by the transmitter. On the other hand, the definition, accuracy, and stability necessary to prevent interference with other stations is such that a plain valve oscillator coupled to the aerial is unsuitable; consequently a more complicated transmitter is necessary. It is usual to generate and control the frequency in a low power circuit, and then to follow this with a power amplifier using one or more valves in " cascade," until the required power is available.

The amateur frequency channels have a convenient harmonic relation, that is to say, certain frequencies in the 3·5 Mc band can be doubled to give frequencies within the 7 Mc band, and so on. This makes possible the type of design in which special valve circuits can be arranged to multiply the frequency originally generated, with the result that a complete transmitter can be built, in which R.F. output on all the amateur bands can be selected from a multiple of the master frequency.

In general, then, amateur transmitters will be of two classes :—

(*a*) The master oscillator and power amplifier,

(*b*) The master oscillator and harmonic amplifier,

according to whether it is desired to work on one band or several bands harmonically related.

FUNDAMENTAL VALVE OPERATION

As the valve is the " heart " of the transmitter, it is necessary to understand something of its operating conditions and general behaviour, bearing in mind that transmitting valves differ considerably from receiving valves, both in design and operation. In a receiver a valve is usually required to deal with very small oscillations, but in a transmitter, all the valves are, generally speaking, power valves, and due to the need for high efficiency are operated at " full steam."

Already it has been shown in Chapter 2 that with normal voltages applied to a valve, and a suitable impedance placed in its anode circuit, the application of an oscillating voltage to the grid produces an amplified voltage across the applied impedance or anode load. Thus in Fig. 1(A), R represents a resistance connected in series with the high tension supply and the anode, whilst an oscillation is applied to the grid, together with bias from a battery. The grid oscillations produce corresponding variations in the anode current. There is a voltage drop across the resistance R which is proportional to the anode current; an amplified reproduction of the original grid oscillations can therefore be developed in the anode circuit.

In a receiver circuit the anode voltage must be strictly proportional to the grid voltage. be a faithful reproduction of the original grid oscillation, which means that the anode current must be strictly proportional to the grid voltage.

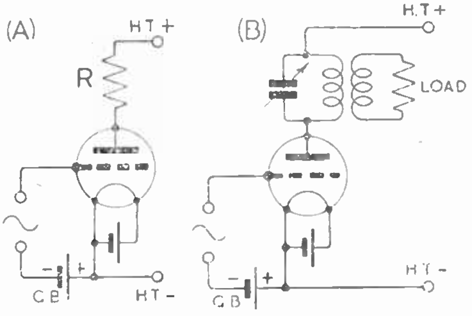


Fig. 1.
Fundamental valve amplifier circuit

World Radio History

in other words, the grid volts—anode current curves must be straight. An inspection of almost any such curve will show that in general it is straight only over a small range, so that for fidelity, only a limited portion of the available current can be used.

Grid Swing

If the " grid swing " is too great, the lower part of the anode current swing is flattened ; also it is not possible to put the steady operating position further up towards zero bias, because the upward peaks would then swing the grid above zero bias (positive) into the region where the grid tends to act like an anode, thus conducting current. This would damp or partially short circuit the driving source, and flatten the upward peaks.

The power of the oscillation is thus a small proportion of the steady power supplied (D.C. volts × mean anode current) and the efficiency is low, corresponding to " Class A " operation which has been described in Chapter 2. " Class B " operation may be used in some cases to allow the valve to be driven harder and so obtain greater efficiency, but in a transmitter it is often possible to operate under " Class C " conditions, which is characterised by high efficiency but considerable distortion.

Pulse Operation: Harmonics

Serious distortion usually results if the grid swing on a valve is too large. The flattening of the crests of the oscillations is equivalent to the introduction of new frequencies which are integral multiples of the original, and these multiples are called " harmonics." The quality of a musical instrument depends upon the proportion of harmonics generated, and if in reproducing them, this proportion is altered by the introduction of new harmonics then the instrument sounds false.

In the detector stage of a receiver this distortion effect is used, and with proper distortion applied to the R.F. oscillation, it can be made to deliver up its modulation as audio without secondary distortion.

In a radio transmitter the valve is concerned only with one frequency, or practically so, which means that a tuned circuit can replace in the anode the usual resistance or transformer of the audio amplifier. Fig. 1(B) shows a valve with a tuned anode output circuit. In this way the anode circuit can be tuned to the desired frequency and will select only that frequency, so that the distortion does not matter : harmonics do not appear in the output. It is thus possible to apply larger oscillations or drive to the grid, and so produce a greater fluctuation in anode current. This means that much more power is available in the anode circuit for the same input, and hence greater efficiency.

The parallel tuned circuit in the anode is equivalent to a high resistance load (its dynamic impedance) at the fundamental frequency. The anode current oscillation develops an oscillatory voltage across the parallel circuit, and there is flowing round the coil and condenser a current which is of much greater magnitude. At the harmonic frequencies, the circuit is out of resonance, and having low parallel impedance does not develop much harmonic power.

The available power may be applied to a load circuit by direct connection to the anode, by tapping on to the coil, or by magnetic coupling to another circuit, as shown in Fig. 1(B). The effect of this extra circuit is to reduce the dynamic impedance of the anode circuit. There is an optimum value of impedance for each valve and for each operating condition, which may be found by adjustment. Obviously the anode coil and condenser employed must be efficient, otherwise they will absorb some of the output power.

Class B Operation

With no restriction on valve distortion, efficiency can be made much higher than in a straight amplifier and by making use of grid distortion as well, a high degree of efficiency is obtainable. The method of adjustment will be made clear by reference to Fig. 2, in which the bias is shown increased to near "cut-off" at the left. The applied grid oscillation or " drive " now causes the anode to conduct pulses, as shown in the solid curve at the right. This is increased as far beyond positive as it can be made to go, and the anode pulses become proportionately stronger. The tuned circuit of Fig. 1(B) thus receives a succession of impulses, and if tuned to the pulse frequency large oscillations are maintained in the closed or " tank " circuit. The amplitude of the anode swing is determined by the size of the pulse, the fundamental output being represented by the broken line. The second harmonic (twice fundamental frequency) is usually of smaller amplitude and may be selected if so desired.

This is typical of a " Class B " R.F. amplifier and it will be observed that, apart from the effects of curvature in the valve characteristic, the amplitude of the fundamental frequency output wave is proportional to that of the input or drive signal. Therefore, if the drive oscillation is made to vary at a comparatively slow rate (as for example, by making it a speech modulated oscillation) these slower variations will be reproduced in the output. " Class B " operation is often used in this way in the output stages of a telephony transmitter.

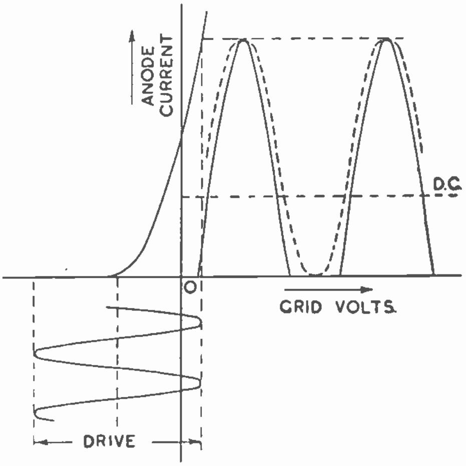


Fig. 2.
Pulse operation.

World Radio History

Class C Operation

The D.C. input, represented by the horizontal broken line of Fig. 2, is about one-third of the peak, and is fixed by the average amplitude of the pulse. The efficiency, therefore, is highest when the pulses are high and narrow. They may be narrowed by increasing the bias still further and increasing the drive to suit; it is usual to bias to at least twice cut-off, provided enough drive is available.

This is typical of "Class C" R.F. amplifiers, and referring back to Chapter 2, it will be realised that the output is no longer proportional to the input, further that it is zero until the drive reaches a certain level (the cut-off point). If modulation is to be applied on the driving side, it is clear that it must be restricted so that the drive never drops below cut-off, otherwise serious distortion will result. "Class C" is the usual condition in telegraphy, as a high proportion of the D.C. power taken from the H.T. supply can be converted into R.F. output power.

Summing up, it can be stated that practically all transmitting valves are operated by one of these pulse methods, which makes a correct understanding of the method very important. The following alternative explanation may help.

Since the current flowing through the valve may be controlled by the grid, the valve may be regarded as a controllable variable resistance; hence the name valve. The effect of the drive may thus be regarded as a means of switching the valve resistance rapidly between high and low values. Starting, then, with the valve at normal, suppose the grid voltage to be lifted suddenly above zero for an instant (this would correspond to one positive peak of drive) and for this instant the valve would be switched on or have very low resistance. The anode circuit of Fig. 1(B) then finds itself exposed to the H.T. supply, which causes a surge of current to flow from the H.T. source to "fill the breach." This "kicks" the tuned circuit into oscillation, and if only one pulse has been given the oscillation will quickly die away (see Chapter 1 Fig. 6). On the other hand, if the drive impulses are correctly timed, the continuous oscillations are maintained at the expense of the power supply.

Power Efficiency

Correct timing of the pulses means that the anode circuit and load must be tuned to the drive frequency, producing in effect a resistance in series with the valve. From a power efficiency standpoint the circuit may thus be regarded as being two resistances in series, namely, the load resistance and the valve. The efficiency is therefore the ratio of the load to the total; the lower the effective resistance of the valve can be forced down, the higher will be the efficiency. If the two are equal, then half the power supplied is lost in the valve, and half is taken by the load, consequently the anode efficiency is 50 per cent.

This term "effective resistance" has been introduced as an artifice to illustrate the operation of a valve as a power convertor (taking direct current and changing it to alternating current), but this bears no direct relation to "anode resistance" which is given in manufacturers' lists, or which may be obtained from the D.C. characteristic curves. Its value depends on two conditions; first, the extent of the drive; and second, a sufficient emission of electrons from the cathode.

It will be noted that the progressive increase of efficiency from "Class A" to "Class C" is obtained at the expense of input, and not by increasing output for the same input. To obtain greater output at the higher efficiency the anode swing must be increased. This can be achieved firstly by increasing the grid drive, but this will not help very much because if the grid is driven too far positive, grid current is excessive and the drive is retarded. Secondly, it can be achieved by increasing H.T. volts, at the same time increasing both bias and drive. The limit to this process is set by the heating losses of the valve anode. The waste power is radiated as heat from the anode, and as the input power increases, so the anode temperature rises. Valves with white molybdenum anodes may safely dissipate enough power to heat the anode red, though it is not recommended for continuous operation. Valves with dull (nickel) or black carbonised anodes should never be run even visibly hot, as over-running is liable to liberate gas from the electrodes, which may quite suddenly destroy the vacuum and ruin the valve. The generation of excessive R.F. voltages may also cause heating and eventual cracking of the glass seals in the valve envelope.

As already indicated, if the valve is to operate at high efficiency it must have sufficient emission of electrons from the cathode to allow it to pass heavy pulses. In a valve passing a steady anode current of 50 mA, the pulses may be required to reach ten times that value, though it is impossible to obtain such a current under direct current test conditions. The filament therefore should never be under-run, for starving the pulses will result in excessive anode heating.

In regard to power amplifier efficiency possible in practice, 60 per cent. is a very good figure for 14 Mc, whilst 90 per cent. can be obtained at lower frequencies. For purposes of estimation, however, 50 per cent. is a safe value to use; that is to say, the input power should not be more than twice the rated anode dissipation. At frequencies above 14 Mc efficiency drops and it is advisable to run normal valves at low rating or use specially designed valves for the purpose. The following table shows the maximum safe inputs for a valve rated at 10 watts anode dissipation, when operated at various efficiencies. For valves of higher rating, proportionate wattages may be taken.

Efficiency, per cent.	Max. Safe D.C. Power Input, Watts	R.F. Output, Watts	Valve Dissipation
90	100	90	10 watts
80	50	40	
50	20	10	
33	15	5	

Driving Power

The R.F. oscillation required for driving the grid represents power and the grid current which flows every time the grid becomes positive represents a power loss made good by the driving agency.

In a triode amplifier stage, the power output available can be 5 to 10 times the power required for driving. In pentodes much better ratios (50 to 100) are obtained.

The driving power may be obtained by " borrowing " some of the output of the anode circuit (in which case a self-oscillator is produced) or it may be derived from the output of a previous stage (in which case a power amplifier is produced).

The actual extent of the power required depends on the type of valve and the operating conditions, information which is often given by the makers. Table 1 at the end of this Chapter gives approximate figures for a number of types.

If no information is available, then an estimation must be made, in which case it would be safe to allow one-fifth of the output power in the case of triodes, and one-twentieth or more in the case of R.F. pentodes. The drive is usually calculated in terms of the grid current, and if this is known, a closer estimate can be obtained. The grid current is usually between one-quarter and one-tenth of the working anode current; thus if the normal power rating of the valve is known, the grid current may be assessed approximately. Drive power is twice the product of grid current and grid bias voltage. For example, suppose that the H.T. supply is 500 volts. The amplifier may be expected to run at 25 watts input, which represents 20 mA. anode current. Assume that the valve is biased to twice cut-off and that this requires 100 volts, then allowing one-fifth of the anode current (or 4 mA.) in the grid circuit:

$$\text{Drive power} = 100 \times \frac{4}{1000} \times 2 = 0{\cdot}8 \text{ watt.}$$

The factor " 1000 " is introduced because the current is in milliamperes. This value of driving power should be sufficient for modern high slope valves, although a low slope valve, working at a higher value of cut-off bias would require more input power.

The factor " 2 " is inserted because only one half of the power actually applied goes into the valve, an equal amount being required for overcoming the bias supply, or for heating the gridleak. When the latter device is used for obtaining bias, the valve automatically adjusts itself to this condition; consequently the " input impedance " is equal to half the gridleak resistance, unless the leak is in parallel, in which case it takes R.F. power as well as rectified D.C., the combined input impedance then being one-third, and the factor becomes 3.

If the normal working bias and grid current are known, it is possible to make a more accurate estimate, using the relation above. In the experimental state, the power actually being absorbed can be found. It should be remembered that the bias value to be used is the *total* bias from all sources, *i.e.*, applied bias voltage plus grid current multiplied by gridleak resistance or (in the case of automatic bias) the cathode resistor value, multiplied by the anode current.

The factor " 2 " given above is increased slightly by the additional losses in the components associated with the grid, coils, condensers, valveholder, etc., but with good components it should not exceed 3 at normal frequencies. At frequencies above 30 Mc. additional factors come into play which eventually reduce the power gain to zero because of excessive grid drive requirements.

These figures hold for telegraphic operation, and to some extent in certain types of telephonic circuits, but the latter are usually more complicated, so that if the correct operating conditions are not available they must be found by experiment.

VALVE OSCILLATORS

Definitions

Before considering practical aspects of transmitter design, it will be helpful to mention some of the conventional methods of building up the circuits which follow.

It has been stated earlier that transmitters are fundamentally composed of a number of valve stages driving each other in succession. Later it will be shown that it is very desirable for circuits carrying radio-frequency currents to be " self contained " as far as these currents are concerned. To further this end " decoupling " arrangements are introduced into the " feed circuits " to each stage, that is, into the leads supplying current for heating the cathodes and voltage for operating the anodes and other electrodes. In some cases it is necessary to use decouplings which are effective for R.F. but which allow currents of speech frequency to pass. At other times it is necessary to stop both.

A complete layout thus comprises:

(*a*) A number of valves, each with its own group of R.F. circuits.
(*b*) Interstage R.F. couplings, to transfer the output power of one valve to the grid of the next.
(*c*) Feed circuits to each stage.
(*d*) Means for transferring the final power to the aerial, or " output network."

In the circuit diagrams which follow, the R.F. circuits have been built up around their respective valves, with the anode and grid closed circuits made to stand out clearly. Closed anode circuits are frequently referred to as " tank " circuits because they act as reservoirs of energy.

The term " earth " is used in a general way. When a point is shown with the conventional earth sign, it does not follow that each point is taken away separately to an earth connection. In fact in normal practice each such point is connected as directly as possible to some part of the apparatus which is at a steady " earth potential," such as a common bus bar, the metal chassis, or frame of the transmitter. Other points are said to be at steady or " earthy " potential when they have a D.C. potential to earth but have no R.F. voltage. The earth connection in these cases may be *via* a large capacity to earth or chassis.

Considering now specific points of design:

Interstage couplings may be arranged simply by tapping the grid on the previous anode coil, a blocking condenser being used if necessary to isolate the H.T. Alternatively simple magnetic coupling between one anode coil and the next grid coil can be used or if preferred the type of magnetic coupling known as a " link."

The D.C. supply to grid or anode may be connected either at a suitable " earthy " point or

World Radio History

through a choke direct to the valve electrode; the former is known as "series feed" and the latter as "shunt feed." These two methods are illustrated in Fig. 3.

The heater supply may be battery or A.C., according to the type of valve, and the cathode may be either directly or indirectly heated. In the case of directly heated A.C. valves, the centre of the filament is regarded as the point of steady, or earth potential, and as this is not usually accessible, the R.F. current is passed through two condensers placed across the filament terminals, whilst the D.C. anode current returns either *via* the centre tap of the heater winding of the mains transformer, or through a centre tapped resistance connected across the filament terminals. This is shown clearly in a later diagram (Fig. 6). In order to prevent diversion of R.F. energy it is also sometimes necessary to decouple the heater winding of an indirectly heated valve by means of condensers to earth.

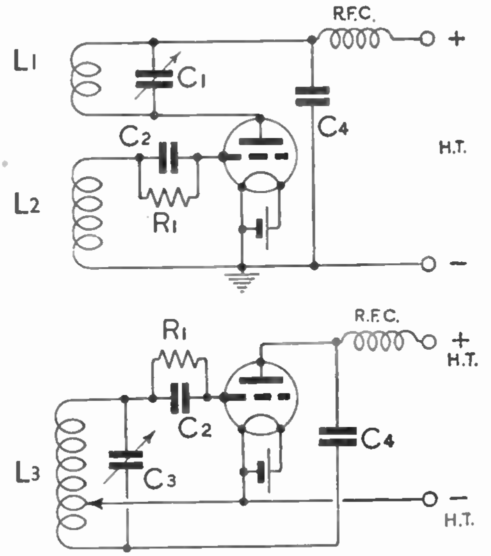


Fig. 3.
The fundamental valve oscillator circuit and the Hartley oscillator derived from it. The former is series-fed through the decoupling circuit of the choke and C_4, whilst the latter is shunt-fed, C_4 then becoming the anode blocking condenser.

Examples of all these circuit details have been worked into the diagrams which follow and are referred to later.

Self-excited Oscillators

Having discussed how the valve can become an efficient R.F. amplifier, it is now proposed to show how it can be made to act as a generator by feeding back some of its output in the form of grid excitation. Such a generator is called a "self-excited oscillator" and the easiest method of producing this condition is to connect a coil between grid and cathode, and couple it magnetically to the anode, as shown in the upper part of Fig. 3.

Referring back to Fig. 1, if the grid is made more positive (that is nearer zero bias), then the anode current increases, and this increased current through the load results in an increased voltage drop across it. Consequently since the H.T. + end is at a steady voltage, the voltage at the anode must drop. Thus if an oscillation is applied to the grid, the anode voltage swings in opposite sense, *i.e.*, opposite phase. This effect is the same whether the load is a resistance, or a circuit tuned to the frequency of the oscillations. In a self-excited oscillator therefore it is essential that the two coils L_1 and L_2 should be connected in the correct direction. In Fig. 3, if the coils are wound in the same direction and connected as shown, the grid voltage will be of the correct phase.

This circuit will be recognised as that of the regenerative detector of a receiver, with the difference that the anode coil L_1 is tuned instead of the grid coil because now it is required to develop power in the anode circuit. For the same reason, the adjustments are different, because now the voltage applied to the grid must give a pulse large enough to make up for the power lost in the previous cycle of oscillation due to the resistance of the valve and by that taken by the output circuit. The coupling between the coils is increased, until sufficient grid voltage is obtained.

Incidentally it should be mentioned that the oscillations always start themselves, as any disturbance in the circuit, however minute, builds up as in a regenerative receiver.

Returning now to the pulse theory, it is essential for efficiency that bias be used, and although this may be applied from a battery, it is easier to use a condenser C_2 and gridleak R_1. Each time the grid swings on the positive side of zero bias a pulse of current flows from it: C_2 averages out these pulses into a steady discharge flowing though R_1 to produce the required bias voltage across it. The value of R_1 is important. If it is too low there is not enough bias, if it is too high then the charge in C_2 leaks away too slowly, in which case "grid howling" sets in and the output of the oscillator instead of being pure R.F. is badly chopped at this frequency. A common value for R_1 is 10,000 ohms, but the best value should be found by experiment. C_2 should have a value at R.F. of between 100 and 1,000 $\mu\mu$F.

The efficiency of a self-oscillator can never be as good as with separate excitation, because part of the output is used in the drive, further it is not possible to apply so much drive.

Hartley Oscillators

The reversed feedback circuit just described is one of a large group of oscillators which rely upon inductive coupling for the feedback. There is another class in which feedback is obtained by capacity, and nearly all oscillators can be placed in one class or the other.

The Hartley oscillator is the best known of the inductive types and Fig. 3 shows how it is derived from the fundamental circuit. It will be seen from this diagram that the tuning condenser C_3 is placed across the whole of the output tank coil as this usually produces the best oscillating conditions. It will also be noted that the choke feeding the anode is now across an active part of the circuit and should therefore be of good quality and suitable for the

World Radio History

frequencies it must reject. For this reason the circuit is known as "shunt fed."

In Fig. 4 the coil is broken and the H.T. supplied at the "earthy" point where there is no R.F. potential. Such a circuit is said to be "series fed." In this circuit the choke is less important provided it is of average quality, whilst a resistance could be used. It will be seen that the oscillating circuit is closed by a condenser which must have a low impedance. A suitable value of capacity is ·01 μF.

Paper condensers should never be used in closed circuits as they introduce more resistance than mica types, and are not suitable for the heavy currents which circulate therein.

Hitherto the diagrams illustrating this chapter have shown filament type cathodes, with battery supply, but in Fig. 4, and later figures a simple cathode only is shown, and unless specially noted the cathode may be either directly or indirectly heated.

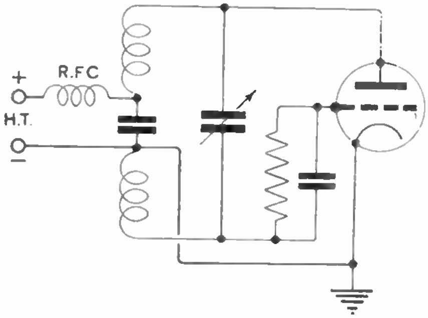


Fig. 4.
The series-fed Hartley oscillator, in which the anode current is supplied at the "earthy" point of the coil, thereby avoiding possible loss of power due to the use of a choke, as in the case of the shunt-fed circuit of Fig. 3.

Tuned Plate-Tuned Grid Oscillators

Fig. 5(A) shows a circuit employing capacitative feed-back, the actual capacity used being that between the grid and anode electrodes of the valve, as illustrated in the lower skeleton diagram Fig. 5(B). Oscillations start when the grid and anode are tuned to nearly the same frequency, and for maximum efficiency these circuits should always be slightly out of tune with one another. This type of oscillator is not so easy to adjust but it is very popular because it is more stable than most of the other circuits in this group.

In Fig. 5(A) the grid condenser and leak are shown connected at the "earthy" end of the tuned circuit; this is not essential, but is often convenient in transmitter circuits, as it helps to keep down the circuit losses.

Oscillator Stability and Tone

As the bands authorised for amateur transmission are very narrow, it is essential to keep the frequency from wandering outside, thereby causing interference with commercial signals. Consequently, before any attempt is made to adjust a transmitter, some means should be available for checking frequency. The best method is to use a monitoring receiver, preferably entirely screened (including batteries), which can be accurately calibrated by reference to the known frequencies of certain stations near the bands, and by cross-reference to a quartz-crystal oscillator. In addition to the above requirement the oscillation must be so steady that during communication it does not move out of audible beat in the receiver tuned to it at a distant point. This means that the variation must not exceed ± 3 kc, which in the 14 Mc band amounts to part one in 5,000. With improving receiver design, the demand for stability becomes more imperative.

The frequency is determined fundamentally by the tuned circuit, *e.g.*, L_1 C_1 (Fig. 3), which must be designed so that the reactance of L_1 and C_1 are equal but opposite. The reactance around the closed circuit is then zero, and the oscillator chooses the frequency which gives this condition. Unfortunately, many factors tend to upset the reactances of the circuit. For example, the inter-electrode capacity of the valve must be included, for as the valve heats up this latter will change slightly and the frequency with it. If the oscillator valve is to be keyed by breaking its supplies, the frequency may change each time the key is closed. The electrodes may cool again when it is opened. This will cause chirpy signals to be heard in the receiver.

The damping effect of the valve and its grid load also have an effect which makes the frequency dependent upon the voltage of the H.T. supply, etc. The ripple from a badly smoothed mains H.T. supply causes the R.F. carrier to "wobble," producing frequency modulation, an effect which is likely to cause interference with other signals. Too large a value of C_2 or R_1 will also cause a chirp owing to the length of time required to charge the condenser, and establish a steady bias.

The choke and condenser C_4 in Fig. 3 are used to prevent the R.F. current from passing into the battery or power supply—another common cause of impurity in the oscillation. This separation of the R.F. components into their proper channels should always be given careful attention.

It should also be remembered that the output

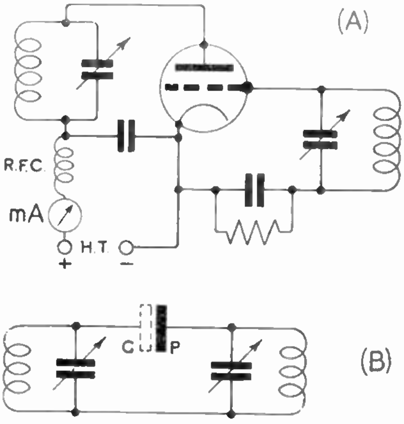


Fig. 5.
The Tuned-Plate Tuned Grid (T.P.T.G.) oscillator with skeleton circuit below showing how feedback is obtained via anode-grid capacity.

circuit throws capacity into the closed circuit, and if this has loose connections or is itself unstable (e.g. a swinging aerial) then general instability may be so great as to render the signal unreadable. It will thus be seen that it is extremely difficult to construct a reliable transmitter from a plain oscillator coupled to an aerial, and such an arrangement is not recommended.

" High C " Oscillator Circuits

Most of the foregoing troubles may be cured by making C large (200 $\mu\mu$F at least) and L correspondingly small to suit, but there is, of course, a maximum beyond which oscillation is not possible. With C large, the variable external circuits have correspondingly less effect.

Some oscillator circuits, especially the " Dow " and " Tritet " described later, actually require " High C " for proper working, and so automatically help in this way.

An important aid towards stability is the use of very low-loss circuits; looser coupling may then be employed and the circuit becomes less dependent upon valve damping. With " High Q " circuits, the condition of zero reactance is more critically dependent on frequency—in other words, the frequency cannot change so easily.

Oscillator Adjustments

Various items of apparatus are necessary for the adjustment of an oscillator. These include a feed-meter, a receiving monitor, and an absorption wavemeter together with some form of output indicator or artificial aerial. The beginner is advised to carry out experiments with simple oscillators in conjunction with these indicating devices, in order to learn how the circuits behave, thus gaining experience which will be invaluable later. Initial experiments may be made with ordinary audio power valves working on low power.

The feed-meter, say 50 mA full-scale, should be included in the H.T. supply as shown in Fig. 5.

Various methods of monitoring may be used, but the best is a completely screened oscillating detector. Other arrangements include listening to a harmonic on an ordinary oscillating receiver (e.g. up on 14 Mc if the oscillator is down on 3·5 Mc). This is a particularly useful method for stability adjustments, as any variation is magnified.

The absorption wavemeter may consist of a variable condenser of about 100 $\mu\mu$F capacity, arranged in any convenient manner to take plug-in coils. It can be calibrated by coupling it loosely to the grid coil of an oscillating detector in a receiver, beating with known stations. With very loose coupling the beat-note is heard to change sharply as the wavemeter condenser is tuned; the centre of this change of note is the resonant frequency. There will be at the same time a change in the feed current to the oscillator.

An absorption wave-meter is not suitable for accurate work, but is invaluable for general adjustments, as it provides a foolproof method of adjusting circuits to roughly the correct frequency; *e.g.* in a frequency-multiplying stage the exact harmonic can be found easily, although the task is very difficult with a monitor. (See Chapter 14.)

For an artificial aerial load the instrument described in Chapter 11 may be used, or a low voltage lamp of suitable wattage may be connected in series with the wavemeter.

Starting with a small H.T. supply, oscillation is indicated by a sharp fall in anode current showing arrival of bias due to grid current. If the anode current rises at the commencement of oscillation, then the value of gridleak is far too low. With any oscillator using more than about 250 volts H.T. supply, it should be possible to light a neon lamp held near the anode connection, whilst a small loop closed by a flash lamp bulb can be coupled to form another type of indicator. At very high frequencies, *e.g.* 30 Mc or more, these effects may not occur; in particular it may not be possible to make the anode current fall when oscillation starts. This usually indicates that the valve is not suitable for such frequencies.

The frequency may be checked roughly by coupling the absorption wavemeter loosely and tuning it for maximum anode current " pull." This method is not in itself sufficiently accurate for ensuring that the frequency is within the amateur bands, but it does locate the correct band, as distinct from the heterodyne beat method which may find a harmonic multiple.

Taps, couplings and gridleaks should be adjusted for maximum output to the load, consistent with stability. Note that as the coupling of the load is increased the power output rises to a maximum and then drops back with tight or over-coupling, whilst the feed current rises continuously until oscillation ceases. This optimum point should never be exceeded in any part of a transmitter, as it invariably leads to instability and a bad note: in fact, under-coupling is always advisable.

It is not always an easy matter to run a directly heated filament from A.C. supply, as the ripple on the signal frequency is often bad. If the oscillator shows abnormal effects, such as sudden changes of feed when tuned, or overheating at low inputs, it may be suffering from parasitic oscillations. These effects are discussed later.

Crystal Oscillators

Quartz is endowed with certain physical properties which allow of its use for the control of transmitters, and it is now generally adopted. Its mechanical properties are such that the natural vibration of a thin slice 1 mm. thick, correctly cut, is of the order of 3 Mc, and the internal damping is so slight that it is equivalent to a circuit having a resonance peak much sharper than any device employing coils and condensers. The " Q " of a coil and condenser circuit may be between 100 and 300, but the corresponding figure for a quartz oscillator may be tens of thousands. Thus, if a slice of quartz is placed between flat electrodes, it can replace the grid circuit of a T.P.T.G. and provide an oscillator of enormously improved stability. The frequency of oscillation is adjusted by grinding the quartz to a definite thickness: skill is needed for this operation as results depend entirely on the accuracy with which the faces are ground flat and parallel to each other.

Quartz crystals may be ground to a frequency of 3·5 Mc with comparative ease, but above this figure the power capacity drops and the grinding becomes

World Radio History

more critical. A type of crystal frequently used employs a 2·4 Mc cut, and when connected to a valve with a 7 Mc anode circuit such a crystal will drive from its third harmonic with good output. These are known as " thick-cut " crystals.

Fig. 6 shows a typical triode crystal oscillator. In this circuit the tank condenser can be 100 μμF max. for 7 Mc or 250 μμF for 3·5 or 1·7 Mc, but the coil should resonate with considerably less than these capacities at the crystal frequency. Suitable coil sizes are suggested in Table 2 (page 114).

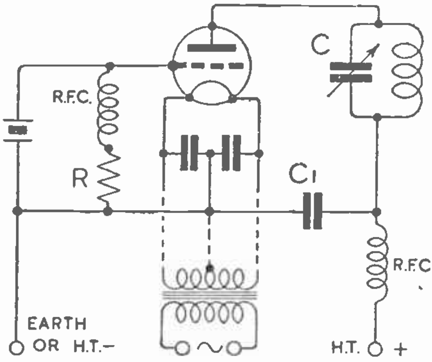


Fig. 6.
Triode crystal oscillator circuit showing also method of feeding a directly heated cathode from A.C. The cathode decoupling condensers may be of 0.01 μF capacitance.

In this circuit C_1 is the plate decoupling condenser, which may be ·01 μF. The choke, which should be of good quality, prevents the gridleak R from becoming an R.F. load on the crystal.

The valve may be any low power triode, capable of handling a few watts, such as the LS5B type, or a *Marconi* ML4. The H.T. should not exceed three hundred volts, especially if the crystal is a good one. A.C. heating may be used with centre tap connection as shown, the condensers being of the order of ·01 μF.

In operation, tuning the anode condenser C from maximum downwards, a sharp drop in current at some point denotes that the crystal is oscillating at maximum intensity. Continuing towards zero capacity, the feed current rises and the output drops (see Fig. 7). It is best to work slightly below maximum output, otherwise stability is slightly impaired, and the initial oscillation is not so certain.

It is not usual to employ this type of crystal oscillator connected directly to the aerial because the starting and stopping oscillations produce a chirpy effect. Further, only a small power may be handled by a crystal stage. Therefore when high power is required this must be amplified by additional stages.

Stability is such that the frequency can be specified to within 1 cycle per 10,000, using fairly good quartz, provided it is not over-run, although it is advisable to check the frequency occasionally as poor samples have been known to vary and move a transmission out of the allotted band.

As with other circuits the frequency depends slightly on temperature. Over-running heats the quartz with consequent frequency drift, which may be sufficient to cause a distant receiving station to lose the signals.

Again, as excessive vibration is liable to crack and ruin a crystal, the input should be limited to about 5 watts. It is a good plan to insert in the " earthy " lead to the crystal a flash lamp bulb which glows at 100 mA, and never to exceed this current for any length of time.

Tetrode and Pentode Crystal Oscillators

The power capacity of a crystal is limited to circuits where the drive required for the oscillating valve is not more than one watt of power. Working at this figure a crystal is liable to heat and drift, or chirp if keyed, and this fixes the safe output power of a triode circuit to about 5 watts. Pentodes and " beam " tetrodes usually have very high output/input power ratios, and make excellent crystal oscillators, and a valve such as the *Raytheon* RK20, or the *Standard Telephones* 4052-A in a carefully adjusted circuit can give as much as 50 watts of output. This is, of course, a very high figure, and special caution would be needed to prevent any of the 50 watts from becoming suddenly diverted into the crystal! Smaller valves, such as the *R.C.A.* 802 or *Standard Telephones* 4061-A will give an output of about 15 watts.

Another advantage of the pentode or tetrode oscillator is that it can be keyed without difficulty. Fig. 8 shows a typical circuit. The screen voltage which may be critical for maximum output, should be kept low (say 150 volts) and for that reason it is advisable to take this from a variable potentiometer R_2 across the H.T. The screen has to work at a steady potential and is therefore decoupled to earth or cathode. The suppressor grid in a pentode may be joined to cathode internally but if it is accessible, it may be better to connect it to screen. The gridleak is higher in value than in triode circuits and may need to be as much as 100,000 ohms. Automatic bias (R_3C_4) is depicted in Fig. 8, but this is not necessary in a low power circuit although it should be used if the H.T. voltage exceeds 300 volts.

Most of the valves mentioned, and in addition those specially designed as R.F. power-amplifiers, are often carefully screened, and in consequence may need a little extra feedback capacity. This does not however apply to valves of the 6L6 or

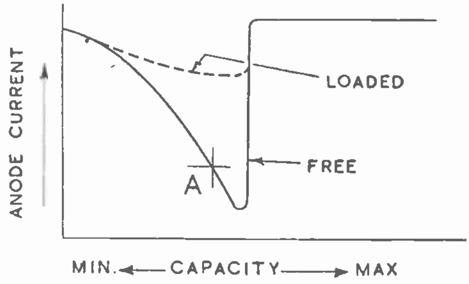


Fig. 7.
Feed current changes with tuning in a triode or pentode crystal oscillator. Unloaded, the crevasse is deep but when output is taken the depth is reduced to about half. The circuit should be set to around the point A for stable operation.

6L6G class. The extra capacity C_5 shown dotted, should be of the order of 1 μμF and may consist of a pair of discs about the size of a halfpenny, set half an inch apart.

Electron-Stream Coupling

A very important self-excited arrangement is known as the Dow, or Electron-Coupled, oscillator. In this type of oscillator the load circuit is shielded from the frequency-determining circuits so that variations of load cause very little change of frequency. Variations of supply voltage have but little effect on the frequency, and the E.C. oscillator is therefore an excellent generator of stable frequency, whether this is required for metering, monitoring, or transmitter excitation.

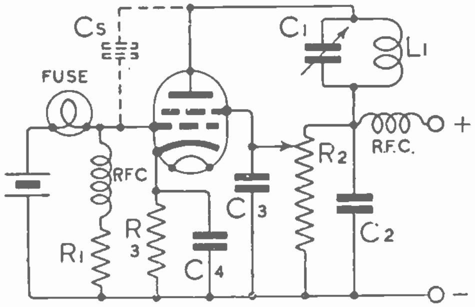


Fig. 8.
Pentode or Tetrode Crystal Oscillator (suppressor grid not shown).

C_1	100 μμF max.	R_1	10,000 to 100,000 ohms.
$C_{2,3,4}$	.01 μF mica.	R_2	10,000-ohms. 5-watts.
C_5	See text.	R_3	200 to 500 ohms.

Valves 802, 4061A, 807, 6L6, 6L6G.

Fig. 9 shows an E.C. circuit evolved from the Hartley oscillator. In the Hartley (Fig. 3) the cathode or cathode tap is at earth potential, although it is not essential for its working that this be the "earthy" point of the circuit. As long as the anode grid, and cathode have the proper *relative* potentials any one of the three may by made the "earthy" point. Now the anode may be held at "earthy" potential with regard to R.F. though still at a high D.C. potential above earth; the condenser C_4 has a negligible reactance to R.F. and holds the anode steady.

In Fig. 9 which shows the substitution of a tetrode, the screening grid has been "borrowed" to make the anode of the "inverted triode" Hartley oscillator.

The real anode of the tetrode, if given a positive D.C. potential, receives the electrons passing through the screening grid. This electron stream is modulated into pulses by the oscillations set up in the Hartley circuit, and therefore the anode current of the tetrode has an R.F. component. A tuned circuit connected in series with the anode, and coupled to the load, can extract power from the modulated anode current (which incidentally consists of quite good pulses), and this can be used to drive another valve. If the screening is good and there is no other coupling between the two tuned circuits, the tuning of the anode or load circuit has very little effect on the frequency generated. To keep the frequency constant with small changes of H.T. voltage, and to allow of optimum output power adjustment, the screen grid is fed from a potentiometer across the anode source, as shown.

The E.C. oscillator is very rich in harmonics, and if the output circuit is tuned to twice the generated frequency the output is almost as great as on the fundamental frequency. Third and fourth harmonics are also strong, so care should be taken in identifying the correct harmonic. Thus the valve may combine the functions of oscillator and doubler.

The circuit is most suitable for valves with separately heated cathodes. If a directly heated filament is used it is necessary to feed its supply through chokes or wind the coil double from the bottom to the tap and supply the filament current through this pair of wires. The complication which this involves tends to make correct adjustment difficult. In modern, indirectly heated valves the insulation between cathode and heater is usually sufficiently good for the small R.F. potential developed across the tap.

Electron Coupled Oscillators

In expert hands, an oscillator of this type is capable of producing a signal almost equal in quality to that of a crystal oscillator, and offers the great advantage that the frequency may be adjusted. On the other hand, it is easily mishandled, and too often leads the owner into trouble with the authorities through the emission of a poor signal or one which is outside the amateur frequency bands. It should not be used therefore unless the frequency is checked continuously against a good standard frequency crystal.

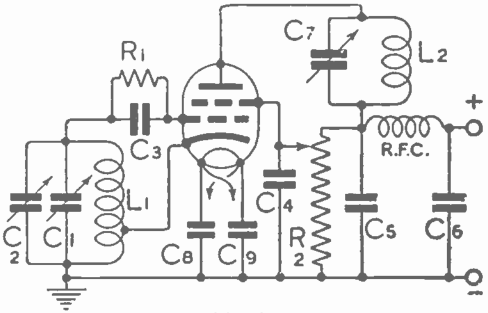


Fig. 9.
The Electron-Coupled Oscillator.

C_1	200 μμF max.	$C_{4,5}$ $C_{6,8,9}$	.01 μF mica.
C_2	15 μμF max.		
C_3	200 μμF.	R_1	5,000-50,000 ohms, 2-watts.
C_7	50 μμF.	R_2	10,000-20,000 ohms, 5-watts.

Valves 802, 807, 4061A, PV05-15.

The circuit of Fig. 9 shows the details necessary to secure correct results, and the following conditions are essential:

(*a*) The parts must be rigidly mounted and protected against shock or vibration. For instance the power pack must be quite separate. Rubber may be used in mounting.

(*b*) The anode circuit should always be set at a harmonic of the grid frequency, the output of the second harmonic being quite as good as that of the fundamental.

(*c*) The grid circuit should have a very high

World Radio History

tuning capacity and correspondingly small inductance. Further, the cathode tap should be adjusted carefully.

(*d*) The power supply should be stabilised with a ballast resistor (see Chapter 9) and have more than normal smoothing. All circuits should be thoroughly decoupled, including the heater.

(*e*) Heating of the valve and the warming up of the compartment in which it is contained will produce some frequency drift; to minimise such changes the valve heater should be switched on some time before use, and remain connected during the period of working.

(*f*) The valve used should preferably be one designed for R.F. work, that is, it should be effectively screened inside. Audio-frequency types and those in which the anode connection is at the same end as the grid or cathode do not give enough separation of circuits. Pentodes in which the suppressor is internally connected and not brought out to a separate valve pin are quite unsuitable.

(*g*) Coil, condenser, valveholder, and even the grid condenser should be of the highest quality otherwise thermal drift and a bad quality signal may occur. Avoid bakelite and use components with ceramic insulation. The *Eddystone* " Scientific " 180 μμF is an example of a suitable condenser and this may be shunted by a bandspread condenser of the same manufacture for fine tuning. The gridleak should be rated for at least two watts.

Many of the foregoing remarks are applicable to any type of self-excited oscillator, and adjustments may be made in the same way, using a screened monitoring receiver. If difficulty is experienced in removing ripple or chirp from the note, attention should be given to points (*a*), (*d*) and (*g*), and various values of gridleak tried. It may be found necessary to keep the anode circuit slightly off tune one way or the other before the last trace of chirp (due to keying of the following valve) is overcome, but with careful adjustment it is possible to make the signal sound as pure as that of a crystal-controlled transmitter.

Tuning Electron Coupled Oscillators.

A state of oscillation is indicated by a rise of anode current when the grid terminal is touched. The oscillating feed (with anode detuned) which should be not less than half the non-oscillating value, is dependent on the adjustment of cathode tap and gridleak value.

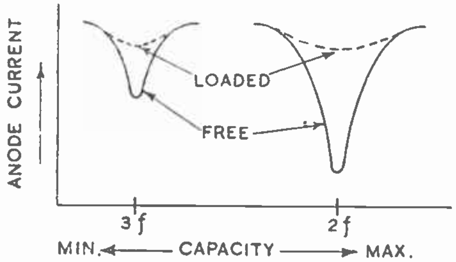


Fig. 10.
Feed current-tuning variations for electron-coupled and Tritet oscillators. At the right, second harmonic; at the left, third harmonic. An unsymmetrical crevasse or a hump at one side indicates feedback.

When the anode circuit is tuned, sharp dips in feed current will be noted, and these correspond to the various harmonics (see Fig. 10). There may be more than one in the range of the variable condenser, and in any case the *correct harmonic must be selected carefully and noted.* The dip should be very deep (to about 25 per cent.) if the anode circuit is good for the second, and progressively less for higher harmonics. When loaded by coupling to the next stage, the dip will, of course, be much less, for example, only 20 per cent. of the total.

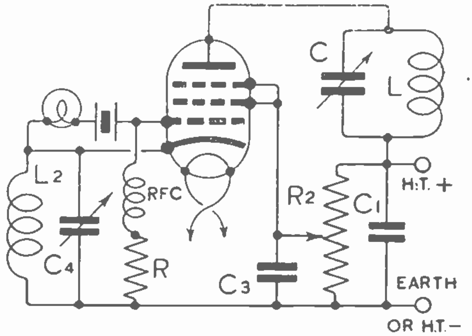


Fig. 11.
The Tritet Oscillator. When a pentode is used it is preferable to connect it as a tetrode. The flash lamp in series with the crystal is an overload warning. The anode circuit LC must not be tuned to the crystal frequency but to a harmonic. Component values are the same as for Fig. 9.

The Tritet Oscillator

This is a very popular circuit, giving good flexibility with great output, and the usual form is shown in Fig. 11. It is called the " Tritet " because like the E.C.O. it combines a triode crystal oscillator with a tetrode buffer-doubler in one valve.

The Tritet is of the T.P.T.G. type, although the feedback capacity is not obvious, as it is the capacity between grid and earth. In Fig. 11 the screen and suppressor grids are shown connected, though in many pentodes this cannot be done as the suppressor is not brought out but is connected to cathode inside the bulb. The tetrode connection gives better output and is more stable.

C_4 must be large enough to pass the harmonic frequencies easily to the anode tank circuit LC. LC cannot be tuned to the fundamental of the crystal as the two circuits will then oscillate of their own accord and overload the crystal. Similarly, on no account must the cathode circuit be tuned as low as the second harmonic, and it is advisable to make sure of this by shunting C_4 with a good quality 100 μμF condenser, and choosing L_2 to tune the crystal with about 200 μμF. Increasing L_2 will not give greater output but will in fact result only in heavy crystal current; therefore a 100 mA fuse lamp or some indicator of crystal current is essential. A suitable value of L_2 can be found in Table 2.

Using an ordinary output pentode with 300 volts on the anode and 100 volts on the screen, 2 watts of second harmonic output can be obtained as well as a fair proportion of third and fourth harmonic. When fundamental output is required the coil L_2

is short-circuited and the anode coil tuned in the normal way. The circuit then becomes the ordinary pentode C.O. The screen voltage must not be much in excess of 100 volts. The condensers C_1 and C_3 are essential, and may be 0·01 to 0·1 μF.

It is a good plan to connect a grid current meter jack in series with the leak R. Grid current should not exceed 5 mA.

Tuning Tritet Oscillators

To place the circuit in operation tune C_4 from maximum downwards; oscillation will be indicated by a drop in plate current. Now tune the anode circuit for a sharp minimum feed (Fig. 10), and use the absorption wavemeter to check that the correct harmonic has been chosen. Set C_4 some way short of maximum output to relieve the strain on the crystal.

The circuit may be keyed in the anode supply, although the adjustment for note may not be easy. Keying the screen supply may be attempted, but a chirp is almost certain to result.

As with the E.C.O., it is often found that a better note is obtained if the anode circuit is detuned slightly to one side or the other.

The output from this circuit will drive a small power amplifier stage on three bands using it as a straight C.O. on fundamental or as Tritet with 2nd or 4th harmonic. Such an arrangement makes a very compact three-band transmitter.

The Franklin Master Oscillator

A very effective oscillator widely used for transmitter drive in commercial practice is that due to C. S. Franklin of the Marconi Company. Its inherent stability is greater than that of typical E.C.O. circuits, and can be made of the same order as that of a crystal, whilst the simplicity of the arrangement makes it particularly attractive to the amateur.

The principle of the Franklin Oscillator is illustrated in Fig. 12. The circuit employs two valves, generally triodes, in a conventional resistance-capacity coupled amplifier arrangement. Potentials of any frequency (provided it is not too high), applied at " A " will result in amplified potentials at the output " B." But there are two special points to notice in which this amplification differs from that of a single valve. First, unless the losses in the couplings are very high (as might occur at ultra-high frequencies), the gain of the two stages will be a good deal greater than that of either valve alone; second, owing to the reversal of phase which normally occurs in an amplifying stage, the potentials at " B " (having been reversed twice) will be in the same phase as those at " A." Thus the conditions are ideal for reactive feedback, since there is a considerably amplified output in the same phase as the input voltage.

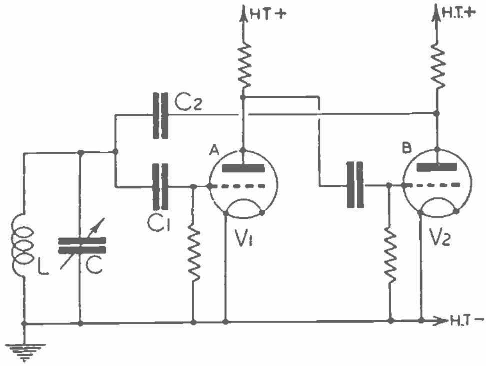


Fig. 12.

Fundamental circuit of Franklin Oscillator. Component values are discussed in the text.

Suppose a feedback coupling be provided from " B " back to " A," such as through two small condensers C_1 and C_2 in series, then provided the coupling is sufficient, the whole amplifier will go into oscillation just as would a single valve when provided with a reaction coil arrangement. In fact, apart from its additional amplification, which naturally assists oscillation, the second valve V_2 can be regarded as an alternative method of reversing the phase of the feedback, just as is done in more usual circuits by arranging the reaction coil to be wound in the opposite direction to the grid coil to which it is coupled.

There is, however, nothing in the circuit so far described, which will fix this oscillation at any definite frequency. Practically therefore the arrangement would oscillate at that frequency which happened to correspond with the greatest effective amplification. It would probably be a low frequency, determined by the time constant of the R.C. coupling, and would not be very definite.

In order to convert the arrangement into a constant frequency oscillator, some means must be provided whereby the feedback, or the amplification, is a maximum at the desired frequency, and much less at all others. This is easily done by inserting a parallel resonant circuit, L and C, between the junction of the two condensers C_1 and C_2 and the earth line. Such a circuit has a low impedance to all frequencies removed from resonance, and it thus virtually short-circuits the reaction path. Also at other frequencies the circuit behaves either as a condenser or an inductance, introducing a phase change which spoils the condition necessary for oscillation. At resonance, however, the circuit behaves as a pure high resistance, and the maximum feedback will occur in the correct phase across it. If C_1 and C_2 are reduced until their capacities are only just sufficient to produce oscillation, the latter will occur exactly at the frequency at which feedback is a maximum, namely the frequency to which the circuit LC is tuned.

It is also possible to convert the circuit into a crystal oscillator by substituting a crystal for the circuit LC. Owing to the high amplification of the two valve arrangement, oscillation is very readily obtained from " difficult " crystals, particularly at low frequencies. It may be applied, for example, to 100 kc bars, and will oscillate satisfactorily with resonator crystals, such as those designed for I.F. filters, and which will seldom perform in the more conventional single valve circuits.

The stability of the Franklin oscillator depends upon two main factors; first the quality of the circuit LC, and second the degree of loose coupling between this circuit and the valves, through the

World Radio History

choice of very small values for the two condensers C_1 and C_2. The circuit LC should therefore be a good one, possessing low losses and a high " Q," and should be of rigid construction.

In most forms of oscillator the resonant circuit is tightly coupled to a valve, and as a result considerably loaded thereby. Whatever may have been the "Q" when measured alone, the " working Q" will be a good deal lower. It is in this respect that the Franklin circuit scores, for the small condensers C_1 and C_2 effectively reduce valve loading to an almost negligible value. In the commercial case it is found possible to work with each of these condensers less than one micro-micro-farad capacity; and in the oscillator to be described they should not exceed about 2μμF. As a result the isolation of the circuit LC, from valve effects, is very complete. Suppose for example C_1 is 1μμF and the tuning capacity C about 500μμF, then since the inter-electrode capacities of V_1 can only act across the circuit in series with C_1, no changes of any kind in the valve circuits can possibly alter C by more than 1μμF or 0·2 per cent. Thus it is permissible to change the valve for another of a different type, alter the H.T. or L.T. voltages widely, or allow heating up to occur, yet the resonant circuit cannot possibly be changed in effective capacity by more than 0·2 per cent. In practice, since such drastic changes are not contemplated, the effect upon frequency would be much less than this percentage. It is this singular immunity from valve and voltage variations, and from the effects of valve heating and consequent drift, that makes the Franklin such a useful arrangement.

It will be noted that no reaction tappings or similar complications occur, but that the frequency is controlled by a simple tuned circuit with one end earthed. Practical construction is thus made very convenient, since the variable condenser can be earthed to the screening compartment, whilst to change frequency ranges it is only necessary to provide several coils, all joined to earth at one end, and to switch them in turn to the condenser by a simple single-pole selector switch. For this reason the circuit has been termed in American publications a " Single Terminal Oscillator." It lends itself very readily to the construction of laboratory oscillators of all kinds, wavemeters, monitors, or to the frequency changing oscillator of superheterodyne receivers.

A Practical Design

Fig. 13 illustrates a practical circuit used by one British amateur station. The main resonant circuit LC is placed by itself in a 6″ cube copper box, the only other components allowed in this compartment being the small condensers C_1 and C_2. This box is spaced an inch or two away from a second similar box which contains the oscillator valves and coupling components, and this simple expedient seems sufficient to keep heat from the tuned circuit, and to minimise drift. Whilst there may be a slight change in frequency from day to day (owing to changes in room temperature), these small effects are unimportant in amateur work compared to the possibility of drift during a contact through the effects of valve heating. The coil L is made from an old broadcast receiver coil which, because it was wound upon a grooved moulded former, was rigid and easily mounted. About half the turns were removed, until the inductance was such as to tune to the 1·7 Mc band with a parallel capacity of about ·0006μF. To obtain a low LC ratio, a ·0003μF mica condenser is joined across the coil, together with a ·0005μF max. variable band-setting condenser adjusted from inside the screening box, and the usual 50 μμF variable band-spread condenser controlled by a good slow-motion dial

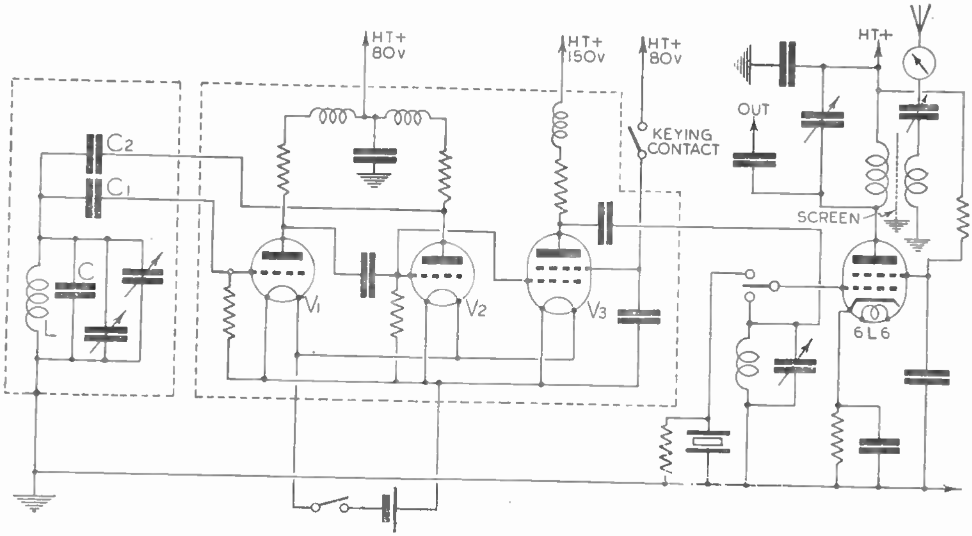


Fig. 13.

A 1.7 Mc. Franklin Oscillator designed for amateur operation. The important component values are given in the text.

World Radio History

from the front panel. A further refinement would be to compensate these condensers for temperature, by the introduction of ceramic condensers in the right proportion.

In order to couple from the oscillator to the next stage, a third valve V_3 is added, which may be an S.G. type mounted through the side of the valve compartment, horizontally, with its anode outside. The grid of this buffer valve is fed from an intermediate point between V_1 and V_2, and is thus isolated by these valves from the live end of the main resonant circuit, thus reducing the risk of pulling by the later stages of the transmitter. The buffer stage, which is not worked at all " hard," delivers about a half watt of R.F. power, which is quite sufficient to excite the grid of the following 6L6 stage.

The component values within the oscillator compartment of Fig. 13 are not very critical. Each valve employs a 1 megohm gridleak, whilst a ·0001μF coupling condenser is used between the stages. The anode resistances used for all three stages are 25,000 ohms, and in series with each is inserted a small R.F. choke to improve the amplification at high frequencies. When high slope pentodes are used in place of the triodes shown, it has been found helpful to reduce the value of anode resistance if oscillation is desired at 7 or 14 Mc. The two small condensers C_1 and C_2 can be 0 to 6μμF ceramic variables, of the tubular sliding-plunger pattern, or any good low-loss type of neutralising condenser. A second ·0001μF condenser couples the anode of V_3 (which is actually outside the screening box) to the 6L6 doubler, the circuit values for which are exactly as usual for a 1·7 to 3·5 Mc doubler stage. The tuned-anode form of coupling is also very suitable for V_3, and may result in rather better output.

The only adjustment necessary to put the circuit into operation (apart of course from usual routine tests to detect faulty connections, etc., and to tune the various circuits to resonance) is to reduce C_1 and C_2 until gentle stable oscillation takes place. The two condensers should be about equal in capacity, but this equality need not be exact. It is most important not to employ too much capacity here, for not only will stability become poor, but it is quite possible to make the oscillator howl and a bad note from the transmitter will naturally result.

The 6L6 stage is intended for use either as a neutralised P.A. or frequency doubler to 3·5 Mc, following the practice described in other sections of this Chapter. It will be noticed that battery valves are shown in Fig. 13, types HL210 and SG215 being suitable for 1·7 or 3·5 Mc operation. They were selected on account of their rapid heating and excellent stability, but mains types can be used with equal success. To obtain performance at higher frequencies it is necessary to retain adequate stage gain by the use of high slope valves, and the recently introduced low consumption short base types such as the Z62, EF8 or SP41 can be recommended. The frequency drift of the circuit as described was found to be less than 300 cycles per hour, when checked against a broadcast station harmonic, and there is no reason why this figure cannot be improved by careful attention to constructional detail.

R.F. POWER AMPLIFIERS

Frequency Multipliers

If an anode circuit is tuned to a multiple of the driving frequency, say three times, then it receives a kick at every third cycle of oscillation, and provided it is not too heavily loaded the pulse maintains oscillations at three times the drive frequency.

Such frequency multiplication has already been mentioned in connection with E.C.O. and Tritet circuits.

The efficiency of this type of amplifier is governed by the same considerations as before; namely, hard driving and high narrow pulses, but now one pulse has to supply several oscillations in the anode tank, and so the efficiency becomes progressively lower as the multiple increases.

The same master oscillator can be used to control the frequency on several multiple frequencies. The amateur bands, though not completely harmonically related, are nevertheless such that one crystal can be arranged to control frequencies in all bands.

Fourth harmonics can be obtained in one stage, though where it is desired to work on the 4th or 8th harmonic it is more usual to employ a chain of doublers. With the advent of the modern R.F. transmitting pentode with its enormous power gain from grid to output, it is now practicable to design a " drive unit " containing all the multiplier circuits in one unit with the crystal oscillator, working at low power. Descriptions of such units giving one or two watts output on any band have been published frequently. Such units usually employ small pentodes and often the fourth harmonic production is sufficiently good for practical use.

The circuit of a frequency multiplier may appear to be the same as that of a straight amplifier, but actually the anode circuit is tuned to a *multiple* of the grid frequency. Neutralisation is not essential, although it sometimes helps to improve the note. The efficiency is often less than that of a straight amplifier even for doubling; in a single valve multiplier the pulse of current contains only a proportion of harmonic, for example only 30 per cent. second, and progressively less for higher multiples. Again, the energy supplied by one pulse has to feed the load for a number of cycles instead of only one. Further the anode circuit must not seriously impede the fundamental component of the pulse or it becomes distorted in such a way as to lose some of its harmonic content, a condition usually incompatible with high efficiency at the multiple frequency.

These difficulties can be overcome to some extent by using two valves in a " push-push " circuit, such as that shown in Fig. 14. This will produce the even but not the odd multiples. In doubling, the anode circuit receives pulses alternately from one or other valve and so the efficiency can approach that of a straight amplifier stage. The fundamental component merely oscillates between the two valves and does not require to flow through the tuned anode circuit.

An interesting variation uses a " Class B " twin valve with two triodes in one bulb and a common cathode connection. This will be seen in V_4 of Fig. 16.

World Radio History

The grid bias conditions of a multiplier are similar to those of a P.A. stage, and are discussed under P.A. stages.

Multiplier Valve Types

In the triode class, a valve such as the *Ediswan* ESW 20, or *Mullard* TZ 05/20, is suitable, or a "Class B" twin triode may be used, though pentodes are often more popular because they are easier to drive and the fundamental has a means of escape through the screen grid.

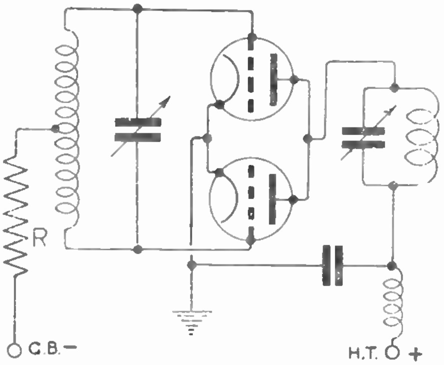


Fig. 14.

The "push-push" frequency doubler. The grids are driven in opposite phase, so that anode current flows through one valve during one half cycle and through the other during the next half cycle; the anode thus receives twice as many pulses as either grid. Under driven conditions, the resistance R provides extra bias in addition to the fixed bias.

The types already mentioned for oscillators are mostly good doublers, but above 14 Mc a specially designed valve, such as the RCA 807, or the *Osram* KT 8, is more successful.

With pentodes, the screen potential is fed through a small resistance or choke and the R.F. component by-passed through a condenser to an "earthy" point in the usual way, and as with E.C.O. or Tritet, it is often advisable to experiment with the screen voltage. When the suppressor is accessible it is often found better to connect it to screen and make the valve a tetrode for frequency multiplying.

When discussing oscillators, the question of the L/C ratio was mentioned, and it was shown that for stability in a self-excited oscillator, high C was desirable, but now that the frequency is determined and fixed, the sizes in the doubler and amplifier stages can be chosen in terms of efficiency only. For driving purposes, volts are required, and to obtain the maximum for a given input wattage high L and low C are necessary. Having found a size of coil to start with, it may be increased until the valve input capacity represents practically all the tuning capacity.

On the anode side a rather high impedance is required to suit the valve, but this must all be due to load and not to internal loss of the coil. This again leads to a high L/C ratio. There is a limit, but it is not usually attained on short waves.

The adjustment of a doubler is a simple process. With reduced H.T. voltage, the drive is applied, the coupling being adjusted for optimum at resonance (the feed rise or grid current is taken as an indication). Tuning the anode circuit then produces a sharp minimum current at its resonance; this should be fairly low, say one-third of the maximum. If this is not the case, or if the tuning is flat, then there is loss in the circuit which may be due to poor connections, a low quality coil former or condenser, or bad insulation. There may also be trouble in the decoupling or feed circuits.

Finding the Correct Harmonic

Repeated reference has been made to the need for care in adjusting and tuning frequency multiplying circuits, such as doublers. Neglect in this respect leads to much waste of time and often to considerable trouble. For example, suppose it is required to drive a power amplifier for 14 Mc output from a Tritet using a 7 Mc crystal and that the *third* harmonic is selected by mistake; the result is that the P.A. stage is adjusted for 21 Mc output which is not authorised for experimental transmission. The mistake would be a serious offence against the terms of the experimenter's licence.

This type of error has occurred, but with care it can be avoided. The correct harmonics cannot easily be found by listening on an ordinary receiver, but an absorption wavemeter, used as a form of artificial load, and giving a visual indication as it passes the resonant point, will lead to the desired frequency.

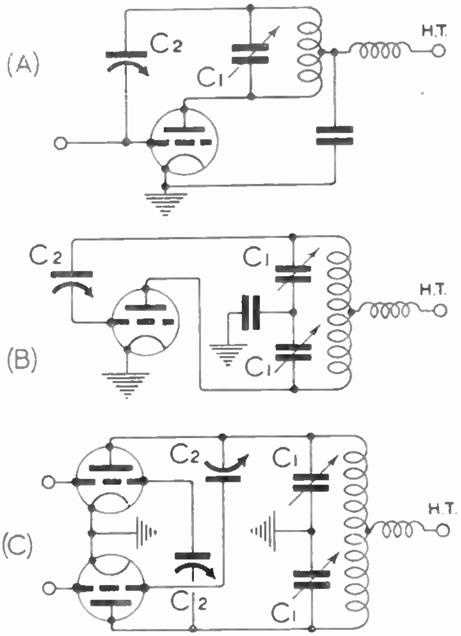


Fig. 15.

Neutralising circuits.

(A) Single-ended centre tap coil.

(B) Single-ended split-stator condenser.

(C) Push-pull split-stator.

In these circuits C_1 is the tuning condenser and C_2 the neutralising condenser.

Final Stage or Power Amplifiers

The first practical considerations are the circuit and the type of valve, the choice lying between triode and pentode and between single-ended and push-pull operation. Triodes have slightly greater efficiency than pentodes but need more drive; pentodes, however, are much more sensitive. As the drive is of minor importance in low power stages, the low power user may choose a triode, whilst the high power man may prefer a pentode in order to simplify the drive problem and allow greater flexibility in his transmitter adjustments.

The push-pull circuit is always to be preferred to the single-ended amplifier from the point of view of performance. Neutralising adjustments are constant with change of frequency and band, whilst the problem of feeding the aerial is simplified, because capacities to various parts of the circuit may be kept balanced. In addition it is easier to keep the circulating R.F. power within the stage, whilst the harmonic output is considerably less. On the other hand, the possession of a valve of a certain type may determine the use of a single ended circuit, and provided care is taken with adjustment there is no difference in efficiency between the two classes of operation.

Power Amplifier Valve Types

For R.F. amplifiers the triode is the simplest type of valve and provided that sufficient drive is available, very high efficiencies can be obtained, but the ratio of drive to output power is not very good for high efficiency. It was seen from Fig. 1 that when the grid is at peak positive the anode potential is at its lowest. Now, the electrons emitted from the cathode are attracted through the grid to the anode when it is sufficiently positive, but at its lowest peak the anode tries to go below the grid potential, and its electric field tends to force the cathode emission into the grid, giving a heavy grid current; consequently much of the drive power is required to overcome this damping effect.

In the pentode there is the screen between the anode and grid which is at a steady potential well above that of the grid, and the electric field of the anode therefore has very little influence on the grid. The result is that much less power is required to drive the pentode and greater stage-to-stage power gain is possible than with a triode.

On the other hand the efficiency of the pentode cannot be so great since there is the steady drain of current to the screen grid; incidentally care should be taken to see that this is not excessive, otherwise the electrode will heat. The screen voltage is usually kept fairly low compared with the anode in order to allow the latter to swing in potential.

A type of valve which has been derived from the pentode is known as the " beam tetrode." This is a British invention, but was first marketed in the U.S.A., and is most popularly represented in the 6L6-6L6G, 807 and KT8 types. By careful design it has been found possible to dispense with the suppressor grid and yet obtain behaviour similar to that of the pentode. (See Chapter 2.) The removal of this grid makes the anode-earth capacity of the valve very low and so high anode efficiency can be obtained at very high frequencies. This is augmented by the fact that the load impedance required is very low and easily obtained at the high frequencies. The 807 type was one of the first valves available which could be run at full rating at 60 Mc. Most R.F. pentodes fall off at 30 Mc and many at about 15 Mc.

Power Amplifier Stability

As distinct from the self-oscillator where deliberate feedback is introduced, amplifiers and to some extent frequency doublers, must be kept free of anode-to-grid feedback, the effect of which may manifest itself in one or more of the following ways:

(*a*) Self-oscillation of the amplifier at or near its working frequency.

(*b*) A tendency for the P.A. to take charge of the master oscillator frequency.

(*c*) Parasitic oscillation at some extraneous frequency.

(*d*) Radiation of signals from the earlier stages, when the final stage is switched off.

This list appears rather formidable, but actually all the points mentioned are simultaneously corrected by careful layout of the components, and in the case of triodes, by correct neutralisation. On the other hand, if feedback occurs, the result may be poor efficiency, a bad note, or the emission of signals on unauthorised frequencies. If transmissions are monitored they are easily corrected, though incipient instability of type (*b*) is commonly heard. Its characteristics are a tendency to chirp and a modulated note, or a signal which though pure " at home " tends to develop chirp or " buzz " at great distances. Further, as it is usually attended by the diversion of power from the P.A. to the C.O. stage, it may damage the crystal through overheating. Some of the suggestions which follow under the title of " Transmitter Layout " are aimed against these forms of instability.

Neutralising and Balancing

With pentodes designed so as to be properly screened between grid and anode, it is necessary only to avoid coupling *outside* the valve.

In practice, this type of valve is arranged to fit through a sheet of thin metal which acts as an electrostatic screen between the input circuits on one side and the output circuits on the other, thus effectively extending the screening grid outside the bulb. In addition it is necessary to avoid magnetic coupling between the grid and anode coils. This may be achieved by arranging the axis of the grid coil to be in the bisector plane of the anode coil, so that the two axes are at right angles. Alternatively the coils can be separated by at least five times the diameter of the larger, though not at the expense of long leads.

With triodes, and pentodes not designed for good internal screening, neutralisation or balancing is necessary, a process which has already been described briefly in Chapter 1.

There are two ways of obtaining the centre tap for neutralisation, first by tapping the centre of the coil and second by using a split-stator condenser. The tap may be made either in the grid or in the anode circuit. The split-stator method is preferable because it is easier to adjust, further it allows a low impedance path through the condenser for the harmonics developed in the valve. The impedance to earth of the centre tap on the coil, Fig. 15A, is not zero even though the blocking condenser is present, and parasitic oscillations frequently occur from this cause. The split-stator circuit can be adjusted more easily so that the neutralising setting is the same for different frequencies. This is especially the case if the coils are made so that the tuning condenser setting is about the same for all bands. As neutralisation takes some time to adjust, the advantages of the circuit given in Fig. 15B are apparent.

In the choice between tapping the grid or the anode circuit, the advantage lies with the anode tap, since a split grid coil absorbs more driving power, or rather the loss due to the extra half of the coil is more noticeable if it is on the grid side.

With single ended circuits a perfect balance is unobtainable without considerable complication, because there are other capacities, such as that of the anode to earth, which are not allowed for in the circuit. These are across one side of the split circuit, and effectively move the tap off centre, so that when the tuning capacity is altered, the tap shifts and the balance is altered. In this way it sometimes happens (especially if the anode L/C ratio is high) that the amplifier is neutralised only at the correct frequency, and when the tuning condenser is rotated, self-oscillation sets in. Such a state of affairs may produce serious distortion or frequency modulation in a telephony transmitter.

The push-pull amplifier, however, may be adjusted for perfect balance, and since the circuit is symmetrical, the neutralising adjustment is the same for all frequencies. This is one of the greatest advantages of the push-pull circuit. Note also that it allows a more compact and symmetrical layout of the components, and helps to avoid long neutralising leads which encourage parasitic oscillation.

Neutralising Adjustment

Rough adjustment may be made by means of a loop of wire closed through a flash lamp bulb, and placed near, or round the anode coil. With drive applied, but no H.T. connected to the amplifier, the grid and anode tunings are adjusted until the lamp glows. The neutralising condenser is now turned until the glow disappears. This will necessitate a slight readjustment of the two tuning condensers. When these have been reset it may be necessary to repeat the procedure a few times before the last signs of R.F. power vanish from the anode coil.

A more accurate balance may be obtained if the lamp indicator is attached to the grid coil. In this case maximum drive agrees with maximum glow, and rotation of the anode condenser will affect the glow at the resonant point so long as the balance can be improved. Again it will be necessary to retune the grid circuit slightly as adjustment proceeds, but with a perfect balance the glow should be independent of the anode tuning. In the single-ended amplifier it may be found that such a condition cannot be obtained. If this is not due to the use of too small a neutralising condenser, or to one with too large a minimum capacity, then it is advisable to reduce the turns in the anode coil. It will be found in this way that the circuit Fig. 15B adjusts better than that shown in Fig. 15A.

The balance so far obtained is a "cold" one and may not be correct when the H.T. is applied, consequently it is advisable to start with low H.T. voltage (or with a heavy duty 5,000 ohm resistor in the H.T. feed) and check for balance.

It is also desirable to check the effect of coupling the aerial circuit before full power is applied, as some types of aerial couplings may have considerable effect on the balance of the final stage.

The most sensitive method of adjustment is by the use of a grid current meter connected in series with the gridleak, so as to indicate rectified grid current. If a meter of about 10 mA range is not available, a suitable voltmeter may be used. The correct balance is, of course, the one which shows no change in grid current as the anode circuit tuning condenser is rotated through resonance. A slight mis-adjustment results in a flicker. The H.T. is disconnected for these tests.

In a single-ended circuit, it may not be possible to remove all flicker, and there may be signs of change at points removed from resonance (due to effective tap shift with tuning), but in any case, the final resonant flicker should be symmetrical in shape, and should agree exactly with maximum drive and minimum anode current when the H.T. is connected.

With hard drive there may be a slight dip in the peak of grid current, but this should coincide with the tuning resonances.

In push-pull circuits it is necessary not only to balance the stage, but also to balance the valves to take equal loading, and for this it is best to have the grid returns separate so that individual grid currents may be observed. The two neutralising condensers should be worked together so as to be equal, until the stage is neutralised, after which they can be worked one against the other until the grid currents balance.

Sometimes it is not possible to stabilise the P.A., a condition for which there are many possible causes. First make sure that the neutralising condensers are equal to the grid-anode capacity of the valve and are not too large or too small. A rough estimate of the value of the condenser can be made by examining the electrodes. If the plate is large and close to the grid a fairly high value, say up to 15μμF, may be needed, but in a well spaced triode the value may be as low as 3μμF. There are a number of suitable condensers on the market, such as the small variables up to about 20 μμF max. for the low power circuit, or the special neutralising condensers in the approx. range 1 to 10 μμF for the modern low capacity triodes.

In pentodes the screen grid reduces the grid-anode capacity to a fraction of a micro-micro-farad. This can usually be ignored in a transmitter, but only if the shielding is carried on outside the valve by arranging it to pass through a hole in an earthed metal baffle and in such a way that the anode and grid components are isolated. If this is not done or if the internal screening is not good, then neutralisation will be needed, although the capacity required will probably be very small. In such cases it can be made up by fixing two small plates about an inch square on a piece of ceramic, so that one

World Radio History

may be twisted or rotated for adjustment of capacity. Another method is to wind a few turns of wire on a glass tube for one plate of the condenser and use a wire sliding inside the tube for the other.

Parasitic Oscillation

Trouble is often caused by the valve oscillating at some unexpected frequency, and finding the frequency is equal to the cure. The stage may appear to be running quite well, yet the efficiency is poor and the electrodes may be overheated.

To discover the unwanted frequency explore with a receiver and listen for spurious notes of bad quality. If there are many, very close together, then the trouble is ultra-short wave oscillation, due to excessive length of anode or grid leads. If it cannot be cured by a rearrangement of the circuit then a small resistance, such as a 50 or 100 ohms composition resistor, in the grid and/or anode leads will cure it.

This type of oscillation is most likely to occur with valves of high mutual conductance, and is also often a sign of bad arrangement of components, long leads, etc.

If the oscillation is of low frequency, as indicated by a row of " whiskers " close to the main carrier, then the trouble is in the feed circuits, possibly due to bad decoupling or too large a grid condenser or leak. There is also the possibility of two chokes producing T.P.T.G. oscillations.

A single, strong, rough signal at some frequency other than that of the crystal is caused by ordinary self-oscillation, and if this cannot be neutralised out, the feed circuits should be examined for a faulty condenser, or an excessively long return circuit from anode to cathode.

It is advisable to monitor the transmitter when in use, listening for unauthorised frequencies, some of which may fall outside the amateur bands. Monitoring of this type is not carried out as much as it should be, for one frequently hears spurious oscillations, even from commercial transmissions.

With such troubles, or poor neutralisation, it is impossible to produce good clickless keying, and local interference often results.

Grid Circuit and Drive

As with doublers, the highest excitation voltage is usually obtained by using the greatest possible inductance. For this reason it is usual to use a separate tuned circuit for the grid of the amplifier stages, and couple this magnetically to the anode coil of the previous valve, rather than to tap the grid through a blocking condenser into the latter. This is more important with triodes than with pentodes.

To save bias supplies, some, if not all of the required bias can be obtained by means of a gridleak connected in series as shown in the single-ended and push-pull circuits of Fig. 16. If it were connected in parallel with the tuned circuit, *i.e.* across grid to earth, then some of the drive-power would reach the leak, and 50 per cent. more drive-power would be needed for the same grid-swing. The parallel connection is, however, sometimes essential, in which case a choke is added at the grid end to prevent these losses. The C.O. valve in Fig. 8 is connected in this manner. In order to observe the grid current flow, the meter, or meter jack is connected in the " earthy " end of the gridleak circuit. Fig. 16 shows the jack connections.

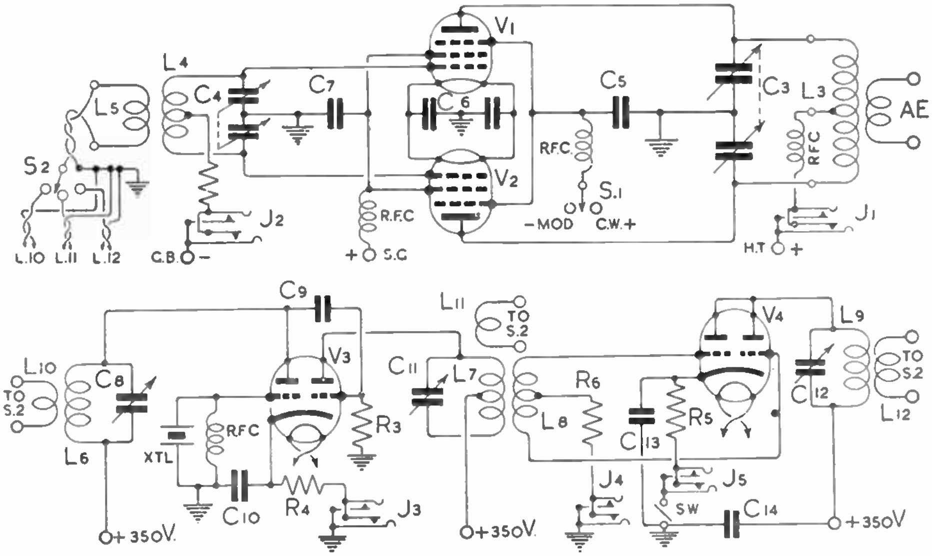
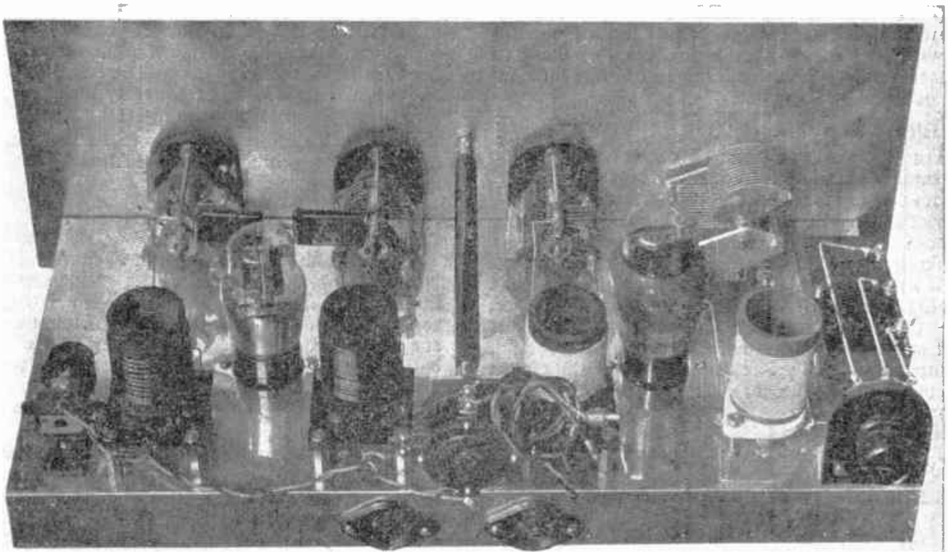


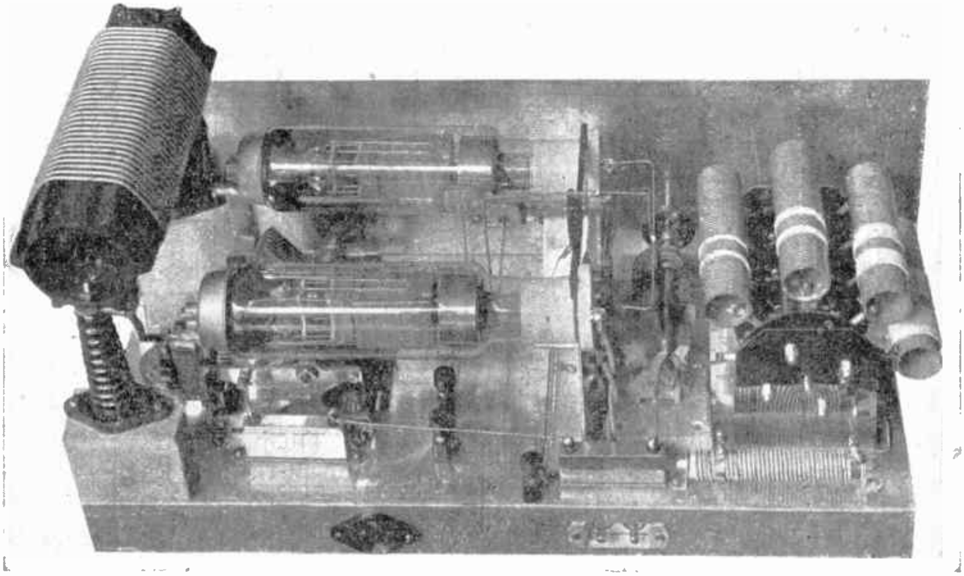
Fig. 16.

A transmitter for quick band change, employing a drive unit with band switching (lower unit) and a push-pull P.A. The twin triode valve V_3 is an oscillator-doubler and V_4 a push-push doubler. Note the method of connecting the self-closing jacks to prevent arcing on insertion of the meter plug.

World Radio History



An example of construction for drive units, such as that of Fig. 16. The switch at the right selects from several crystals, whilst that in the centre selects the link from the required doubler stage. Doubling is in the order left-right. The valves shown are of the twin triode type.



A layout suitable for the P.A. circuit of Fig. 16. The switched grid coils are at the right but the anode coil shown on the left is changed for different bands. An all-metal construction is used.

World Radio History

Anode Efficiency

The correct load for maximum efficiency in the valve is usually of the order of several thousand ohms, and is much higher than the aerial impedance. To overcome this it is necessary to transform from one to the other either by tapping the real load along the anode coil or by using a small coupling coil. The correct impedance transformation is obtained in the one case by adjusting the tap position and in the other by the size and position of the coupling coil.

Now the anode tuned circuit has its own losses and these make up part of the load of the valve. The power dissipated by this form of loss is not available in the output circuit; high output efficiency can only be obtained by making these negligible in comparison with the desired load.

This is achieved firstly by the use of high quality components, and secondly by raising the value of the anode tuning inductance to as high a value as possible, and choosing the condenser to suit. The transformed load resistance appears in parallel with the coil and so fixes its dynamic impedance at the value required for correct operation of the valve. With this fixed parallel resistance an increase of L/C ratio has the effect of reducing the " Q " of the circuit. (" Q " has been defined in Chapter 1, as the ratio of the reactance to series resistance; in terms of a parallel resistance it is the inverse ratio, *i.e.* ratio of parallel resistance to reactance.) Thus by increasing L, the Q " on load " can be made much less than that of the free circuit and nearly all the power goes into the load.

On this score, it would be best if the coil were chosen so large that it tunes with the stray capacities only, but there are factors which limit the efficiency if this is done. In the first place, the required transformer action fails if the Q is less than about 5. Also the generation and radiation of harmonics increases with L/C ratio, till it interferes with the efficiency of the valve. Thirdly, if the amplifier is to be modulated with telephony, serious distortion of speech quality occurs.

A compromise between efficiency, harmonic limitation, and telephony requirements must be made, and a Q of between 10 and 15 is suitable. The load required by the valve is not, as might be supposed, the ratio of H.T. voltage to anode feed current, but is lower because the pulse peaks are of a much higher value than the steady current. Suppose, for example that the operating condition is given as 50 mA at 500 volts; this would represent a load of 10,000 ohms, but the pulses probably

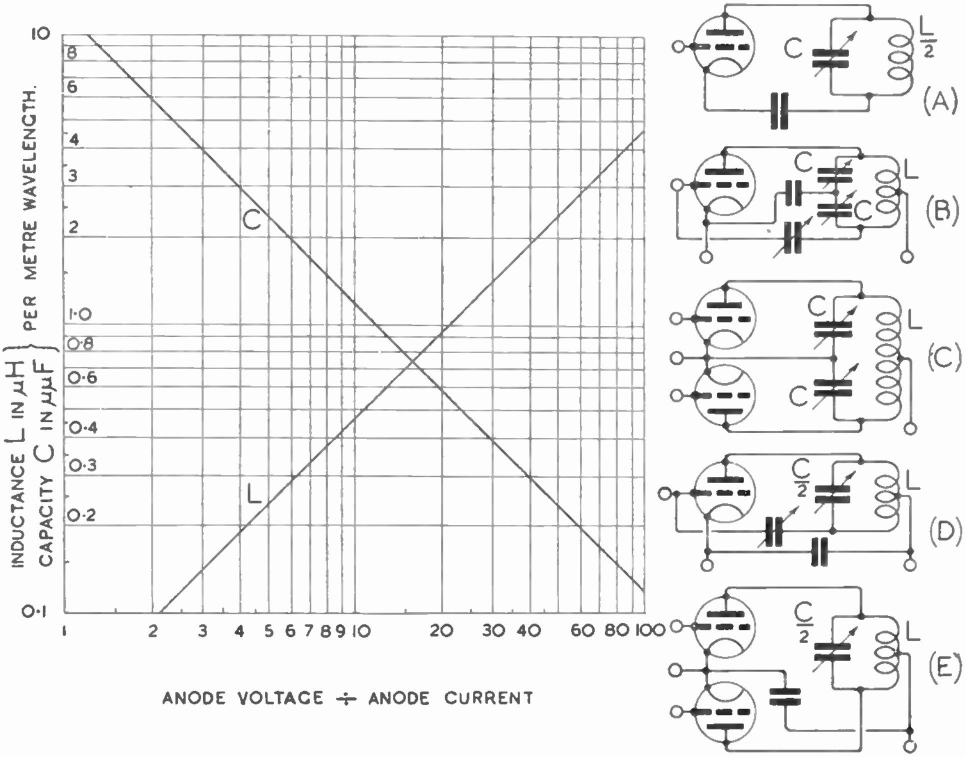


Fig. 17.

Chart giving optimum L/C ratios for P.A. anode circuits, in terms of the ratio of H.T. voltage to current taken on full load. The current value to be used is that of one valve only, i.e., half the total in the case of a push-pull stage. Five skeleton P.A. circuits are shown. The value of L given by the chart must be halved for circuit (A) and the capacity halved for (D) and (E). C in (B) and (C) refers to one section of a split-stator condenser: L and C are given in μH and $\mu\mu$F per metre, i.e., if the P.A. operates on 14 Mc. (21 metres) the chart values must be multiplied by 21. See text for further details.

reach 150 mA, and so the load is more likely to be about 3,000 ohms. This is the anode load, since the valve passes to practically zero impedance at the tips of the pulses.

To operate with a Q of, say 12, the reactance of the anode coil must be one-twelfth of the load resistance, that is, about 250 ohms in the case quoted, and when this is known, the actual values of inductance and capacity can be found from the formulae given in Chapter 1.

The chart of Fig. 17 has been drawn to simplify the determination of this important L/C ratio, and gives the values of inductance and capacity in terms of the " D.C. impedance," or ratio of H.T. voltage to steady anode current, and is calculated for Class C operation of any type of valve, with a peak current of between two and three times the steady D.C., and an anode efficiency of about 70 per cent.

The values given in the chart must be multiplied by the operating wavelength in metres, and must also be doubled or halved, according to the circuit information attached to the chart. The chart may also be used as a guide to suitable values for the anode circuit of a frequency multiplier.

As an example, the *Standard Telephones* 4061A pentode is a 25 watt valve, rated at about 500 volts with 50 mA on load when biased to twice cut-off and suitably driven. For these figures the chart gives $1 \cdot 2$ μμF per metre and $0 \cdot 47$ μH per metre. Since this valve may be used without neutralising connections in a suitable layout, circuit (A) may be chosen, whence one obtains, for 14 Mc (21 metres) $21 \times 1 \cdot 2 = 25$ μμF for the anode tank capacity, and $21 \times \frac{1}{2} \times 0 \cdot 47 = 5 \cdot 0$ μH for the coil inductance. The capacity figure, of course, includes the anode/earth capacity and stray capacity of the coil, etc., and so a variable condenser reaching 25 μμF max. would be in order. A suitable size and number of turns for the coil may be obtained from the Chart in Chapter 24. When the valve is set up with this size of coil the current, off load, is likely to be about 10 mA, but assuming screen voltage, drive, etc., are correct, then the optimum output occurs when the load pulls the anode current to the design figure of 50 mA. This represents an input of 25 watts and since the chart represents an efficiency of about 70 per cent., the actual output is 17·5 watts, of which perhaps, one watt may be lost in the components. Under these conditions, increasing the coupling of the load will increase the anode current, but probably not the output, consequently the figure of 50 mA at resonance should not be exceeded. It will be seen from this that the chart also acts as a guide to the correct point to which the feed of the valve should be drawn.

On ultra-short waves, it may be found for many types of valve that the L/C ratio given by the chart cannot be obtained in practice because the capacity value comes lower than the anode/earth capacity of the valve, *i.e.* the coil given will not " tune down " to the wavelength. This means that the valve will not work to full efficiency at such a high frequency. Great care must always be taken not to overheat the valve anode. The 807 and KT8 types, which require high current at low voltage on the anode, and which have low output capacities, can be run correctly at frequencies of the order of 60 Mc. An examination of the characteristics of this class of valve shows what is required in the design of ultra-high frequency equipment. Briefly these features are low impedance, and correspondingly high cathode emission, together with low output capacity.

Tuning Power Amplifier or Doubler Stages

The grid is first biased to cut-off, and starting with reduced H.T. the grid circuit is tuned. The drive must be enough to increase the feed to 50 mA at least in the case of a 10-watt stage. Tuning the anode to resonance without load should cause a drop to well below 10 mA, after the manner of Fig. 10. An artificial aerial should then be coupled and tuned for maximum output, which, in the case quoted, will be about 30 mA.

If the anode tuning under load does not exhibit the flatness of a low-Q circuit then it is fairly certain that an increase in coil size will improve output. If it will not draw well as the load is coupled then, if there is no lack of drive, it is possible that the coil is too big, although this condition is not likely to occur above 7 Mc where capacity is usually the limitation. Fig. 17 should be consulted as a check.

The adjustment for a doubler stage is much the same, except that the flatness of tuning and dip on resonance are not so marked. The frequency of the output should be checked with an absorption wavemeter.

In the case of an amplifier it is essential to ensure that the stage is correctly neutralised before testing for efficiency. Adjustments for maximum efficiency or maximum output should then be made by finding the correct driving conditions. This is done by adjustment of drive coupling, and variation of battery bias taps or gridleak value.

The resulting output should be listened to critically for note and general quality with the aid of a monitor ; in fact this should be done earlier if there is any suspicion of abnormal behaviour.

Reduction of Harmonics

Any high efficiency power amplifier must of necessity generate considerable harmonic power, but it is very desirable that this should not be allowed to radiate. An inspection of the relationship between the various amateur bands will show that harmonics of some permitted frequencies do not necessarily fall in authorised bands, and even if they do, they can cause unnecessary interference with other stations. In particular, the 3rd, 5th, 6th, etc., are far removed from amateur frequencies ; the third harmonics of the 14 Mc band, for example, can spoil local television reception near London.

There are three simple ways in which the effect can be reduced. Firstly, by the choice of circuit and component values so that harmonic power does not develop in the transmitter. Secondly, by the use of an earthed screen between the P.A. and aerial coils. Thirdly, by the use of a suitable aerial coupling which only passes the required frequency. In addition, with cases of serious trouble, harmonic filters may be employed in the P.A. or in the aerial feeder. The transmitter aspect is considered here, the aerial aspect being treated in Chapter 12.

L/C ratio in the P.A. has already been shown as a choice between harmonics and efficiency, and the values given in Fig. 17 represent a good com-

World Radio History

promise. Increase of inductance beyond these values results in very little improvement of output, but a rapid increase in harmonic content, as there is insufficient capacity to by-pass the harmonics. In cases of interference, a small decrease in L/C ratio may be very helpful; on the other hand, radiation may occur from the earlier stages of the transmitter, but a clean layout, with each stage a compact and separate unit and well decoupled, will minimise this difficulty.

The absence of all "even order" harmonics from a balanced push-pull amplifier is another point in favour of this type of circuit.

In severe cases the methods of adjustment shown in Fig. 18 may help; the upper for single-ended stages, the lower for push-pull. It will be seen that the anodes are tapped down from the top of the tank circuit, the correct point usually being about one-third of the way from the top to the "earthy" point of the coil. This may be regarded as a means of providing a series resonant circuit of low impedance to earth for a particular harmonic, but a high impedance for the fundamental. One particular harmonic may be dealt with in this way, and it is usually the third which is most troublesome. The tap may be adjusted by listening at a distance to the offending harmonic, after first making sure that it really comes from the P.A. and not from some previous stage.

Listening tests should be made away from the transmitter room, and a check should again be made, by switching off the P.A., to ensure that the trouble is not due to radiation from an earlier stage. When dealing with ultra-short wave interference, it may be found that R.F. energy is feeding into the mains, and chokes of a few feet of wire, suitably coiled, may be inserted in the mains lead to cure this trouble.

Other methods are discussed in Chapter 10.

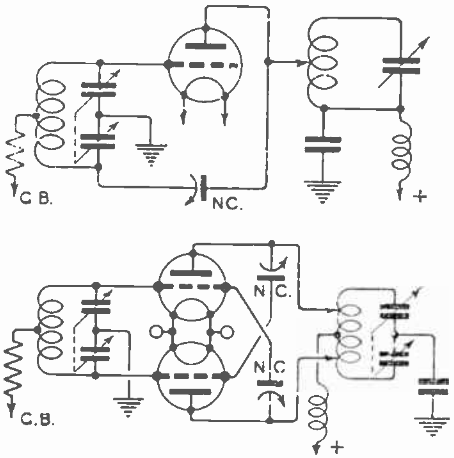


Fig. 18.

Harmonic suppression circuits. The upper diagram shows a single ended circuit and the bottom diagram a push-pull circuit. In the former arrangement, grid neutralisation is essential.

Use of Electrostatic Screen

When more than one harmonic is involved, an electrostatic screen may be interposed between the anode coil and the aerial tank circuit. This may consist of a small frame of wood or other such material, about three times the width of the anode coil, across which are strung a number of wires separated by about half an inch, and connected together at *one end only*, the whole being earthed to a suitable earth point which must be found by experiment.

Interstage Couplings

Several methods of coupling an oscillator to a subsequent stage are available. For example the grid following the oscillator can be tapped through a condenser into the oscillator anode coil. But this is not usual, except in the first stages where plenty of drive is available. In the power stages where all possible drive is required, two inductively coupled circuits are used. The direct tap leads to trouble because part of each anode circuit capacity is in the next stage, and the current branching into this must return down the common earth line. The result is that interstage coupling occurs, which may react on the stability or tone of the signal. It also leads to unbalance when stepping from a single-ended to a push-pull stage.

Link Coupling

Plain inductive coupling between pairs of circuits has the disadvantage that movable coils are needed for adjustment of coupling, making the construction complicated. By introducing an auxiliary circuit to do the coupling, this disadvantage is overcome. Such an arrangement, known as "link coupling," is illustrated in the transmitter circuit Fig. 21, where it transfers the output of V_2 from the coil L_3 to the grid coil L_4 of the pentode amplifier stage. The flexible connection in the link circuit acts as a type of transmission line. (See Chapter 12.) The energy in L_3 is stepped down to a low impedance by means of the small pickup coil; in other words, it passes down the connecting link at low voltage and high current so as to minimise loss, and by the inverse process it is stepped up again into L_4. The coupling coils are usually a few turns placed round or near the "earthy" part of the coil, and the link is usually twin flex or concentric screened cable. Adjustment is made by the number and position of the turns. Suitable turns are one for 28 Mc. one or two for 14 Mc, and three for 7 Mc. The couplings can slide on and off the ends of the coils, or if the coils are self-supporting they may slide in and out between the end turns. If there is H.T. potential on the coil the coupler can be insulated by high-grade sleeving.

The link may be of any length, although if more than a few feet is used it should be built and adjusted as a proper transmission line, first by terminating the far end with the correct resistance and adjusting the sending end for maximum output, and then by replacing the resistance by the input circuit and adjusting this end. The behaviour of transmission lines is explained in detail in Chapter 12, but it may be noted here that the value of the resistance will be about 60 to 100 ohms for concentric lines, and between 100 and 150 ohms for

World Radio History

twin lighting flex. Except in the case of the aerial coupling link, the power to be absorbed will not exceed a few watts, and the test resistance may therefore consist of one or more composition resistors making up approximately the required resistance value. When more than one is used, they should be in parallel, and it is important to see that they are *non-inductive*, (*i.e.*, not wire wound), but composition, as for example *Dubilier* type F, or *Eire*.

The link couplers are placed at the "earthy" part of the coils to prevent the undesirable transfer of energy by capacity as well as inductance; in fact it is good practice to earth the link at some point. Coupling can be adjusted by sliding one of the link coils.

Link coupling offers the great advantage that each stage of the transmitter becomes a distinct and separate unit, and feedback troubles are reduced. If desired, the drive unit, or the P.A. can be several feet away from the rest of the apparatus, allowing much greater flexibility of layout. Then again, the links can be brought out to ordinary plugs and jacks, so that any individual stage can be removed on to the bench for adjustment. By taking R.F. drive from any part of the circuit, new circuits can be tried on a separate assembly, without dismantling the transmitter.

The separation of stages by this means is not merely a convenience to suit circumstances, but is a definite technical advantage as one of the finest aids to the suppression of undesirable emissions, such as key-clicks and spurious notes. Separation is worth any amount of screening, and helps to reduce stray coupling with consequent instability.

Aerial Coupling

In general this is a function of the aerial, and is considered in the Chapter dealing with them. Broadly, it consists of some means of transferring the power from the high impedance of the anode circuit to whatever impedance the aerial presents, and is usually some form of tuned transformer. There is everything in favour of a link coupling between the anode and the aerial network, though probably the simplest way is to bring the aerial or aerial feeder to a resonant condition and couple its tuning coil to the anode with variable coupling. The aerial should damp the tuning circuit to flat resonance, though if it overdamps it, it may not be possible to draw any power from the anode circuit. A popular method is to tap the aerial or feeder directly into the anode circuit, but this is very poor practice. Apart from the danger of having H.T. voltage on the aerial, it is the surest way to trouble, as it allows everything in the transmitter to radiate, such as key-clicks and harmonics, thereby causing interference in local receivers. It also upsets the earthing arrangements, often allowing R.F. energy to flow back into the mains.

A point to note is that the presence of the aerial circuit may disturb the neutralising adjustment, and it is advisable to check it after the aerial is coupled. This effect does not occur with link coupling.

Adjusting the Aerial Link

Technically there is everything in favour of the link type of coupling, but as its behaviour is more complicated than the other types, results may be very puzzling until its operation is understood. It will therefore be described in some detail, with particular reference to aerial coupling. Fig. 19 gives a simple summary of the method of adjustment. First the aerial tuning network should be adjusted so that it tunes correctly and can be made to take a load on the transmitter. If it cannot conveniently be brought up to the transmitter, a low power battery oscillator of correct frequency may be used instead. The exact details are within the province of Aerials, and are dealt with in that Chapter, but once the aerial network has been tuned it should be left set, and changes made only in the couplings at the ends of the link.

The output tank circuit is tuned for minimum feed to the valve, and the coupling at both ends of the link gradually increased until the P.A. is fully loaded; the final criterion being of course the ratio of aerial or feeder current to current taken by the anode. It is important not to exceed the anode current which gives maximum aerial current, that

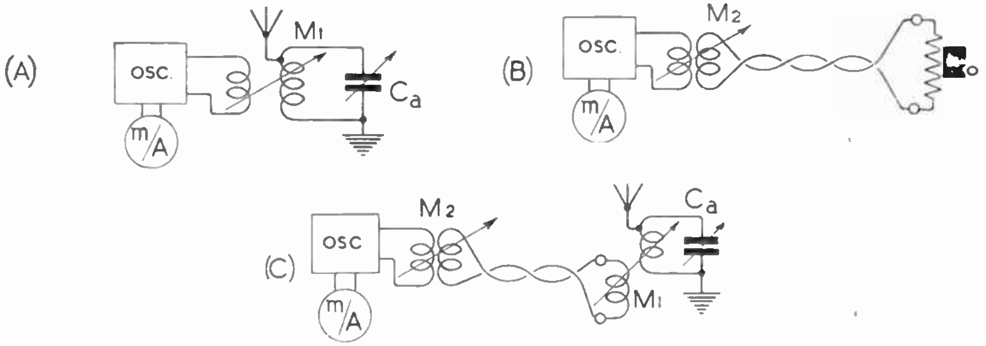


Fig. 19.

Adjustment of link couplings, or transmission lines.
(A) Set frequency : Adjust C_a and coupling M_1, to tune the aerial.
(B) Terminate with R_0 : adjust M_2 for convenient load. Note feed current.
(C) Leave C_a, M_2, and adjust M_1 to repeat feed current of (B).
Transfer M_2 to main transmitter if necessary and adjust for correct loading.
For short links step (B) may be omitted and M_1M_2 adjusted simultaneously, leaving setting of C_a alone.

is, the feed at which the artificial aerial has shown maximum output. Such over-coupling not only overloads the valve, but also has a detrimental effect on the aerial performance.

In order that the introduction of the link coils shall not affect the tuning of their respective circuits, due care must be taken to see that it is a true inductive coupling and not due to capacity. For this, the link must be applied at the "cold" parts of the coils, *i.e.* at the "earthy" end in the case of single-ended circuits (single valve amplifiers, or single wire aerial feeders) or at the centre in balanced circuits (push-pull P.A. or twin aerial feeders). The link is the very best way of changing from one type to the other provided the above points are kept in mind.

If, in the adjustment of the link coupling, retuning is attempted, confusion may result, as it is very different from the easier types of coupling in this respect.

When the aerial is coupled to the transmitter in a simple manner the feed rises in sympathy with the tuning of the aerial network, whilst retuning of the anode tank produces a dip at the correct tuning point though of less magnitude than when free. Detuning of the aerial results in a drop in feed current.

In the link circuit, the behaviour at the anode end remains as before, but the effect of detuning the aerial is usually exactly opposite; *i.e.* bringing the aerial into tune drops the anode feed to the loaded minimum. This is because there is no resistive load at the end of the line until the aerial is tuned (the coupling determines the value of the resistive load). The unloaded line can then only load reactance into the tank circuit, which is equivalent to detuning the tank, and so the feed rises to the untuned value.

When the link to the aerial is very long (for example, in another room) if may be necessary to adopt other methods. The anode feed meter may be brought up to the aerial point on a long flex, taking care to keep it well away from the link line, or it may be necessary to effect the resistance termination first as already described under "Link Coupling." As it will not be easy to find a non-inductive resistor capable of dissipating the output of the transmitter, the low power battery oscillator may be used for this part of the work. The aerial is first coupled to the oscillator and then tuned up to load it. The oscillator is then taken to the far end of the line, and the aerial end is resistance terminated as before. The oscillator is then loaded up from the link, after which the terminating resistor is replaced by the coupling coil which is applied to the aerial network until the meter reading on the oscillator is correctly reproduced. The sending end may then be applied to the transmitter proper until a suitable load is taken.

The procedure outlined may appear rather complicated, but the first method described will usually suffice, and the extra trouble involved in getting a link to work is well worth the smooth transmitter operation which it brings. The aerial has been chosen as the most difficult case, but the general method of operation and adjustment given is equally applicable to interstage couplings in the transmitter.

ACCESSORIES

Power Supplies

The design of anode power supplies is considered in Chapter 9. For a small two-stage transmitter a single H.T. supply can be used, but with more stages it is usual to have at least two, one for the driver unit and the other for the P.A. stage. If a self-excited non-crystal oscillator is used, its power supplies should be well separated from an R.F. point of view, and should be very pure, heavy low-frequency decoupling or smoothing being used. Remember that keying or modulation of the final stages is liable to react seriously on the voltage of the H.T. supplies unless the power pack is separate, or has a heavy bleeder resistor, and this may result in chirp, or objectionable frequency modulation.

Grid Bias

There are many methods of obtaining bias for the various stages. The first is, of course, from batteries, but as several hundred volts may be required this is not very convenient or economical. Another method is to use gridleaks. This is quite satisfactory for the early stages where the valves are not liable to come to much harm if the bias is removed, but in the final stages it is important to note that if the drive stops so does the bias. Consequently if the valve is operating at high voltage it will be damaged. The gridleak method has the great advantage that the valve automatically adjusts itself to suit varying drive conditions.

A third method is automatic bias, obtained from the voltage drop due to the plate current passing through a cathode resistor, which is shunted for R.F., as for example, R_5, C_{13} in Fig. 16. Automatic bias is not easy to arrange unless a separately heated cathode is used, but this is often possible in the drive unit. In the P.A. stage, where bias to twice cut-off is needed, it results in much of the H.T. being used for bias, and makes adjustment difficult, because when the plate current drops to zero there is no bias. It is, however, always a safe method for pentodes, and can be recommended. The resistor should be of sufficient wattage to stand the power which it is required to dissipate.

Fourthly, a power pack may be used for bias. This should have a heavy load resistor across it, liberally tapped, and each tap or lead should have a 1 μF condenser between it and earth. The steady load should be at least three times the total grid current.

Probably the best arrangement is to use sufficient battery or power bias to give cut-off conditions, together with a 10,000 to 20,000 ohm gridleak in each grid return. This will provide the extra bias required under full drive conditions. When switching on the transmitter it is as well to see that the bias voltage comes on before the H.T.

All the various methods of bias supply are well illustrated in the diagrams chosen, as well as a good selection of cathode connections, which may be used at will.

Components

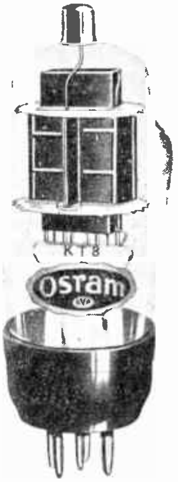
In the drive stages, ordinary receiving components can be employed, although they should be of good quality. Coils may be simple and wound

World Radio History

on ordinary good formers. Plug-in types can be used where flexibility is needed, as, for example, the *Eddystone* formers. The *Eddystone* range of small variable condensers also helps to make the layout compact. When selecting condensers, note that quantity of dielectric matters as well as quality. For example, bakelite end-plates are not recommended. Condensers and coils using ceramic insulation are now available, and these are usually very good.

Resistances should be of sufficient rating. In gridleak circuits a safe figure for triodes is 10 per cent. of the anode power of the valve concerned, but for pentodes a 1-watt leak will be sufficient for nearly all cases.

Fixed condensers must be able to withstand the voltages applied across them, and if R.F. currents of any magnitude are passed, this must be considered as an additional requirement in performance.



The Osram KT8 is a screen radio frequency transmitting tetrode rated at 25 watts anode dissipation. The valve has an indirectly heated cathode aligned grids and beam confining plates.

Decoupling and blocking condensers should have a " D.C. test " figure of at least twice the voltage to which they are connected, and four times the working voltage in amplifiers carrying telephony modulated currents. Substantial life can only be assured in this way, for even a momentary overload may cause permanent damage, soon followed by a breakdown of the insulation. All condensers carrying, or decoupling, R.F. currents should have mica insulation. Paper types are not usually designed to withstand the extra strain, whilst the impedance is not sufficiently low.

In the final stage, where the utmost efficiency is needed, the anode components, at least, must be as near perfect as possible. The variable condenser for example is called upon to withstand high R.F. voltages, and should have large spacing between vanes. Very often a receiving type can be dissected and rebuilt with two plates and two washers at a time, giving double spacing and a quarter of the original capacity. In this operation it is essential to see that all spacing washers and plates are clean and bright, as a few dirty contacts may completely " kill " the R.F. in the circuit tuned by the condenser.

The P.A. anode tank coil should be of larger girth than the others, say 3" diameter, and composed of heavy wire or tubing, so as to give plenty of surface and very low H.F. resistance. It should be bolted straight on the tuning condenser, or joined with similar conductor or copper strip.

Neutralising condensers should be of the highest possible quality, as they must withstand more D.C. and R.F. voltage than any other part. Specially designed condensers are available from several manufacturers.

In P.A. circuits where voltages of 1,000 or more are encountered, steps must be taken to avoid " flash over," particularly in modulated transmitters. This may occur between sharp points or edges where the gap is too small, and is followed by an arc which can only be removed by switching off the power. The most common place is between the plates of the variable condenser in the anode tank circuit which may flash each time the modulation exceeds a certain value. Dust between the plates, or sharp edges, encourage this effect, and it is advisable to choose a condenser with adequate spacing between plates. Other parts of the P.A. stage should be considered in the same way.

Meters and Jacks

Meters represent an expensive part of a transmitter, and it is desirable to keep down the number if possible. One milliammeter is absolutely essential and two very desirable, and these can be arranged to measure all feed and grid currents. A 0/50 or 0/100 mA is most useful with a 0/10 mA type for grid currents. The meter can be arranged with a plug, and telephone jacks fitted in all circuits, as in Fig. 16. Self-closing jacks must be used and the preferred method of connection, parallels the closing contacts (see Fig. 16) by cross connection. In this way the circuit is not broken when inserting or withdrawing the plug, thus avoiding arcing at the contacts. There is no reason why a low reading meter should not be used with the appropriate shunt across each jack, the multiplying factors being marked over the jacks.

COMPLETE TRANSMITTERS

Layout and Construction

There is no best method of design, and transmitters are often built to suit the geometry of the radio room (the method of link coupling helps to make this possible), but certain points are worth bearing in mind. Each stage of the transmitter should, as far as possible, be a separate unit, although the whole may be on one base. All parts should be as accessible as possible, but the H.T. circuits should not be exposed so as to allow accidental contact. An ideal design would thus be housed in some form of frame or case which can be thrown well open for adjustments other than normal.

The simplest and cheapest style is the baseboard or " breadboard " layout, where the various stages are assembled in a row along a wooden base. A front panel is not essential and all controls can be mounted on brackets or plates screwed to the front edge. A hollow shallow box type of base allows all the supply wiring to be concealed and meters

World Radio History

and meter jack points can be mounted in the shallow front edge. This style allows easy access to all adjustable parts, and so is very suitable for experimental work; also part or all of the transmitter can be rebuilt as desired, without spoiling its appearance.

Alternatively, each stage can be built on a separate base, say 15″ × 9″ with or without front panel, the service wiring and link couplings being taken *via* terminal strips at the rear. These units may be set in a row for experiment, and later, when it is desired to establish the design more permanently, they can if necessary be fitted with new fronts and mounted in a vertical frame. The disadvantages of open layouts are (1) high voltage points are easily reached by accident, (2) it is very difficult to keep them clean. The rack and panel construction is somewhat better in this latter respect.

Rack and Panel Construction

The frame can consist of two uprights of angle iron or well seasoned 3″ × 2″ wood, securely braced to a short foot extending six inches forward and about a foot to the rear. These are then set a suitable distance apart with top and bottom rails, a good width being 20″. The panels, with baseboards attached, are then made up to a uniform height, standardised for interchangeability, and screwed to the front of the frame, rails or brackets being fitted to the frame to support the weight. The power decks, being heaviest, are mounted at the bottom and given extra support at the rear.

Sometimes the frame is made like a skeleton box with extra uprights at the rear. Front to back slide rails can then be fitted for the decks and hinged or detachable doors assembled at the sides and back. This box frame construction is much cleaner and smarter than the open styles, and yet can be made nearly as accessible. If the design of the transmitter is more or less established, the front panel can be in one piece and the decks mounted separately in the frame. The *Eddystone* rack is of this type.

The ideal for a fixed type of design is, of course, a steel cabinet, but this is expensive unless it is possible to acquire one of the commercial cabinets or amplifiers which are sometimes offered in the second-hand market.

If wood is to be used, it should be thoroughly seasoned, and much trouble will be saved if the plan is adopted of always giving the decks and panels a covering of thin aluminium, and making all common earth connections direct to this material. A metal veneer has two advantages; firstly, the earth impedances are low, which helps stability; secondly, the electrostatic field from all parts of the apparatus to earth absorbs less power if it is not required to pass through a mass of dielectric, such as wood, or other insulating materials. A metal covered plywood of this type is marketed under the trade name *Plymax.*

In the same way, the magnetic field of a coil wastes power in adjacent large metal objects, and to avoid loss the coils should not be nearer to such objects than one diameter.

The power supplies should be kept separate from the R.F. circuits, and the feed wires brought up in a neat cable form to the various stages and not allowed to wander indiscriminately through the circuits. The power switching should be so arranged that no H.T. can be applied until after the bias and filaments have been switched on. If a separate filament transformer is used then the mains to the H.T. transformer can be looped through the filament switch and then again switched. If one transformer is used for all supplies, then an extra well insulated switch should be included in the centre tap of the H.T. winding.

It is advisable to arrange the switching so that all filaments are permanently on whilst the station is in operation. This "idling" helps to lengthen valve life, because switching on H.T. and filaments simultaneously is extremely detrimental.

A 1.7–3.5 Mc. Transmitter.

The circuit illustrated in Fig. 20 is that of a transmitter which was designed primarily for the 1·7 and 3·5 Mc bands and frequencies between. The rear view of the R.F. unit is shown in the photograph on page 109. This transmitter employs a CO-PA circuit, using a pair of beam tetrodes of the 10-watt class. The P.A. stage, with a supply voltage of 500, can be loaded to 25 watts, but since the amateur permit never normally exceeds 10 watts on 1·7 Mc, the H.T. must be reduced when working on this band: for this purpose a resistance R_2 is included in the power unit, which may be shorted by the switch S_2 when the higher power is permissible. Frequency is varied by changing plug-in crystals and retuning, the crystal frequency being the same as that of the outgoing signals.

The grid bias in each stage is automatic, and uses a combination of cathode resistance and gridleak. The keying is effected in the cathode return of the crystal oscillator stage, and it will be noted that a filter C_5R_{11} has been included to overcome key-clicks. Smooth starting and stopping of oscillation, without chirp, has been obtained by a suitable choice of components. Also, the use of automatic bias in the P.A. allows it to pass some current when not driven, and this, by stabilising the power supply also helps to give smooth keying. The keying lead may be any reasonable length without the use of relays, but in such a case it might be necessary to place the keying filter at the key end of the leads. It will be observed that, since the crystal stage is not oscillating when the key is up, the receiver can be operated normally in such intervals: in other words the transmitter may be used for "break-in" working which means that the operators at each end of the circuit can interrupt each other as necessary.

The anode coils are both tapped, that on the anode coil of V_2 being adjusted to give suitable drive to V_3, without loading the C.O. stage too heavily. The P.A. anode coil is centre-tapped to allow neutralisation of the anode-grid capacity by means of the condenser C_3. The L/C ratio of the P.A. anode circuit has been chosen according to the rules given in this Chapter, but some compromise has been necessary so that the range 1·7 to 3·5 Mc may be covered without coil changing. The variable condensers in the anode circuits may be good quality ordinary receiving types, unless telephony

World Radio History

modulation is intended, when a wider-spaced condenser will be necessary in the P.A. tank circuit, to prevent flashover.

The anode/grid capacity of the P.A. valve is very small, and the neutralising condenser C_3 will have less than 1 µµF capacity. It may consist of two small metal plates about ½" square mounted on stand-off insulators so that the air-gap is about ⅛". One plate has a slotted hole by means of which it can slide to adjust the capacity.

The coil in the anode of the C.O. stage is wound on a moulded 2" former and consists of 30 turns 20 s.w.g. enamelled wire, close wound, with a tap at 6 turns from the anode end. The P.A. tank coil is on a 3" ceramic former, and consists of 30 turns of 14 s.w.g. enamelled wire, with the H.T. tap in the centre. The aerial coupling link consists of two or three turns of the same wire. These may be spaced over the centre by Trolitul spacers, or may be mounted as a self-supporting coil on small insulators. The various components may all easily be identified in the photograph.

No aerial coupling network is shown, as it is intended to couple the aerial by means of a separate circuit and a link coupling, as already described in this Chapter. Further details will be found in the chapter dealing with aerials.

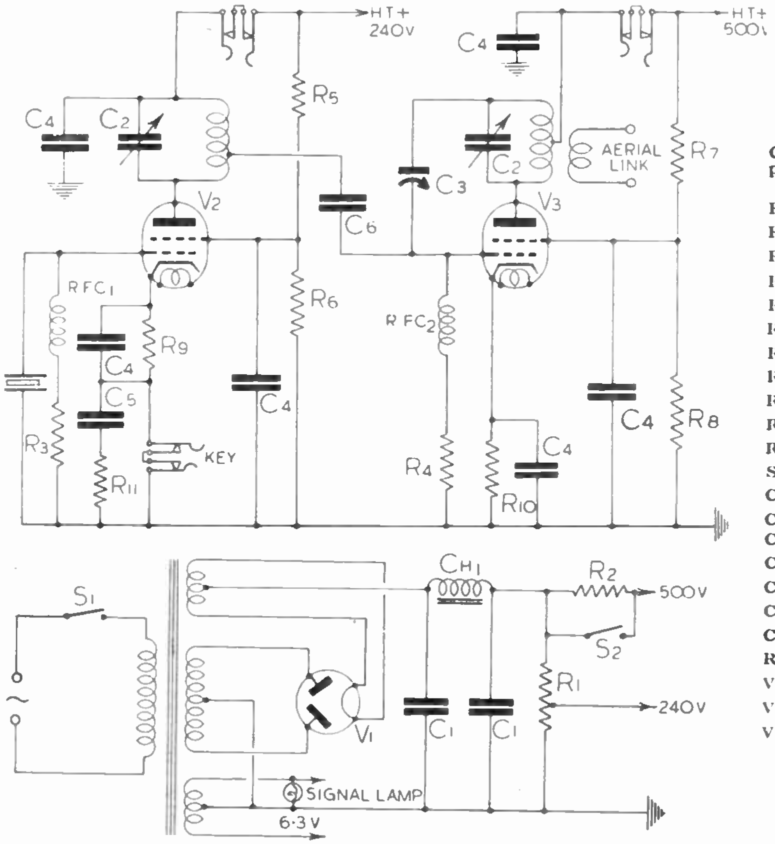


Fig. 20.

Circuit of transmitter and power supply unit for 1.7 and 3.5 Mc operation.

R_1	**25,000 ohms.**
R_2	**7,500 ohms, 20 watt.**
R_3	**50,000 ohms, 0·5 watt.**
R_4	**10,000 ohms, 1 watt.**
R_5	**7,000 ohms, 1 watt.**
R_6	**50,000 ohms, 1 watt.**
R_7	**20,000 ohms, 2 watt.**
R_8	**80,000 ohms, 2 watt.**
R_9	**300 ohms, 1 watt.**
R_{10}	**1,000 ohms, 2 watt.**
R_{11}	**500 ohms, 0·5 watt.**
S_1, S_2	**Toggle switches.**
C_1	**2 µF. Type 111 T.C.C.**
C_2	**.0005 µF.**
C_3	**See text.**
C_4	**.1 µF.**
C_5	**.1 µF. Type 341 T.C.C.**
C_6	**.001 µF.**
Ch_1	**15 H. choke.**
$RFC_{1,2}$	**H.F. choke.**
V_1	**U12/14.**
V_2	**6V6G.**
V_3	**6L6G.**

Preliminary adjustment is carried out with S_2 open. The first step is to ensure that the crystal is oscillating, and this is done with the aid of a feed meter for V_2, and a monitoring receiver, described earlier in the chapter. The next step is to neutralise the P.A. Further, a pea-lamp loop is coupled to the C.O. anode coil, and the P.A. tank is tuned through resonance, with its H.T. supply disconnected. When the neutralising condenser is correctly set there will be no flicker in the lamp as the P.A. anode tank passes through resonance. This neutralising setting will hold over a wide tuning range. The adjustment of the aerial coupling network and link circuit are then made so as to load the P.A. correctly. The P.A. anode current with no drive will be about 30 mA at 500 volts. When driven, but with no aerial link connection, the anode current should dip to a very low value, and with correct aerial load can be drawn to 50 mA or more. If meter jacks are inserted in the cathode leads, instead of in the anode supplies as shown, the tuning variations will be masked, as the cathode also passes grid and screen currents.

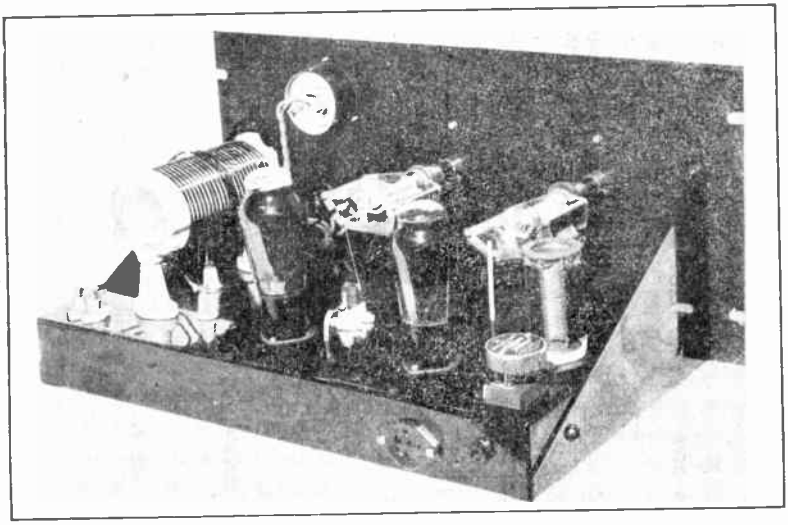
A 50-watt Three-Band Transmitter

This transmitter employs a 50-watt power amplifier—the *Standard* 4052A R.F. pentode—and

World Radio History

with a crystal oscillator followed by a frequency multiplier stage, will deliver its output on 7, 14, or 28 Mc. With slight modification 3·5 Mc operation can also be included. Interchangeable coils are used in all but the cathode circuit of the oscillator. The circuit diagram is given in Fig. 21.

The crystal oscillator circuit is of the Tritet type using a beam tetrode of the 6V6G class. The anode circuit selects the second harmonic of a 3·5 Mc or 7 Mc crystal, which may drive the P.A. either direct, or through a frequency doubler stage using another 6V6G. Fig. 22 shows how the wiring is arranged so that the frequency doubler stage is introduced or left out as necessary, when the correct coils are inserted. The following arrangements are possible :—



A Transmitter for 1.7/3.5 Mc operation. The circuit is given in Fig. 20. The C.O. is on the right of the picture and the P.A. on the left.

C.O. Stage.		Frequency Multiplier L$_3$.	Power Amplifier L$_4$, L$_5$.
Crystal.	Anode L$_2$.		
3·5 Mc	—	7 Mc	7 Mc
3·5 Mc	—	14 Mc	14 Mc
7·0 Mc	—	—	7 Mc
7·0 Mc	14 Mc	—	14 Mc
7·0 Mc	14 Mc	28 Mc	28 Mc

Output on 3·5 Mc is in some cases obtained by working the crystal as a straight Tetrode oscillator. This is effected by short-circuiting the cathode coil L$_1$. A popular way is to bend one of the plates of the condenser C$_5$ so that it is short circuited when in full mesh. For 3·5 Mc output it will be necessary to increase the tank tuning condenser by paralleling a 100 μμF air-spaced condenser, in order to provide a suitable L/C ratio.

The type 4052A valve requires a drive of about 1 watt, and is well screened internally, the anode to control grid capacity being about ·012 μμF. The input and output capacities are of the order of 10 μμF, and optimum anode L/C ratio (see Fig. 17) is possible on all frequencies up to 28 Mc.

Grid bias is obtained by a combination of grid-leak and battery bias. If preferred, a small power supply can be built for the bias, with a heavy ballast resistor incorporating a good selection of tappings.

No details of aerial coupling arrangement are shown in the circuit, as these depend to some extent on individual requirements. This subject is discussed at length in Chapter 12.

For telegraphy operation, keying is applied to the P.A. stage which may be arranged in various ways. For example : (*a*) screen circuit keying, (*b*) cathode circuit keying, (*c*) mains primary keying. All of these, with their various features are described in Chapter 7. With the anode supply of the P.A. stage set at 750 volts, the R.F. power output is about 35 watts, whilst with 1,250 volts, 80 watts output may be obtained. For telegraphy the suppressor grid of the P.A. valve is connected to 45 volts positive.

Telephony modulation can easily be applied at the suppressor grid of the P.A. valve, and for this purpose a simple three stage resistance coupled amplifier with an output of between one and two watts is sufficient. Suitable amplifiers are described at the end of Chapter 8.

It is of course necessary to reduce the standing carrier output when suppressor modulation is used, and to this end, the suppressor must be biased to — 40 volts. A simple switch may be incorporated to change the suppressor bias from the telegraphy to the telephony positions. The steady carrier output for telephony operation, using 1,250 volts anode supply is about 20 watts. Reference should be made to Chapter 7 for further details of modulation.

The layout of the transmitter is illustrated in the photographs, the valves being arranged in the same order as in the circuit diagram Fig. 21. Good

World Radio History

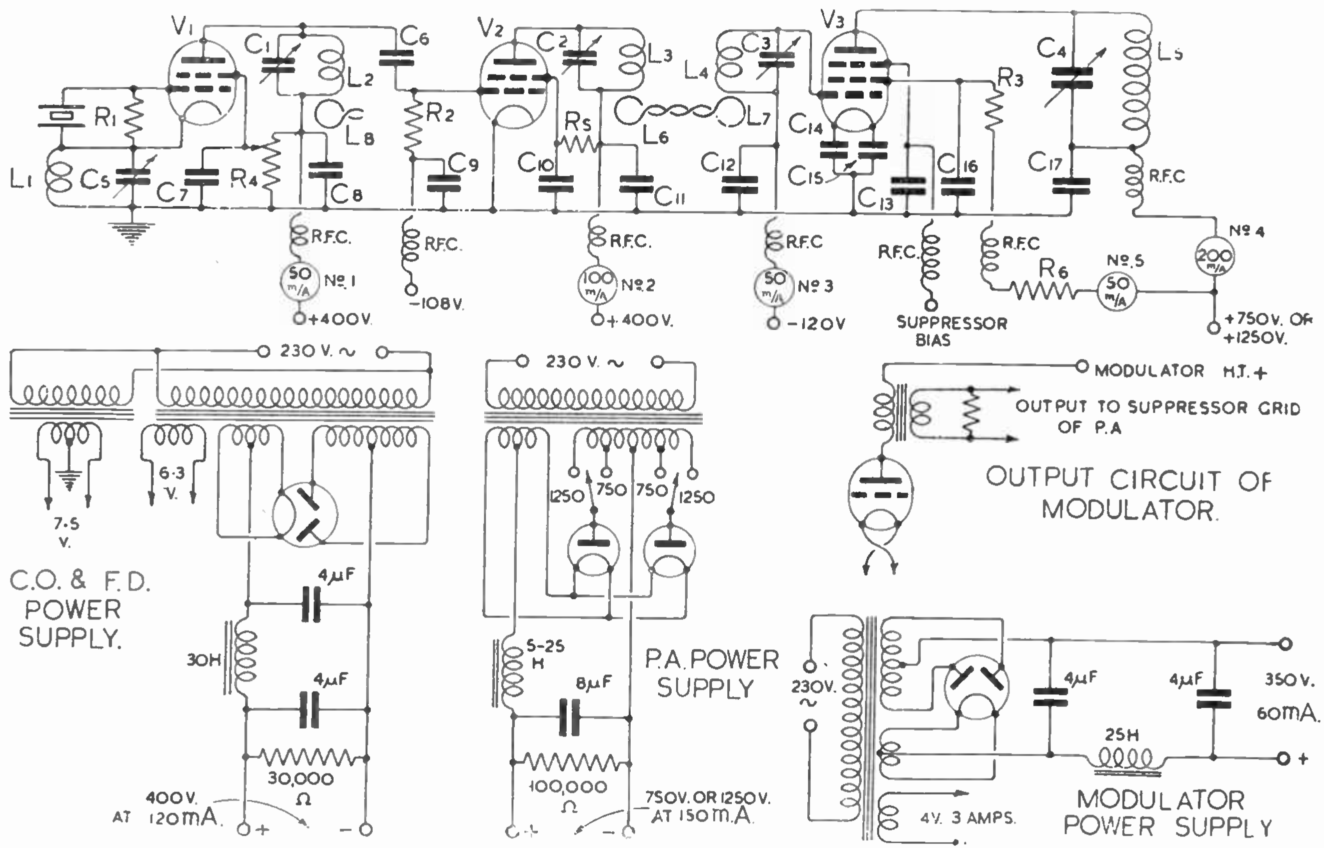


Fig. 21.
Circuit diagram of a 50-watt Transmitter, and Power Packs.

$C_{1,2,3}$	40 μμF.
C_4	50 × 50 μμF, split-stator.
C_5	100 μμF.
C_6	.0001 μF, Mica.
$C_{7\text{-}15}$	.001 μF, Mica.
C_{16}	.006 μF, Mica.
C_{17}	.002 μF, Mica, 1,500-v.

$R_{1,2}$	50,000 ohms, 1 watt.
R_3	50 ohms, 2-watts, carbon.
$R_{4,5}$	25,000 ohms, 20-watts, variable.
R_6	2-15,000 ohms, 40-watts (in series).
RFC	R.F. Chokes.
$L_{1\text{-}8}$	See tables and text.

screening is necessary between the grid and anode circuits of the P.A. stage. To achieve this result the valve is passed through a hole in a metal partition, and the grid end screened by a 2" diameter cylinder for a distance of about 2¼" up to the base of the screen inside the valve. This screen can be arranged to support the valveholder, and can conveniently be made from a coil screen.

It should be remembered that although R.F. pentodes are internally screened there is no neutralising circuit to compensate for stray couplings, hence the need for effective external screening.

The cabinet for the transmitter is made of a suitable non-ferrous metal, but the cupboard below, which houses the power supplies and modulator, is of steel.

The cathode coil of the C.O. stage contains 10 turns of 20 s.w.g. enamelled wire on a 1" diameter paxolin tube. The plug in coils for the doubler and drive circuits are wound on 6-pin formers which are about 2" diameter and threaded 14 turns per inch. The tank coils for the P.A. are wound on frequentite formers. Suitable windings are as follows :—

Crystal	L_2	L_3	L_4	L_5	Output
3·5 Mc	34	18	18	17	7 Mc
7·0 Mc	18	9*	9*	9*	14 Mc
7·0 Mc	9*	4*	3*	3*	28 Mc

* Double-spaced.

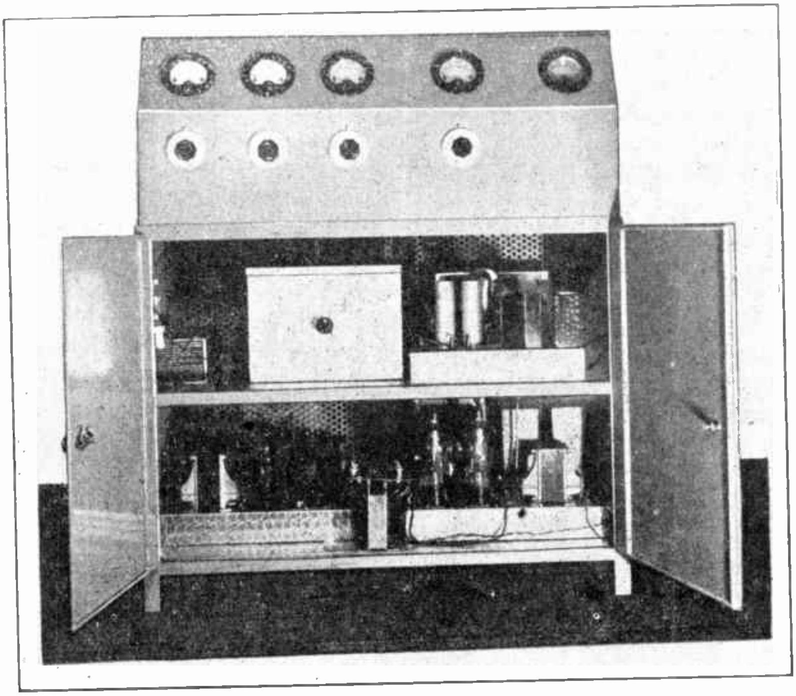
All coils except L_1 and L_5 (the P.A. plate tank) are wound 14 threads per inch and link windings (L_6, L_7, L_8, L_9) are 1½ turns. All coils are wound with 20 s.w.g. enamelled wire, except the P.A. tank coils, which are wound with 14 s.w.g. bare copper.

The power supplies necessary are as follows :—

For the drive unit, a transformer giving 400–0–400 volts at 120 mA for the H.T., together with 4 volts 2 amps for a MU14 rectifier, and 6·3 volts 2 amps for the small valves and 7·5 volts 3 amps for the P.A. With a 30 henry 150 mA choke and two 4μF condensers a sufficient supply at about 400 volts D.C. can be obtained. The power supply for the P.A. is of the choke-input type using mercury-vapour rectifiers. The mains H.T. transformer delivers 1,250–0–1,250 volts at 150 mA and has taps for 750–0–750 volts. It is best to provide a separate transformer giving 4 volts at 10 amps, centre tapped, for the mercury rectifier filament, since these must be run up before the H.T. voltage.

A photograph of the power pack used for this transmitter is included in Chapter 9.

The tuning up is carried out stage by stage, starting at the Tritet and working towards the aerial circuit. The adjustment of the crystal stage is as already described under the headings " Crystal Control " and " The Tritet," whilst the other stages are tuned by the " dip and draw " method described in the appropriate section of this Chapter. Using voltages as given in Fig. 21, the anode current of the C.O. stage will be 25 to 40 mA



The 50-watt transmitter with its power supplies and modulator equipment housed in a steel cabinet.

according to the condition of the circuit, the doubler should drive to 40 mA or more, but pull down considerably when tuned on the lower frequencies. The power amplifier conditions for c.w. are grid current 10 mA, screen current 35 mA and anode current (fully loaded at 1,250 volts) 90 mA.

For telephony modulation the suppressor bias must be adjusted carefully so that the aerial current is half the optimum c.w. value, and the grid current should not exceed 7 mA. The latter may be adjusted by varying the bias or tuning on the doubler stage.

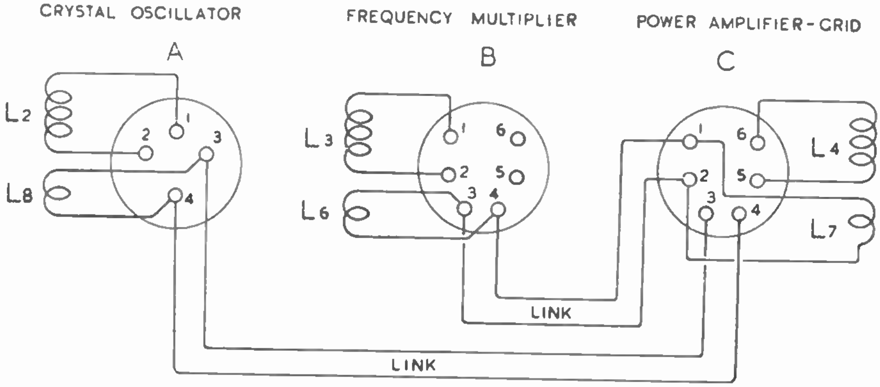


Fig. 22.
Three-Band 50 Watts Transmitter.
Method of Link Coupling when Frequency Multiplier is in use. When the transmitter is operated direct from the C.O. stage a coil is used in position C, which has the link winding connected to Pins 3 and 4 instead of 1 and 2, as shown above.

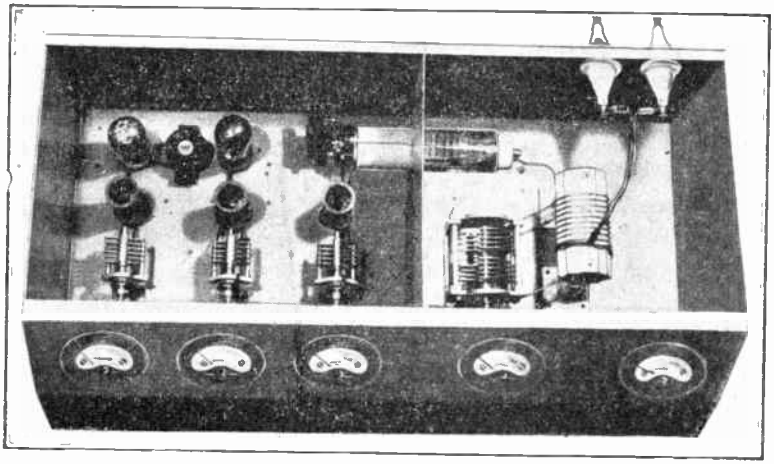
A Compact High Power Unit

Fig. 23 shows a complete high power design built on a metal panel and chassis to fit into a rack. The circuit comprises a C.O. to the right, pentode doubler in centre, and a high power triode output stage. A metal 6L6 valve is shown in the C.O. position. In a compact layout such as this, it is, of course, essential to frequency double in each of the first two stages; the C.O. is therefore a Tritet circuit.

The anode circuit of the P.A. uses a split-stator variable condenser, which is mounted in such a manner as to allow a short lead to the top anode connection of the valve. It should be noted that this lead is made of strip in order to prevent parasitic oscillations. The support for the condenser is used to isolate from the rest of the circuit the choke feeding anode current to the centre tap of the coil. The coil is raised above the top of the panel, so that when the unit is mounted in its rack it reaches into the aerial coupling unit above. The neutralising condenser is mounted between the grid coil and the condenser support. All supply wiring, decoupling, etc., is below, and all R.F. circuits above the chassis.

A 100-Watt Multi-Band Transmitter

The circuit of Fig. 16 illustrates a transmitter which will run at 100 watts input on telegraphy, or 25 watts on telephony.



Plan view of the 50-watt transmitter built to the circuit of Fig. 21. The drive unit is to the left whilst the 4052A output valve will be seen passing through the interstage screen.

The drive unit is of a type known as the " Jones Exciter " and uses two twin triode valves. V_3 is a combined crystal oscillator and doubler, whilst V_4 is a second doubler of the push-push type. This unit alone will give an output of 10 watts on any of three bands and is itself an interesting little transmitter. By switching of the link circuit, the output can be taken from any of its three stages ; the valve V_4 being out of action in some cases. The link coils are L_{10}, L_{11} and L_{12}, and these are taken to the switch S_2, whence they may go to an aerial coupler or *via* L_5 to drive the P.A. The unit can be used thus as a single C.O. or a C.O. with one or two doublers. With the aid of crystals in the 1·7, 3·5 and 7 Mc bands drive is available on any band from 1·7 to 28 Mc. Plug-in coils are used to provide the various combinations. Note that in the push-push doubler a plain step-up transformer is used in the grid circuit.

The P.A. stage is push-pull with split-stator condensers in grid and anode, which can be seen in the illustration on page 100. The method of shielding the input from the output circuit can also be seen, the valves passing through holes in the metal screen. Telephony modulation is accomplished by the application of audio-frequency voltages to the suppressor grids and for this purpose the suppressor must be biased negative to reduce the standing carrier output power as explained earlier in the chapter. For telegraphy it may be given positive voltage for maximum output, and this change is made by the switch S_1.

Jacks are shown at all points where anode or grid currents are measured, but if sufficient meters are available they may of course be wired in permanently.

Valve Tables

Table I gives details of certain valves frequently used in amateur transmitters but reference should be made to Chapter 2 for further details.

Coil Tables

An accurate specification cannot be given for each case, for the reason that valve capacities, etc., vary considerably, but the following information may be used as a guide for initial experiments, after which better values may be found by trial. Fig. 17 should also be consulted.

TABLE I

Basic details of some transmitting valves.

Maker.	Type No.	Class.	Watts output.	Approx. drive watts.	U.S.A. equivalent.
Mullard	TZ05–20	Triode	21	2·4	—
	TY1–50*	,,	75	5·0	—
	PV05–15† PZ05–15	Pentode	20	0·2	—
	PZ1–35	,,	40	1·0	—
	PV1–35†	,,	75	1·5	—
Ediswan	ESW 20	Triode	40	5·0	T20
Standard Telephones	4304B*	Triode	85	5·0	304B
	4316A*	,,	6	1·5	316A
	4305A*	Tetrode	85	5·0	305A
	4061A†	Pentode	24	0·5	RK25
	4052A	,,	50	1·0	RK20
	4069A	,,	160	1·8	RK28
	4307A*	,,	20	1·5	307A
	4074*†	Twin Triode	10	1·0	RK34
Tungsram	6L6G*	Tetrode	24	2·0	6L6G
	OS12/500	Pentode	20	0·8	837
R.C.A.	807*†	Tetrode	25	0·25	—
	802†	Pentode	16	0·25–·8	—
	804	,,	80	0·9	—
Marconi Osram	DET12*	Triode	65	6·0	—
	PT 5	Pentode	90	1·0	—
	PT 7	,,	1·5	0·1	—
	KT8*†	Tetrode	37	0·5	807
	DET19*†	Twin Triode	10	1·0	RK34

* For ultra-high frequencies. † Indirectly heated cathode.

World Radio History

TABLE 2.

Triode and Pentode Crystal Oscillators Anode Circuits.

Frequency.	Variable Condenser.	Turns.	Wire and Former.
3·5 Mc	100 μμF	35	14 or 16 s.w.g. on 1½″ former.
7·0 Mc	100 μμF	11	
14·0 Mc	50 μμF	8	
28·0 Mc	50 μμF	4	

For Tritet and E.C.O. cathode coils use half the number of turns specified in Table 2, with a 300 μμF variable condenser. For the latter coils, tap the cathode about one-third from the "earthy" end of the coil.

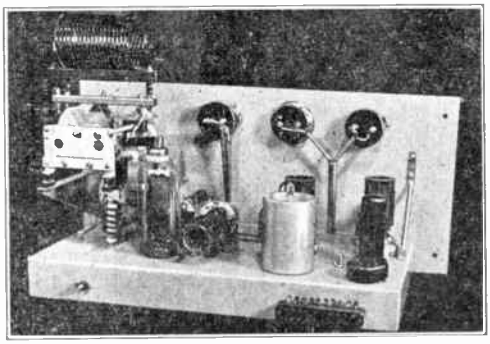


Fig. 23.
A rack unit comprising a Tritet C.O., pentode doubler, and high power output triode. Note the compact layout of the P.A. stage at the left, to allow short anode and grid leads.

TABLE 3.

Buffer and Doubler grids and anodes; Tritet or E.C.O. anodes; P.A. grids.

Frequency.	Turns.	Coil Length.	Wire and Former.
3·5 Mc	35	1½″	18 to 22 s.w.g. on 1½″ formers.
7·0 Mc	20	1″	
14·0 Mc	10	1″	
28·0 Mc	5	1″	

All coils link coupled. Variable condenser 50 μμF.

Where direct coupling is used reduce turns by 30 per cent. For split coil neutralising circuits or for push-pull circuits using 50 μμF single variable, or 100 + 100 μμF split-stator condensers, increase turns by 50 per cent.

TABLE 4.

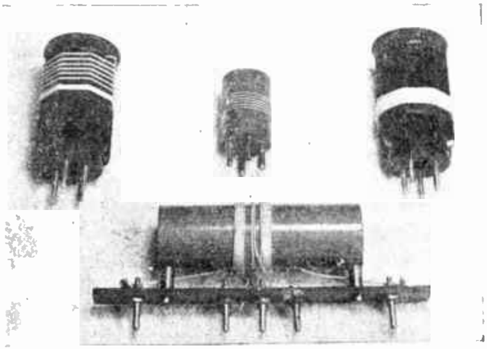
P.A. Anode Coils.

Frequency.	Diameter.	Winding.
7 Mc	3″	12 turns 3/16″ copper tube 4″ long.
	2″	20 turns 14 s.w.g. 3″ long.
14 Mc	3″	5 turns 3/16″ copper tube 2″ long.
	2″	10 turns 14 s.w.g. 1½″ long.
28 Mc	2″	4 turns 3/16″ copper tube.

See notes, Table 3.

Link Couplings

Link coupling windings should employ three or four turns for 3·5 Mc, two or three turns for 7 Mc and one or two turns for 14 Mc circuits.



Group of coils for low power circuits.
Top.—Various moulded formers which plug into standard valve-holders.

Below.—Centre tapped grid coil for push-pull or push-push circuits, with link coil in centre.

Chapter Seven

TRANSMITTER MODULATION & KEYING

Theory—Keying Circuits, Negative H.T., Grid, Cathode, Suppressor, Primary, Grid Controlled Rectifiers—Keying Filters, Relays—Break-in—Modulation Theory—Modulation Methods, Anode, Series, Grid Cathode—Modulation Measurements.

GENERAL THEORY

Radio Communication Systems

IN the preceding Chapter attention has been focused on the ways and means of producing a carrier wave. That is to say equipment has been described which will deliver to a radiating aerial system a high frequency alternating current of the necessary power and stability. But the steady wave radiated from this unvarying current will not convey any intelligence to the receiving station. Its purpose is to carry any communication which it is desired to make. For this purpose the carrier wave must be varied in some manner.

A radio-frequency current can be varied in two respects only. Either the amplitude or the frequency is available for modification. It is by this process that intelligence is conveyed to the receiving station. At the transmitter the information to be sent will be in the form of an electric current of which the magnitude may represent, for example the air pressure of a sound wave in the case of telephony transmission. In the case of picture transmission or television there exists a current which varies in intensity, according to the fluctuations of the light in the scene. In order to convey the information to a distance, either the amplitude or the frequency of the carrier wave must be varied in accordance with the signal currents produced by the sound or light variations. This process is known as " Modulation."

Fig. 1A shows a waveform known as a sine wave. This represents a constant or unmodulated carrier wave. In B of the same figure the amplitude of this current is varied, although the frequency, and consequently the wavelength is maintained constant. This is known as " Amplitude Modulation." At C is shown an example of " Frequency Modulation." Here the amplitude remains constant but the frequency varies from instant to instant. The function of the receiver is to convert the received R.F. current, which will vary in exactly the same manner as the transmitter aerial current, into a current which is a replica of that used to modulate the transmitter.

In the simplest method of radio communication the information to be transmitted is translated either by the operator or by means of a machine into a code of two elements. These two elements, termed dots and dashes differ only in length. The carrier current is completely interrupted into periods of short and long duration. A given number of dots and dashes are understood to represent a particular letter, figure or other symbol generally according to the International Morse Code. The received R.F. current will be similarly interrupted and can be retranslated by the operator or machine. When the amplitude only of the wave is varied between its maximum value and zero in this manner the system is known as " Continuous Wave " or " C.W. Transmission."

Sidebands

Now, an unmodulated pure carrier wave is of a single frequency only. As soon as either its amplitude or frequency is modulated a series of

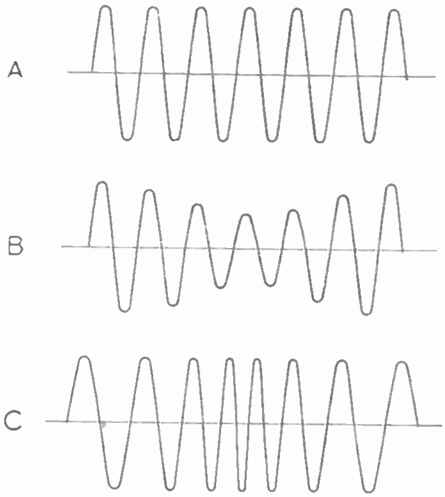


Fig. 1.

A. Sine wave of constant amplitude and frequency.
B. Amplitude modulated wave.
C. Frequency modulated wave.

World Radio History

additional frequencies, known as side frequencies, which constitute the so-called sidebands, is produced. For a carrier whose amplitude is modulated at a single frequency there are two side frequencies at the sum and difference respectively of the carrier and modulation frequency. Thus if a 7,000 kc carrier is modulated at a frequency of 1,000 c.p.s. (*i.e.*, 1 kc) there will be radiated three distinct frequencies of 7,001 kc, 7,000 kc, and 6,999 kc. In the receiver these three frequencies are "demodulated" to produce a 7,000 kc carrier and a 1 kc modulation frequency. The carrier is filtered out and the 1,000 c.p.s. note which was originated at the transmitter is reproduced. It is for this reason that a transmitter occupies a definite width in the frequency spectrum. As will be shown later an incorrectly adjusted transmitter may occupy far more than the minimum band width of twice the modulation frequency. Systems known as "Single Sideband Working" have been developed in which one sideband and possibly even the carrier frequency are eliminated with a consequent reduction in the amount of space occupied in the band. Such systems are however difficult to operate and are not common in amateur practice.

Telegraphic transmission, therefore, forms a particular case of modulation, and as it is perhaps the simplest will be treated first.

KEYING OF TRANSMITTERS

Requirements

In order to transmit telegraphy, the R.F. aerial currents must be capable of being reduced to zero at will. For amateur transmitters, it is usual to use a hand-operated key for this purpose. It is necessary to arrest the flow of R.F. current completely in order that no radiation shall be produced in between the dots and dashes.

A further requirement is that the operation of keying shall not cause any variation in the frequency of the transmission, because this will render the reception of the signals difficult, perhaps impossible, and will also cause interference with other transmitting stations.

It is also desirable to keep the currents and voltages in the keying circuit within reasonable limits to prevent arcing at the key contacts, a condition which would cause them to become dirty and unreliable. Also unless elaborate precautions are taken, there may be an element of danger with high voltages on the key. It is, of course, necessary to arrange the circuit in which the key is situated so that it can be extended to a convenient position near the receiver.

Another very important requirement for satisfactory keying is that the R.F. current must not be interrupted or started too suddenly, because a great deal of interference in neighbouring receivers might be so produced. Further reference will be made to this point.

The most obvious place to insert the key is in the source of R.F. energy, *i.e.*, the master oscillator stage of the transmitter, since when this stops oscillating there will be no output from a correctly neutralised transmitter. This, however, is to be strongly deprecated, except in the simplest of transmitters, as it is difficult to avoid changing the frequency of the oscillator slightly when the key is operated. This applies to a certain extent with even a crystal oscillator, and in any case throws unnecessary loading on the crystal.

Negative H.T. Keying

As a result it is more usual to key one of the transmitter stages following the master or crystal oscillator. In low power transmitters it is quite common to key directly in the high tension circuit of the power amplifier. If this is done the key is preferably placed in the negative lead as shown in Fig. 2A. This has the disadvantage that when the key is open it is possible to receive a shock from the H.T. supply if the fingers are placed across the key contacts.

Grid Blocking Method

A circuit which does not possess this disadvantage is shown in Fig. 2B, where the key is connected directly in the grid leak circuit. When the key is open, the grid collects a very high negative charge, and the anode current through the valve ceases to

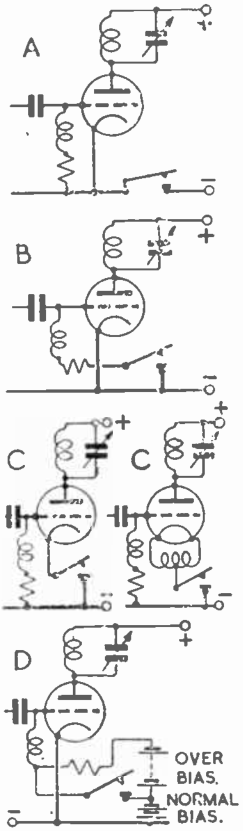


Fig. 2.
Four typical methods of keying a transmitter.
A. Negative H.T. keying.
B. Grid blocking keying.
C. Cathode keying.
D. Grid blocking keying with over-bias.

World Radio History

flow. It is necessary that the insulation resistance of the key and the grid circuit should be very high to obtain satisfactory grid blocking, otherwise there will be a tendency for the valve to "squegger."

Cathode Keying

It is probably better to combine both these types of keying in the circuit shown in Fig. 2C. Here the key is connected in the cathode circuit; in this position it interrupts both the grid and the anode circuit simultaneously. When directly heated filament valves are used, the key must be placed in the centre tap lead of the filament transformer.

Grid Blocking Method with Over-Bias

Fig. 2D shows an alternative arrangement which has some advantages. An additional grid bias battery is employed and this is placed in series with the normal battery and so connected through a resistance that when the key is open, the grid receives a bias equal to the sum of the two batteries. This bias must be so arranged that the anode current is reduced completely to zero. When the key is closed, the normal working grid bias is applied and the additional or over-bias is shunted by the resistance. This should not be of too low a value; 1,000 to 5,000 ohms for every volt of over-bias being suitable.

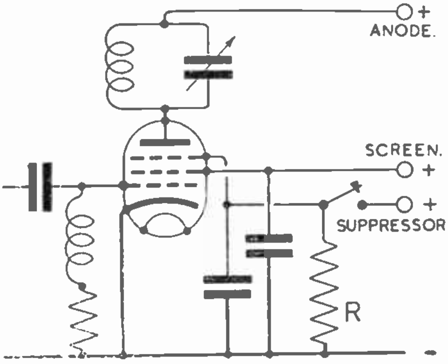


Fig. 3.

Suppressor grid keying for pentodes.
The resistance R should be high enough to give cut-off with the key raised. From 10,000 to 50,000 ohms is a suitable value.

A separate grid bias rectifier consisting of a receiver type rectifier valve is sometimes used. The usual smoothing circuits (see Chapter 9) are required and a potentiometer across the output is convenient to supply the correct voltage to the valve being keyed. It should be remembered that the positive terminal of the supply will be earthed in a bias power supply.

Suppressor Grid Keying for Pentodes

When screen-grid and pentode valves are used in a transmitter, advantage may be taken of the additional electrodes for keying purposes. The screen circuits may be keyed in the same way as anode circuits but unfortunately reducing the screen voltage to zero seldom completely stops transmission. With a pentode, however, the valve can be completely cut off by reducing the suppressor grid potential from the usual small positive value tc a sufficiently high negative value. Batteries may be used for this purpose, but Fig. 3 shows how this voltage may be obtained automatically. The value of R must be found experimentally so that the valve is cut off with the key raised. A fairly high value, 10,000 to 50,000 ohms, is necessary.

This method is not possible with tetrodes and screen keying is not, therefore, recommended fcr such valves.

Primary Keying

When using rectified A.C. for the H.T. supply, the primary circuit of the H.T. transformer may be interrupted by the key, but this can only be done where a separate transformer is used to heat the rectifier filaments. When employing primary keying in this way, it is generally necessary to connect some load across the transformer primary to stop heavy surges due to the magnetising current. This may take the form of an ordinary incandescent lamp or a Neon tube. R.F. surges are also apt to be sent back into the mains when keying in the primary in this manner, and it is generally advisable to utilise an R.F. filter to prevent this effect. A suitable filter is illustrated in Fig. 4.

Unless the power to the final stage of the transmitter is less than about 40 watts it is generally advisable to key the supply to the frequency doublers or buffer only. For keying high power transmitters, any of the previous circuits may be employed, but it is always advisable to avoid keying the high power stages. In these cases the chosen circuit should be applied to one of the doubler stages or perhaps a buffer amplifier.

Gasfilled Relays

An alternative to primary keying consists in using mercury vapour rectifiers which contain a grid. Valves of this type are generally termed gas-filled relays. Typical examples are the *Osram* GT1 and GT1C grid controlled rectifiers. The former has a maximum peak voltage rating of 1,000 volts and the latter 500 volts. In each case a pair will deliver up to 500 mA of rectified D.C.

It is a property of a gas relay that as long as the grid is held negative by more than a certain amount, no anode current can flow. Once the negative bias is removed, however, allowing the flow of anode current, it is impossible to reduce or stop the latter by

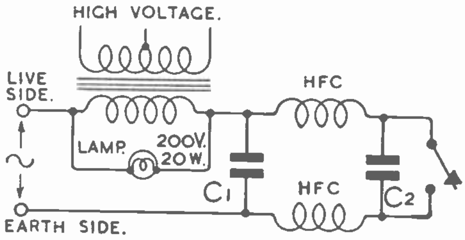


Fig. 4.

Primary keying.

C_1 0.01 μF to 0.05 μF.
C_2 0.001 μF.
H.F.C. 210 turns No. 30 D.S.C. on ⅜-in. former.

means of the grid voltage. In the case of a rectifier circuit the anode voltage is alternating and if the grid is made negative the valve will continue to pass current for the rest of the conducting half-cycle but will not conduct again after that period until the negative grid voltage is removed. It is possible therefore to control up to a full power output of say 500 watts, from a rectifier circuit, using two of these valves, merely by the application of a suitable grid bias. As this bias is only needed every half-cycle when the anode is positive an A.C. voltage can be used. Fig. 5 shows a suggested circuit wherein T_1 is the main H.T. transformer. The grids are connected to the secondary of T_2 which has to supply a voltage large enough to cut off the valves, but no current. R is a resistance to limit the flow of grid current and can be about 100,000 ohms. A circuit such as that shown in Fig. 4 should be used if sparking is apparent at the key contacts. The insulation between the windings of T_2 should be as good as that of the heater transformer T_3. The secondary voltage of T_2 is not critical but a voltage about one-twentieth of that of the secondary of T_1 would be suitable for GT1 valves. In place of the back contact key a relay can be used which must be made to open when the key is down. It is, of course, necessary to connect the secondary of T_2 so that the grid of each valve is negative when its anode is positive. If the valves are not cut-off when the grid voltage is applied the primary connections of T_2 should be reversed.

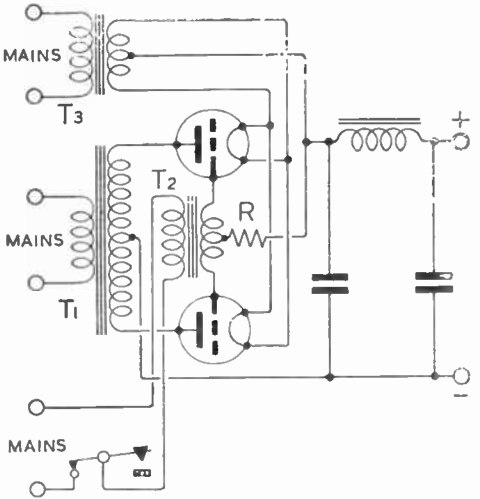


Fig. 5.
Grid controlled rectifier circuit.
The transformer T_2 supplies a negative grid bias cutting off the rectifier valves when the key is up. A back contact key is required.

Keying Filters

When primary keying is employed, the circuit is effectively interrupted previous to the H.T. smoothing circuit. The current is prevented from growing rapidly by means of the low frequency chokes and from dying rapidly by the smoothing condensers. The effect is illustrated in Fig. 6A. In the case of the keying circuits shown in Fig. 2, the current will start and stop suddenly, as illustrated in Fig. 6B. This causes signals to be radiated over a very wide band of frequencies at the moment of opening and closing the key, and will produce severe interference in the nature of "clicks" in neighbouring receivers even when these receivers may be tuned to some frequency widely different from that of the transmitter. In order to avoid this effect, the waveshape of the signal must be similar to Fig. 6A, *i.e.*, the sharp corners must be rounded off. This is done satisfactorily when primary keying, provided the condensers in the smoothing circuit are not too large. If this is the case, the signals will "tail" and be difficult to read. To prevent this effect the condensers should be reduced in value and the inductances increased to maintain good smoothing.

When using the type of circuits shown in Fig. 2, the rounding off of the signals is accomplished by the use of a key-thump filter of the type shown in Fig. 7. The condenser here prevents the circuit from being interrupted immediately the key is opened while the resistance in series with the condenser prevents sparking at the key contacts when the key is closed. Suitable values must be chosen for each particular case, and it is always advisable to use a monitor to check that the signal output is satisfactory.

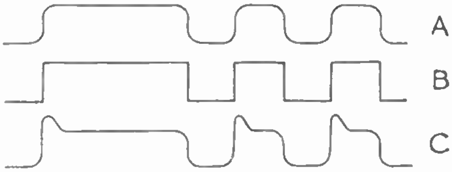


Fig. 6.
A. Keying waveshape which will not cause local interference.
B. Keying waveshape using no keying filter.
C. Peaky waveshape resulting from poor regulation in the H.T. supply.

It is sometimes found that an R.F. filter of the type shown in Fig. 4 is useful in addition to that of Fig. 7. In this case it should be connected as close to the key as possible.

If the regulation of the H.T. supply is poor, the high voltage which may be produced when there is no load will produce a peak at the beginning of each signal as shown in Fig. 6C. This may cause trouble and should be prevented by the use of an artificial load across the H.T. supply, taking approximately 15 per cent. to 20 per cent. of the full load current.

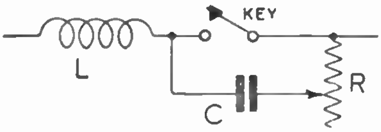


Fig. 7.
A common type of keying filter.
L 5 to 20 Henrys depending upon load.
C 0.5 to 2 μF.
R Approximately 1,000 ohms.

Keying Valves

It is sometimes convenient to key the grid circuit of an additional valve whose sole function is to control the current to one or more of the ordinary transmitter circuits.

In Fig. 8 a triode is connected in series with the main H.T. negative lead. When the key is closed this valve passes the feed current of the keyed stage losing a few volts only but when the key is open the resistance R forms an automatic bias resistance for the keying valve, and if sufficiently high (say 20,000 to 50,000 ohms) will reduce the current almost to zero. The keying valve must obviously be capable of passing the full load anode current of the keyed stage, but it should be noted that the anode dissipation will not be excessive as the voltage on the anode of the keying valve is not very high. More elaborate keying filters may be used in the grid circuit if desired.

A gas relay forms an exceedingly good keying valve since its resistance is very low. The voltage drop across the valve will not exceed 15 volts. It has been found that a type 83 full-wave rectifier can be used, one of the anodes functioning as a control grid. Fig. 9 shows a circuit suitable for keying a stage taking 50 to 60 mA at 500 volts. V_1 is the valve being keyed and V_2 is the type 83 keying valve. R_1 can be any value from 50,000 to 100,000 ohms, and need not be rated higher than 5 watts. The key is connected directly across R_1. Interference may be bad unless a screened keylead and the R.F. chokes are used. These chokes are easily constructed by winding 80 turns of No. 24 d.c.c. wire on a 1½″ diameter former. The audio choke L_2 is not always necessary, but if used it should be of very low resistance, a few ohms only, and its inductance should be one or two Henrys. The chokes must be fitted close to the key contacts with R_2 and C across the contacts. R_2 is a variable 0–400 ohm resistor while C is 0·5 μF. The best values for R_2 and C can be ascertained only by actual experiment. If the leads to the key can be kept short all the better. A relay across R_1 would probably solve the problem of radiation from the cable, since the leads would then be very short. A point to remember is that the resistance of the cable, plus the chokes, must be kept small, otherwise there will be a low resistance and not a short circuit across R_1. This will have the effect of a small cathode resistance and will reduce the voltage on the anode of V_1. The keying valve filament is supplied by a separate transformer.

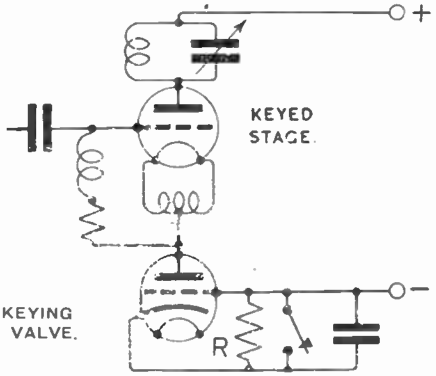


Fig. 8.

Showing the use of a keying valve. The lower valve is used to control the anode current of the upper.

Keying Relays

Where considerable power is being keyed or where the key is located in a very remote position from the transmitter, it is advisable to use a relay. In this case the key closes a local battery circuit which operates the relay, the contacts of which are connected in the circuit in the place of the key.

When a relay is used a small mica condenser should always be connected across the key contacts in the local circuit to prevent clicks; these latter are caused by small amounts of high frequency energy generated by the spark being radiated by the long key leads. This remark also applies to direct keying when long leads are used even if a filter is employed at the transmitter end. A value of ·01 μF would be suitable.

Break-in

A method of operating which saves a great deal of time is known as "break-in." The receiver, which has its own aerial independent of that of the transmitter, is left continually in operation. The system of keying must be such as to reduce the transmitter output to a very weak signal or complete absence in the receiver when the key is up. A distant station can be called with the receiver left tuned to its frequency, and the operator can be informed, by means of the abbreviation BK, that he may start transmitting immediately rather than wait until the call ends.

As the crystal oscillator output is generally strong enough to block a sensitive receiver it becomes necessary to key the oscillator stage. Although this is not good practice, there is seldom any alternative if break-in working is required.

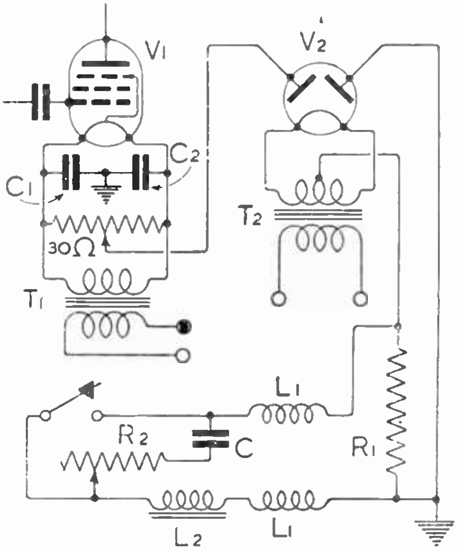


Fig. 9.

A valve keying circuit using mercury vapour rectifier as keying relay.

C	.5μF.	V_1	Keyed Valve.
C_1 C_2	.01 μF.	V_2	Keying Valve.
R_1	.1 megohm.	L_1 L_2	See text.
R_2	400 ohms.	T_1 T_2	L.T. Transformers.

World Radio History

In order to prevent a chirpy note the oscillator should be run lightly and in the case of crystal oscillators the tuning condenser should be adjusted to the middle of the range over which the crystal will oscillate rather than to the position of maximum output. The supplies to anode and screen circuits should be of good regulation. Therefore the use of series resistances for voltage dropping is not recommended. Potential dividers are more suitable than series resistances for screen supplies. The same remarks apply to electron-coupled oscillators. It may be sufficient to key the anode supply only, leaving the oscillating circuit running, but unless this part of the circuit is exceedingly well screened the output may be large enough to block the receiver over too wide a waveband. For safe stable operation the keying of an electron-coupled oscillator is not really recommended.

The method shown in Fig. 2D can generally be successfully applied to crystal oscillator valves for break-in operation. Fig. 10 shows such an application to a 6L6 C.O. The Resistance R_1 acts as the usual grid leak with the key down, but when the key is released the 45 v. negative bias is applied to the grid *via* R_1 and R_2. The cut-off is complete, and there is the additional advantage that the key is at earth potential.

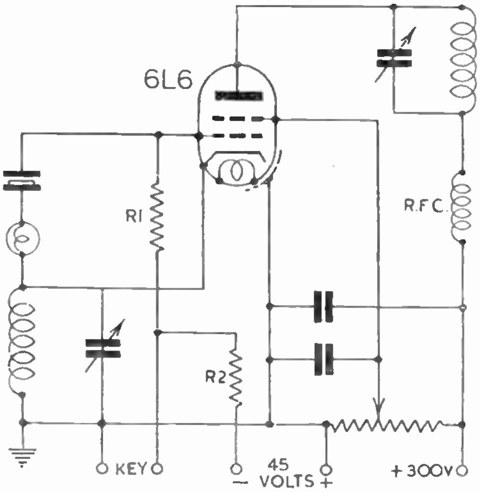


Fig. 10.
A method of keying the oscillator stage for break-in operation.
R_1 25,000 ohms. 1 watt. R_2 50,000 ohms. 1 watt.

Broadcast Interference

If a transmitter be keyed along the lines suggested above no serious interference should result in neighbouring broadcast receivers. Should any trouble of this nature be experienced with either a telegraphy or telephony transmitter the practical information given in Chapter 10 will be found useful.

TELEPHONY TRANSMISSION

Theory of Modulation

In the first section of this Chapter it was explained that either the frequency or the amplitude of the carrier wave may be modulated by a waveform corresponding to the variations in air pressure or light intensity of a sound or picture image. This Chapter will deal with the transmission of sound only, more especially that of speech. Further information on television modulation will be found in Chapter 19. Of the two types of modulation, *i.e.*, frequency and amplitude, the latter only will be considered because at present frequency modulation is an intricate process to carry out accurately and is not in common use in amateur work.

It is important to note that, once amplitude modulation has been decided upon, every precaution should be taken to prevent frequency modulation as well. Considerable distortion will otherwise result and the likelihood of interference with other stations will greatly increase.

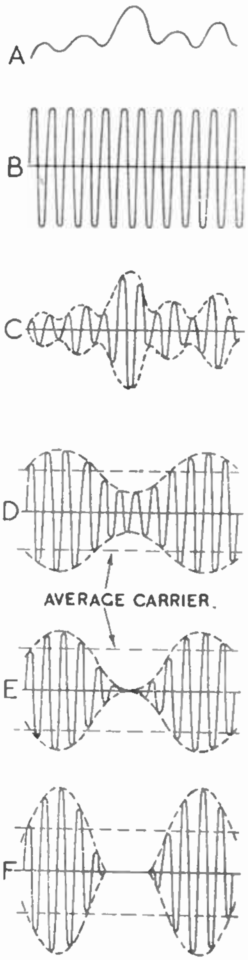


Fig. 11.
A. Nature of acoustic waveform which is to be transmitted.
B. A constant amplitude (unmodulated) carrier wave.
C. The carrier modulated by curve A.
D. A carrier modulated by a single low-frequency.
E. Full or 100 per cent. modulation.
F. Overmodulation.

World Radio History

Fig. 11A shows a curve which may be taken to represent part of a complex sound waveform, such as that of speech. B of the same figure illustrates the constant amplitude R.F. current in the aerial, *i.e.*, the carrier. C shows the carrier varied in amplitude to conform to the curve shown in Fig. 11A. The frequency is unaltered, but the amplitude is constantly changing and is defined by the dotted line which is called the " Modulation Envelope." For purposes of explanation it is more simple to consider the transmission of a single low frequency. For example, Fig. 11D illustrates a carrier wave modulated by the sine wave shown with the dotted line. When the modulation is such that the amplitude of the carrier is increased to twice its average value, and decreased to exactly zero, the modulation is said to be complete, or 100 per cent. This is shown in Fig. 11E. If the modulation exceeds 100 per cent. the condition shown in F is reached ; in this case 150 per cent. Such a condition, referred to as " over-modulation," causes the carrier to " break " or become zero over a considerable period. The radiation of a wide waveband is produced by this effect and considerable interference with local receivers as well as distortion of the transmitted signal will almost certainly result. It should be noted that up to 100 per cent. modulation the average value of the carrier is constant and except in the case of controlled carrier transmission, to be described later, this will always be so.

The percentage modulation is defined as :—

$$\frac{\text{Max. modulated amplitude} - \text{carrier amplitude}}{\text{carrier amplitude}} \times 100\%$$

Since the maximum current at 100 per cent. modulation is twice the carrier current the peak power must be 4 times the carrier power.

If the modulation envelope is a sine wave it may be proved mathematically that the effective power input at 100 per cent. modulation is 1·5 times the carrier power. Hence to modulate the carrier fully, the average power in it must be increased by 50 per cent. In order to produce 100 per cent. modulation it is necessary to supply a low frequency power of an amount equal to one half the carrier power. For example, to modulate fully a 10-watt radio-frequency stage 5 watts of audio-frequency power will be required. Since power varies as the square of current, the aerial current will rise to $\sqrt{1\cdot5} = 1\cdot226$ or by 22·6 per cent.

Aerial current meters do not, of course, follow the modulation frequencies. All the usual types indicate R.M.S. current, which increases on modulation. As already shown, this increase will be approximately 22½ per cent. when the carrier is modulated fully by a sine wave. Speech and music waves, however, are peaky in nature and their R.M.S. values may be very much less than that of a sine wave of the same peak value. This gives a very much smaller increase in the measured aerial current.

For example when a transmitter is being modulated to a *peak* value of 100 per cent. with ordinary speech the *average* value of the modulation is in the order of 30 per cent. When using a continuous pure tone (sine wave) for modulating, however, the percentage modulation can be obtained by the Heising formula :—

If I_0 = R.M.S. value of unmodulated aerial current (as read on hotwire or thermo-junction meter).
I_M = ditto when modulated.
m = modulation factor.

$$\text{Then } I_M = I_0\sqrt{1+\frac{m^2}{2}}$$

If I_M and I_0 are measured, m can be found from the formulæ :—

$$m = \sqrt{2\left(\frac{I_M^2}{I_0^2}-1\right)}$$

Percentage modulation = m × 100.

The modulation can also be expressed in terms of the ratio of the audio power required for modulation to the unmodulated power supplied to a modulated stage.

$$m = \sqrt{\frac{2A}{W}}$$

where A is the audio power,
W is the unmodulated D.C. input to a modulated stage.

This gives rise to another useful formula from which the audio power required for any given percentage modulation can be obtained.

$$A = \frac{m^2}{2}W.$$

A few values of m for various aerial current increments and audio to carrier power ratios are given in the table following.

Per cent. Modulation	Audio Carrier Power	Per cent. Increase of I_0
100	0.5	22.5
75	0.281	13.0
50	0.125	6.0
25	0.033	1.5

Methods of Modulation

The method of achieving this variation of aerial current must now be studied. One obvious method is to vary the resistance of the circuit in which it flows. This might be done by the insertion of a carbon microphone in the aerial circuit. But this is a very unsatisfactory method, because the microphone is at radio-frequency potential and there is a limit to the current for which microphones can be built to carry. Secondly, it is possible to vary the output of an oscillating valve circuit by varying the anode volts, the grid volts, or maybe the screen volts at the modulated frequency. When this method is applied to self-oscillating valves, the frequency is also likely to be varied and as has already been stated, frequency and amplitude modulation together can only produce serious distortion. In order to keep the frequency stable, therefore, it is usual to modulate only driven amplifier stages.

Consider, first of all, modulation by varying the anode volts of a driven amplifier valve. It is

World Radio History

necessary for the modulation envelope to correspond to the low frequency modulation input. Thus the output R.F. current must be proportional to the anode voltage. This is achieved by the use of what is called a " Class C amplifier." According to the definitions given in Chapter 2 this is an R.F. amplifier where the grid bias is at least twice the cut-off value, and where the R.F. input or drive is very large. Fig. 12 shows by the full line the conditions obtaining in a well adjusted circuit, where proportionality is achieved between the applied anode voltage and the R.F. output; in other words, when the anode voltage is doubled the R.F. output current is also exactly doubled.

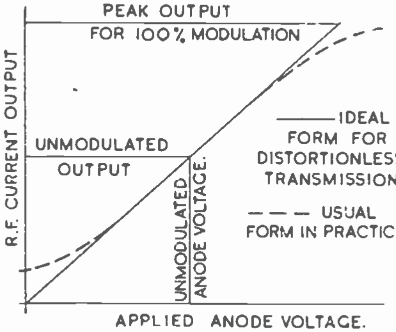


Fig. 12.
Relationship between anode voltage and output of a modulated R.F. amplifier.

In practice this curve may be very closely approximated to as shown by the dotted line.

In order to obtain good linear modulation it is very important that there should be sufficient R.F. grid input to drive the stage when the anode voltage is at its highest on modulation peaks. It is for this reason that a Class C type of amplifier must be employed in anode modulated amplifiers.

There are two common methods of varying the anode voltage of a modulated R.F. amplifier.

Anode or Heising Modulation

This method is illustrated in Fig. 13. The H.T. supply feeds both the oscillator valve V_1 and the modulator valve V_2 through a common L.F. choke L_3, which has a high impedance to all modulation frequencies. The circuit shown for V_1 is a typical neutralised power amplifier, L_1 and C_1 being the tank circuit, and L_2 and C_2 the usual R.F. choke and by-pass condenser. It will be seen that considering the valve V_2 as an ordinary Class A low-frequency amplifier the valve V_1 is its anode load. By this is meant that the inductance L_3 by virtue of its high impedance, prevents any audio-frequency change of H.T. current and consequently the anode voltage variations of V_2 are applied directly to the anode of V_1, and all the audio-frequency output power of V_2 is delivered into V_1. When V_1 is arranged as a Class C amplifier described above, it will be found that its resistance defined as :—

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

will be substantially constant. This resistance is the load impedance of the modulator.

For 100 per cent. modulation the anode voltage of V_1 must be swung from its normal value to twice that value and down to zero without distortion at all modulation frequencies. It must, therefore, be arranged that the value of the anode load of the modulator is suitable for the valve employed.

It will be clear that this range of voltage cannot be obtained with the same H.T. voltage on the modulator as on the Class C amplifier, because the maximum anode swing that can be obtained from any Class A amplifier without distortion is considerably less than its own anode volts. It is, therefore, necessary to have more H.T. voltage on the modulator than on the driven amplifier. Fig. 14 illustrates several methods of achieving this result. Fig. 14A shows a circuit very similar to Fig. 13 except that V_1 is fed through a resistance R, shunted by a condenser C_3. This resistance produces a drop in anode volts of V_1, equal to the anode current of V_1, multiplied by R. Knowing the maximum anode swing to which V_2 may be driven, the anode volts of V_1 must be dropped by means of R to be just one-half this value, and V_1 must be driven to such an anode current that its anode voltage divided by its anode current gives the optimum load for V_2. The distortionless output from V_2 must be enough to swing this impedance to twice the unmodulated anode volts of V_1. This will enable the anode volts of V_2 to be fixed. R can thus be found and will be equal to the difference in anode voltage of V_2 and V_1 divided by the anode current of V_1. C_3 is inserted to by-pass the resistance R for the modulation frequencies and is usually of the order of 1 to 2 μF. In order to produce very low frequency modulation satisfactorily, the reactance of L_3 at the lowest modulation frequency must be greater than the impedances of V_1 and V_2 in parallel.

In Fig. 14B the required anode voltages are applied directly to the respective valves by means of low frequency chokes L_3 and L_4. In order to couple the two anodes together, condenser C_4 is connected. In Fig. 14C the maximum permissible swing of V_2 is increased by means of a suitably designed transformer T. The anode swing is, of course, increased by the turns ratio, but it should be noticed that the impedance of the load is now equal to the anode voltage of V_1 divided by its anode current and further divided by the square of the turns ratio. An important feature of this circuit is that the direction of the windings

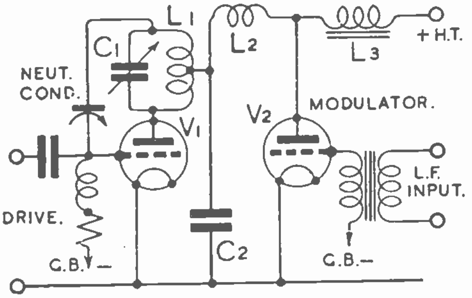


Fig. 13.
Simple anode modulation circuit.

T can be so arranged that some of the D.C. magnetisation of the core is balanced out.

Push-pull Class C power amplifiers may be modulated in an exactly similar manner by any of these three circuits.

Series Modulation

Instead of feeding the modulator and modulated amplifier in parallel through a choke, they can be fed in series as shown in Fig. 15. This obviates the use of a cumbersome and expensive low frequency inductance. The driven R.F. amplifier is still the load for the modulator and the conditions stipulated for parallel feed still hold. The voltage drop across the modulator will require to be considerably greater than across the modulated amplifier in order to secure the full modulation as in the choke control case. The valves are chosen to effect this with the required R.F. drive on the amplifier and bias on the modulator.

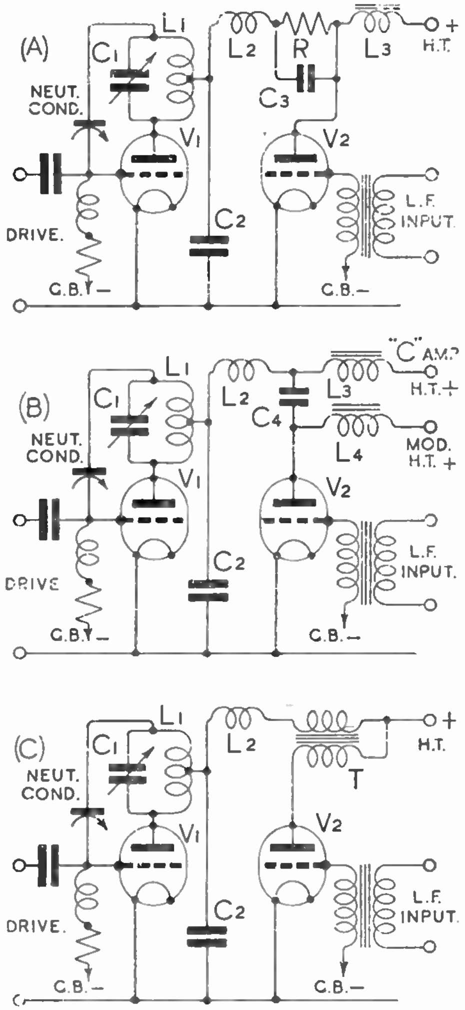


Fig. 14.

Three practical anode modulation arrangements.

A. V_1 and V_2 coupled by single choke L_3. Resistance R drops anode volts to V_1

B. Separate H.T. voltages are supplied to V_1 and V_2 by separate chokes L_3 and L_4.

C. A transformer T couples V_1 and V_2.

Two arrangements are possible. In Fig. 15A the modulated amplifier is connected with its cathode to the negative of the H.T. supply and the modulator V_2 is connected in series with the positive lead. This means of course that the filament of V_2 is not at zero D.C. potential, and the windings of the transformer or batteries employed to light this filament must be suitably insulated. It is also necessary to have good insulation between the primary and secondary of the low frequency transformer which feeds the grids of the modulator.

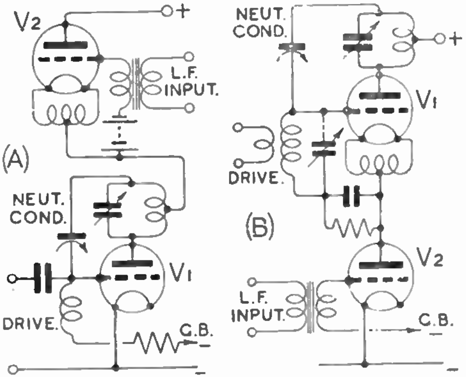


Fig. 15.

Series modulation.

A. V_1 is a stage being modulated by V_2.

B. V_2 is the modulator and V_1 in this case is connected next to the H.T. positive.

In Fig. 15B the positions of modulator and modulated amplifier are reversed. The modulator filament is in this case at earth potential and the modulated amplifier filament and grid circuits are at a D.C. potential above earth. This means that some form of inductive coupling, for example, link coupling for the R.F. valve, must be employed.

In this type of modulator there is no L.F loss due to the modulation choke, but care must be taken that the capacity thrown across the modulator anode circuit, due to the capacity of the filament windings to earth, is not large enough to produce a loss of modulation at high audio-frequencies.

Design of Modulator

In all the foregoing circuits the modulator valve has been shown as a single triode for simplicity, but there is no reason why one or more valves should not be operated in parallel to obtain more audio-frequency output. Single modulator valves must always be worked as Class A amplifiers, *i.e.*, their grids must never be driven positive or far into the curved part of the characteristic. They must always be arranged to have their optimum anode load which is usually of the order of two to three times the anode impedance of the valve. If these conditions are not observed, considerable harmonic distortion will be introduced, which distortion must also occur in the received speech or music.

World Radio History

Frequency distortion, *i.e.*, the production of various degrees of modulation at different frequencies when a constant input at all frequencies is applied to the modulator grid, must also be avoided. This is liable to occur in the input transformer to the modulator grid unless it is of suitable design. In the modulator itself a loss of bass frequency response is most likely to occur with choke control. It is necessary for the inductance of the choke, when carrying the total D.C. in the circuit, to be such that its reactance, *i.e.*, 2πfL where f is the lowest modulation frequency, shall be preferably two or three times the impedance of the modulator and modulated amplifier in parallel. Similarly condenser C_2, in the circuits of Fig. 14, while being large enough to by-pass the radio frequencies, which is its true purpose, must not have a reactance at the highest audio-frequency which is low compared with the two valve impedances in parallel. If this reactance becomes less than say twice the parallel valve impedance, there will be a noticeable loss of high modulation frequencies.

Class A Modulators

When using Class A amplifiers as modulators, it is not possible to obtain a better anode efficiency than about 15 per cent. To increase this, two Class A valves may be used in push-pull. Owing to the cancellation of even harmonics by this method, more power can be obtained out of such a modulator than with the same two valves in parallel, and, for amateur purposes at least efficiencies up to 25 per cent. are possible. When using push-pull modulators, however, it is always necessary to employ an output transformer. The type of circuit shown in Fig 14C can obviously be modified to employ a push-pull modulator stage. In this case the primary would have a centre-tap for the modulator H.T. supply, the two push-pull valves having their anodes connected to the ends of the primary winding.

Class B Modulators

Of recent years high efficiency modulators have been developed where two valves are used in push-pull, but working with Class B characteristics, *i.e.*, the pair are biased to cut-off, and only pass anode current when audio-frequency drive is applied. The L.F. voltage applied to the grids may be large enough to drive them positive and grid current will flow at the peaks. This type of modulator, however, requires considerably more care in adjustment in order to obtain good results, and is not to be recommended for beginners until some experience has been gained on more simple modulator circuits.

The important points to remember with Class B modulator stages are, first that the previous stage or driver must deliver the power absorbed by the grid circuit, which means that it must be of the nature of a power amplifier not a voltage amplifier, and will generally have to deliver about 10 per cent. of the maximum Class B stage output. It is usual to arrange a low impedance valve for this purpose and also very often to use a step-down transformer to the grids of the Class B stages. This is to ensure that the Class B valves are fed from a low impedance in the grid circuit, thus enabling grid current to be drawn without distorting the input waveform. It is also most necessary that the regulation of the high tension supply to the modulator stage shall be very good, since the anode current is constantly varying during modulation, and falls to zero when the input ceases. It is almost essential, unless a D.C. generator is employed, to use mercury vapour rectifiers with a well-designed choke input smoothing circuit. For the same reason grid bias cannot be conveniently obtained from a cathode resistance and either a battery supply or a separate small rectifier should be used. Further information on this subject will be found in Chapter 9. In compensation for these difficulties of design efficiencies up to 50 per cent. or 60 per cent. can be obtained in Class B stages.

A special type of valve, known as a " Beam " valve (see Chapter 2) is frequently used in Class B circuits. Popular valves of this type are the 6L6G (either American or British) and the *Marconi* KT63 and KT66. Triodes are also used in Class B circuits, the conditions being different to Class A operation in that more grid bias and less standing anode current is used.

When operating with quite low powers it is possible to use some of the Class B valves specially designed for this purpose for use as output stages of ordinary broadcast receivers. These valves really consist of two separate valves in one bulb and possess a characteristic which makes them particularly suitable for Class B operation.

The table which follows, supplies most of the information required to design an efficient Class B modulator stage. Care should be taken to run the valves under the correct conditions as distortion is much more readily produced in a badly adjusted Class B stage than in the case of Class A operation.

Operating Conditions for Modulator Valves

Valve.	Class.	Anode Volts.	Grid Volts.	Optimum Anode load. (ohms)	Peak power Output. (watts)
PX25 or PP5/400	A	400	—32	3,000	6
4211	A	1,000	—55	7,000	10
DA60	A	500	—135	3,000	10
DA60(2)	A*	500	—135	6,000	30
6L6	A	300	—12	4,500	6.5
PX25A(2)	B	400	—100	2,800	32
KT66(2)	B	400	—32	5,700	35
KT63(2)	B	250	—30	11,000	12
6L6(2) (self-bias)	B	400	—24	6,600	32
6L6(2) (fixed-bias)	B	400	—25	6,600	60
T20 or (ESW20)	B	600	—30	8,100	50
B21	B	150	—6	12,000	2.5

* In pusn-pull.

World Radio History

Grid Modulation

An alternative method of modulating a radio-frequency amplifier consists in varying its grid bias by the modulation frequency. The modulated stage of this type always draws the same anode power from its H.T. supply, but the variation of grid bias alters its efficiency as a radio frequency amplifier during the modulation cycle and hence the radio-frequency output. It requires much less audio power to modulate a stage in this manner, but for a given R.F. amplifier valve and a given anode voltage, less modulated output is obtained than when using an anode modulated amplifier.

The maximum efficiency is the same as that of a Class B stage, *i.e.*, about 60 per cent., since the peak modulation must not carry the grid bias below cut-off point. The unmodulated efficiency is, therefore, approximately 30 per cent.

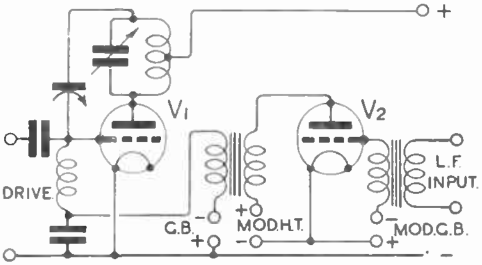


Fig. 16.

Grid modulation.

The modulator V_2 supplies an audio voltage in series with the grid bias of V_1, through a transformer.

Fig. 16 shows V_1 as a typical radio-frequency amplifier where its grid bias (which is fed through the usual R.F. choke in the grid circuit) consists of a fixed bias battery supply, in series with the output from the modulator stage V_2, *via* a low frequency transformer. It is usual to make the value of the fixed grid bias about 50 per cent. more than the cut-off value. The R.F. input is then adjusted to make the R.F. amplifier just take grid current. The grid drive is then reduced until the aerial current falls to half its previous value. Full modulation will be obtained when V_1 just shows grid current on modulation peaks.

Several other types of grid modulation are in use, but the method in general is not recommended as the best for beginners. The economy which is effected in the audio-frequency gear required is generally outweighed by the considerably larger R.F. amplifier valves required to produce a given fully-modulated output.

Low impedance triodes are usually the most suitable modulators, although higher impedance valves may be used with a step-down ratio of 1½ or 2 to one in the anode of the modulator. A resistance load on the secondary of about 10,000 ohms is often used.

The audio output required is quite small compared with the output of the radio-frequency stage being modulated. An output of 5 watts will comfortably modulate a 100 watt transmitter.

Modulating Screen Grid Amplifiers

Where tetrodes or screen grid valves are used for the modulated stage, it is possible to produce modulation by varying the screen voltage, but unfortunately only low modulation can be produced without distortion and the adjustments are very critical. It is also possible to modulate the anode voltage of a screen grid valve, but difficulties are soon encountered when full modulation is attempted owing to the secondary emission which occurs when the anode voltage is less than the screen voltage. This difficulty can be overcome by modulating the anode voltage and the screen voltage simultaneously and in the correct proportion, although there is very little to recommend the method.

The modulator circuits will be exactly the same as for anode modulation of a triode but the screen supply will also be connected to the modulated H.T. positive lead supplying the anode. One difficulty encountered is that the screen has usually to be supplied with a reduced voltage by means of a series resistance or potentiometer.

The R.F. by-pass condenser from the screen to earth will probably cause a loss of high audio-frequencies, although a condenser of several microfarads connected across the screen dropping resistance will reduce this loss.

Suppressor Grid Modulation of R.F. Pentodes

The foregoing remarks apply *in toto* to pentodes when anode modulation is used. A more usual method of modulating pentodes however is to introduce the modulation into the suppressor grid circuit. For a given anode voltage and radio-frequency grid drive, the output is dependent upon the suppressor grid potential. As a small change in voltage on the suppressor grid produces a considerable change in output power, there is available a means of modulating considerable R.F. energy with quite a small audio-frequency input. The modulated peak output power of such a stage will be comparable with the carrier output of a Class C stage working under similar operating conditions.

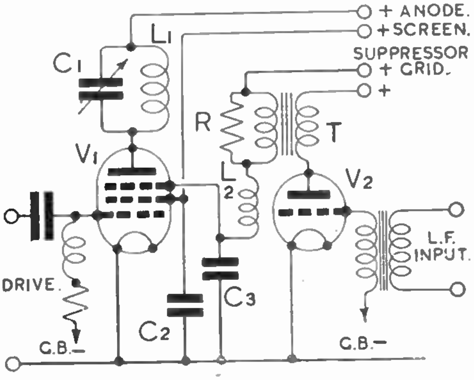


Fig. 17.

Suppressor-grid modulation of an R.F. pentode.

World Radio History

The correct method of adjusting a pentode modulated stage is first to obtain maximum radio-frequency output with the suppressor grid at the recommended maximum voltage, then to reduce the suppressor grid voltage, keeping the drive constant until the anode current is reduced to half its previous value. The L.F. modulation voltage is then added in series with the suppressor grid bias.

Fig. 17 shows V_1 as a radio-frequency pentode arranged for suppressor grid modulation. L_1C_1 is the tank circuit which is not shown with a neutralising circuit, although this may be necessary with some pentodes. The screen grid voltage is applied as usual with C_2 as a by-pass condenser to earth. The suppressor grid voltage is fed through the radio-frequency filter L_2 and C_3, from the suppressor grid bias in series with a resistance R. V_2 is the modulator valve which is generally of the Class A variety and supplies the modulating voltage across R through the transformer T.

As in the case of grid modulation an audio power of about 5 watts is sufficient to suppressor grid modulate up to a 100 watt pentode amplifier.

The following table gives the suppressor grid voltage and the carrier power available from some of the more popular transmitting pentodes in use.

Operating Conditions for Suppressor Grid Modulation of Pentodes:

Valve Type.	Anode volts.	Screen grid volts.	Suppressor grid volts.	Approx. carrier output power (unmodulated).
802, 4061A, RK23, RK25	500	200	—45	3·5
PVO5/15	500	250	—80	4
DET8	400	200	—110	5
OS12/500 837	500	200	—65	5
4307A	500	200	—50	6
4052A, RK20	1,250	300	—40	20
4069A	2,000	400	—45	70

Cathode Modulation

When discussing anode modulation it was stated that the audio power required to modulate a carrier fully is equal to 50 per cent. of the power to the modulated R.F. amplifier. In the case of grid modulation only a few per cent. is required. On the other hand, the unmodulated efficiency of the grid modulated stage must not exceed about 30 per cent.

The advantages of both systems are obtained by using a combination of both methods. This may be done by the introduction of the audio power into the cathode circuit of the modulated R.F. stage.

The audio power then required is in the order of 10 per cent. and an unmodulated efficiency of from 50 per cent. to 60 per cent. can be used.

It can be proved that the impedance of the cathode circuit of a valve is approximately equal to $\frac{1,000}{g}$ ohms, where g is the mutual conductance of the valve in milliamps per volt. Thus if g = 2mA/volt, the cathode impedance will be 500 ohms. If two such valves are used either in series or push-pull the cathode impedance will be one half this value, *i.e.*, 250 ohms.

If the cathode voltage of an R.F. amplifier is raised, the effective grid voltage is made more negative, thus reducing the anode current. At the same time the anode-cathode voltage is reduced, which also reduces the anode current.

Conversely, when the cathode voltage is reduced the grid voltage is made more positive, and at the same time the anode voltage is increased, thus increasing the anode current. Therefore, the changes in both grid voltage and anode voltage act together in modulating the anode current, and hence the R.F. power output. This enables the carrier to be modulated to 100 per cent. with the reduced audio input, and increased unmodulated efficiency already referred to.

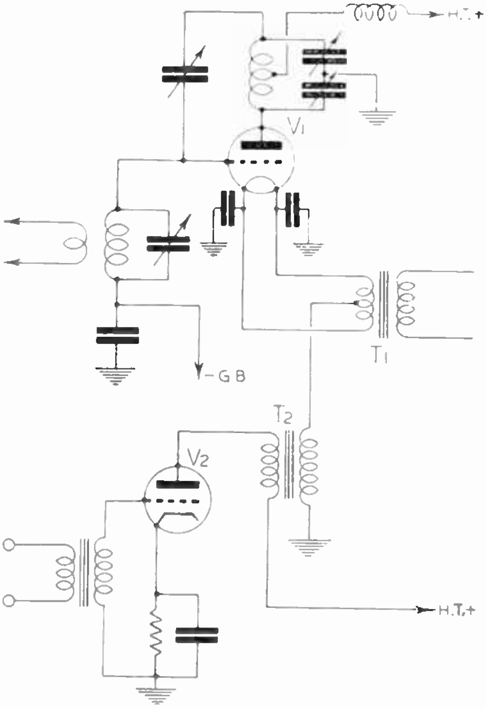


Fig. 18.
The principle of cathode modulation.

Referring to Fig. 18, V_1 is the R.F. stage which is being modulated. A neutralised triode is shown, as a low μ triode is much more effectively modulated in this manner than a pentode. The circuit of V_1 is orthodox except that its filament has its own mains transformer T_1 with a centre-tap on the L.T. side. A fixed grid bias is shown, as this is most satisfactory for cathode modulation.

World Radio History

The modulator V_2 can be any conventional audio frequency stage and is coupled to the cathode circuit by means of the audio transformer T_2. This should be designed to match into the cathode impedance, which is calculated in the manner described above.

The adjustments are not difficult or critical. The grid bias should be adjusted to several times cut-off, and the anode load of the P.A. should be adjusted to put the unmodulated efficiency at about 50 per cent. to 60 per cent. The drive should be sufficient to run into rather more grid current than is usual for grid modulation, but if too much drive is used distortion will not result.

Amplifying Modulated R.F. Power

Having discussed ways and means of modulating R.F. energy, it is now necessary to consider in what stage of the transmitter this is best done. In order to avoid distortion, care must be taken not to frequency-multiply the carrier after it has been modulated. Thus it is not possible to modulate before the actual transmitted carrier frequency has been produced. For most amateur sets this means that the modulation must take place in the final P.A. stage. The modulated radio-frequency energy is thus fed straight into the aerial.

If the power is to be increased after modulation, it is necessary to use a Class B or linear amplifier. In this class of amplifier, the output power is proportional to the square of the input voltage. Although some distortion is necessarily produced, the radio-frequency harmonics are filtered out by the use of a tuned anode circuit in the usual manner, but the amplitude of the R.F. current is proportional to the input driving voltage. In this way no distortion of the modulation is produced.

In general the construction and arrangement of such an amplifier is exactly the same as the Class C amplifier, but the grid bias must be fixed and is generally made equal to or slightly less than the cut-off value. The amplifier is then driven from a Class C amplifier which has been modulated by one of the foregoing methods. In practice the Class B amplifier is tuned to give the maximum aerial current possible with an unmodulated drive. The drive should not be enough to cause very heavy grid current, although a reasonable amount is permissible. The drive is then reduced until the aerial current is half the previous value. When the previous stage is modulated to 100 per cent. the aerial current will rise to double its unmodulated value and the peak power will be four times the unmodulated carrier power. A Class B amplifier, therefore, has to work with only a quarter of the carrier power which would be obtainable from the same tube operated as Class C. Consequently the economy of power obtained by modulating a low power stage and subsequently amplifying the modulated R.F. current, as compared with modulating the final P.A. is not as great as might, at first, be expected. On the other hand the size of the audio equipment required is considerably reduced, which may be an advantage in some circumstances.

One useful feature of this method of designing a transmitter is that by increasing the bias on the Class B amplifier beyond the value suggested above and by driving harder to keep up the output it is possible to increase the percentage modulation, so that if the Class C amplifier cannot be modulated fully, it is possible to raise the modulation to 100 per cent. in the Class B stage. This, however, must be carried out with care and a certain amount of experience is required to obtain good results.

Controlled Carrier Telephony

All the modulation systems described so far employ an R.F. stage which produces a carrier wave whose average value is constant, the degree of modulation varying from instant to instant according to the speech input. Even when no speech is being transmitted the full carrier is radiated. This represents unnecessary radiated energy and may cause heterodyne interference even during periods of no modulation.

In controlled carrier systems the amplitude of the carrier wave is varied according to demand so that the modulation percentage is always in the order of 100 per cent.; that is to say, when the speech input is low the carrier amplitude is small, but as the input rises the carrier is automatically increased by an amount which just prevents over-modulation. Comparison of Fig. 19 with Fig. 11 will make this clear. It is necessary to ensure that the average carrier shall increase as rapidly as the speech input demands and decrease to a small value immediately the speech ceases.

The advantages are:

(*a*) Economy in power supplied to the R.F. stages since full anode power only obtains when the speech input is a maximum. This means that smaller valves may be used for the same peak output.

(*b*) Reduction in heterodyne interference with other transmitters.

(*c*) Reduction in receiver noise level at low speech levels.

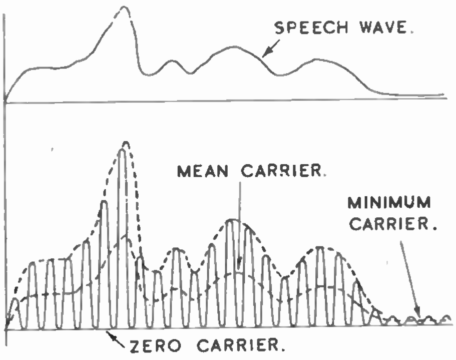


Fig. 19.
Controlled carrier telephony.
The instantaneous value of the carrier varies in order to maintain approximately full modulation at all speech levels.

Several methods can be employed. One is to control the grid bias or suppressor grid voltage of the modulated stage in sympathy with the average value of the modulation. Alternatively the anode voltage may be varied. Since the introduction of Class B modulators the latter method has become popular.

World Radio History

In Fig. 20 V_1 and V_2 form a push-pull radio-frequency stage of conventional type which is to be modulated. V_3 and V_4 are the Class B modulator valves. The audio input is applied through transformer T_1 to the modulator grids. Note that a fixed bias is necessary to hold these valves at nearly cut-off. The audio voltage developed across R on the secondary of the output transformer T_2 is applied to the anodes of V_1 and V_2 *via* the tank inductance. The main H.T. supply, which must be of good regulation, is applied to the R.F. stage and the modulator in series. That is to say the negative is connected to the modulator cathodes, the positive to the anodes of V_1 and V_2, while the cathodes of the latter are connected to the anodes of the modulators through the centre-tap of the primary of T_2. When there is no audio input the anode current of V_3 and V_4 is almost zero due to their bias. Thus the anode voltage of V_1 and V_2 is very low and a very small carrier is produced. When the speech input is applied, the anode current of V_3 and V_4 rises, enabling V_1 and V_2 to feed and produce a carrier which is modulated by the audio voltage which occurs across R. The condenser C which is generally 1 or 2μF prevents the actual modulation voltage from reaching the valves by this path and makes the carrier vary according to the mean value of the speech wave.

The value of R can be so set that the modulation voltage is just sufficient to give full but not over-modulation.

Such a circuit when correctly adjusted can produce good commercial quality, particularly if the bias of V_3 and V_4 is so adjusted that there is a minimum carrier of about 10 per cent. of maximum, but first-class quality is not easy to obtain. Similar valves are generally used in all four positions.

Duplex Telephony

Duplex telephony is a term used for a system of transmission where the transmitter and receiver are simultaneously in operation at each of the two contacting stations. In this way either operator may talk at any moment instead of waiting for the other to finish speaking. The commonest way of achieving this is to use some form of carrier control transmission where the carrier falls to zero with no speech input. Another term for this type of transmission is " quiescent carrier." In addition it may be advisable to use special aerials for transmitter and receiver; in any case the latter will require to be as selective as possible. If the two transmitters are at opposite ends of the frequency band in use then controlled carrier may not be necessary, in which case, apart from being particularly careful to avoid overmodulation, there are no special points to be considered in the design of the actual transmitter. It will, however, be necessary to screen the receiver carefully and if it is mains operated to ensure that no R.F. energy passes back into the mains.

ADJUSTMENT AND OPERATION

While it is not difficult to obtain modulation of some kind by merely connecting up one of the circuits described in the foregoing paragraphs, correct adjustment ensuring distortionless modulation can only be obtained by careful attention to the operating conditions of each valve in the system. For this purpose there is no more useful device than a cathode ray oscilloscope, although considerable information can be gained from indications of the various meters in circuit.

For example, the meters in the anode circuits of a microphone amplifier (which it is assumed employs Class A valves only) should never indicate a variation in anode current, if distortion is to be prevented. In the case of a push-pull Class A amplifier, slight kicks on high modulation may be permitted without serious distortion. The same remarks, of course, apply to Class A modulator valves which are really low frequency power amplifying stages. When using Class B push-pull amplification, however, there will be little or no anode current unless modulation is taking place and the meters will flick upwards during modulation. The modulated Class C amplifier or linear Class B amplifier should generally show no variation of anode current. If it does, it denotes that the amplifier is being overloaded, or that the correct operating conditions have not been reached. Further details are given in a later section of this Chapter.

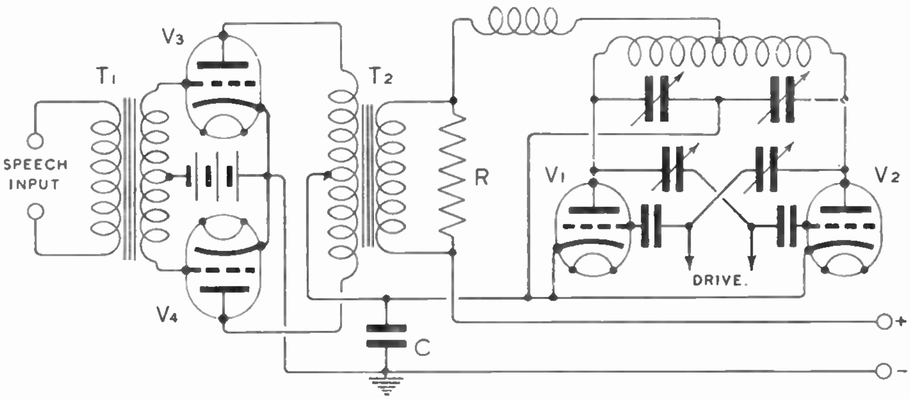


Fig. 20.
Controlled carrier circuit using class B modulator. The D.C. input to the modulated stage (V_1 V_2) is controlled by the anode current of the modulator valves V_3 and V_4.

The aerial current will theoretically rise from its unmodulated value by 22·6 per cent. for full modulation with sine waves, but when transmitting speech or music, very little change will be observed. If, however, a downward movement of the meter is observed during modulation, the operating conditions are incorrect.

Modulation Measurement

There are several methods by which the degree of modulation in a transmitter may be measured. When using choke modulation, an electrostatic voltmeter can be connected directly across the modulation choke. Knowing the unmodulated anode voltage of the Class C amplifier, the modulation percentage can be calculated from the following:

$$\text{Modulation} = \frac{\text{choke volts}}{\text{amplifier volts}} \times 141 \cdot 4 \text{ per cent.}$$

It is, however, better to base measurements on the actual R.F. output. The rise in aerial current is not a good indication, and the use of a peak voltmeter is to be recommended. A suitable circuit is shown in Fig. 7 of Chapter 15.

A short aerial is connected to the input terminal in order to pick up enough of the unmodulated carrier to give a suitable reading. Suppose a value of V_1 volts is obtained. The transmitter is now modulated steadily and the potentiometer re-adjusted until the anode current again just starts to flow on the highest peaks. Suppose the voltmeter now reads V_2 volts, then :

$$\text{modulation} = \left(\frac{V_2}{V_1} - 1\right) \times 100 \text{ per cent.}$$

A very simple device which will not measure the actual modulation but which can be made to indicate overmodulation is fully described later under the heading of Monitoring. When the transmitter is correctly adjusted there will be no movement of the milliammeter connected to the monitor with modulation less than 100 per cent., but should this figure be exceeded, the meter will flick upwards. Some such simple over-modulation indicator should be in use in all amateur transmitting stations to avoid interference with neighbouring receivers.

The Cathode Ray Oscillograph

The cathode ray oscillograph forms a very useful device for studying and checking the operation of radiotelephony transmitters, because it can be made to indicate *visibly* the actual waveform of the voltage in a circuit. As a result it is possible to apply it to a modulated radio-frequency circuit and obtain a picture on the screen similar to the diagrams in Fig. 11. In practice, however, with a carrier wave on any of the amateur bands, the actual individual carrier oscillations will be so cramped up as to appear continuous and a solid picture of the modulation envelope shape will result. Such features as overmodulation can readily be detected. Fig. 21A illustrates the appearance of a carrier 100 per cent. modulated with a steady tone. In B is shown the waveshape observed when overmodulation occurs in an anode-modulated stage.

To obtain these images it is necessary to supply the vertical or Y-deflecting plates with the modulated R.F. from, say, the output tank circuit. The horizontal or X-plates are fed from the "time-base" circuit which should operate at about one-third or one-quarter of the modulation frequency.

Another valuable way of using the cathode-ray tube is in the production of the so-called "trapezoidal" figures. In this case the vertically deflecting plates are fed from R.F. voltage either through a small condenser from the tank-circuit or a coupled tuned circuit. The horizontally deflecting plates are connected to the same source as that used for modulating the transmitter. The shape of the figure so obtained indicates clearly the performance of the set.

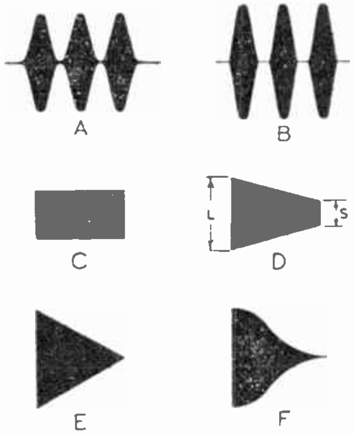


Fig. 21.
Typical oscilloscope images.
A. 100 per cent. modulated wave.
B. Overmodulated wave.
C. Carrier only.
D. Distortionless modulation less than 100 per cent.
E. Distortionless 100 per cent. modulation.
F. Non-linear modulation.

In Fig. 21C is shown the rectangular figure obtained with zero modulation. The figure becomes trapezoidal as in D when the modulation is applied and triangular when exactly 100 per cent. linear modulation is reached as in E. The percentage modulation may be obtained by measuring the height of the short and long ends of the figure. Calling these S and L respectively.

$$\text{Modulation} = \frac{L - S}{L + S} \times 100 \text{ per cent.}$$

Any curvature of the edges of the figure indicates non-linear modulation due to overloading or incorrect adjustment in one of the stages.

The construction of an oscilloscope does not fall within the scope of this Chapter, but it should be mentioned that there are now available a number of inexpensive cathode ray tubes suitable for this purpose, and reference should be made to Chapter 22 for publications dealing with their operation.

A small oscilloscope such as the RCA.913 or the GEC 4051 is suitable for obtaining all the effects described and this requires only a few hundred volts to operate it. A larger tube known as the E.40–G.3

World Radio History

has been introduced by the *Mullard Valve Co.* which has the advantage of a 3″ diameter screen on which the image can be made large enough for measurements of an accuracy sufficient for all amateur purposes.

Modulation Circuit Adjustment

It must be stressed at the outset that the operations to be described should invariably be made with the transmitter connected to an artificial aerial. Only when the operator is satisfied with the performance of his transmitter should the radiating system be connected.

Dealing first with the anode modulation system ; as has already been stated there should be no movement of the anode current meters of the modulated stage or of the modulator itself if this is of the Class A type. The presence of any movement of the modulated stage anode meter with less than 100 per cent. modulation can often be taken to indicate that which is incorrect in the adjustment of the circuit. The movement of the overmodulation indicator meter can similarly be used. A list of a few possible faults follows, together with the probable indication of the meter.

Anode Modulation

Fault.	Oscilloscope diagram (Fig. 22).	Meter movement.
P.A. bias too small	—	Down
R.F. drive too low	A	Down
Overmodulation	B	Up
Oscillation in P.A.	C	Up
P.A. to modulator, matching incorrect.	D	Down
P.A. overloaded	—	Down

The oscilloscope diagram letters shown in the anode modulation table, which refer to Fig. 22, show the probable type of image which will be obtained with the fault in question and when the oscilloscope is connected to produce the trapezoidal type of figure.

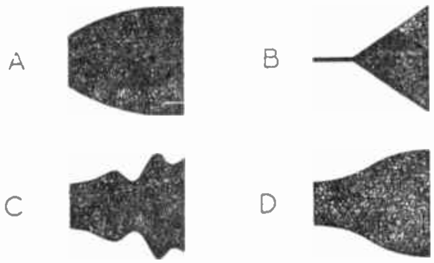


Fig. 22.
Oscilloscope patterns of an anode modulated stage.
A. Drive too low.
B. Overmodulation—too much audio input.
C. P.A. unstable or oscillating.
D. Incorrect matching of P.A. to modulator.

The adjustment of grid bias and suppressor grid modulation circuits is similar in principle, both being variable efficiency systems. The bias and drive conditions have been described earlier. It will generally be found, however, that a heavier aerial loading can be put on a grid modulated P.A. than on a plate modulated amplifier. This is a result of the unmodulated efficiency being necessarily much lower.

In the case of grid modulation a small rise of anode current at maximum modulation is permissible, but this should not exceed 10 per cent. at the most. Some of the more typical faults are given in the table below.

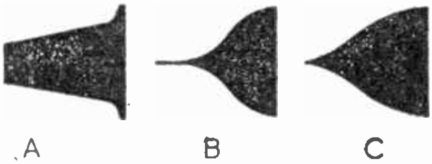


Fig. 23.
Oscilloscope patterns of a grid modulated stage.
A. Drive too high.
B. Overmodulation—too much audio input.
C. P.A. insufficiently loaded.

Grid Modulation

Fault.	Oscilloscope diagram (Fig. 23).	Meter movement.
R.F. drive too high	A	Down
Overmodulation	B	Up
P.A. insufficiently loaded	C	Down
P.A. bias too large	—	Up
P.A. bias too small or of too high resistance	—	Down

Monitoring

The continuous monitoring of a telephony transmitter is always advisable. This, of course, can be done on the station receiver, but unless it is well-screened and contains an input radio-frequency volume control, the detector stage is liable to be saturated and its output is no indication at all of the quality of transmission. It is also not permissible to listen to the harmonics of the transmission as is often done for C.W.

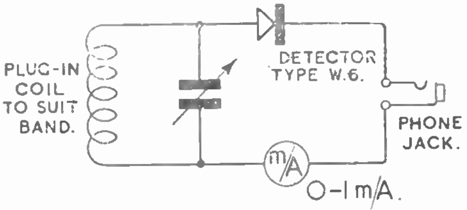


Fig. 24.
Circuit of phone monitor and overmodulation indicator.

A far better method is to use a separate monitor consisting simply of a tuned circuit which feeds a diode detector or more conveniently a Westector. The tuned circuit is weakly coupled to the transmitter, and the D.C. in the circuit is measured by means of a milliammeter. Fig. 24 shows the circuit of such a device. A pair of telephones can be jacked in and the quality of transmission judged by listening. A suitable detector is the Westector type W.6, but the coupling should not be increased beyond the point at which a current of 0·25 mA is obtained. If using a diode, this may consist of an ordinary triode with grid and anode strapped, but it has the disadvantage over the Westector that it needs an L.T. supply. It will operate more satisfactorily at the higher frequencies however.

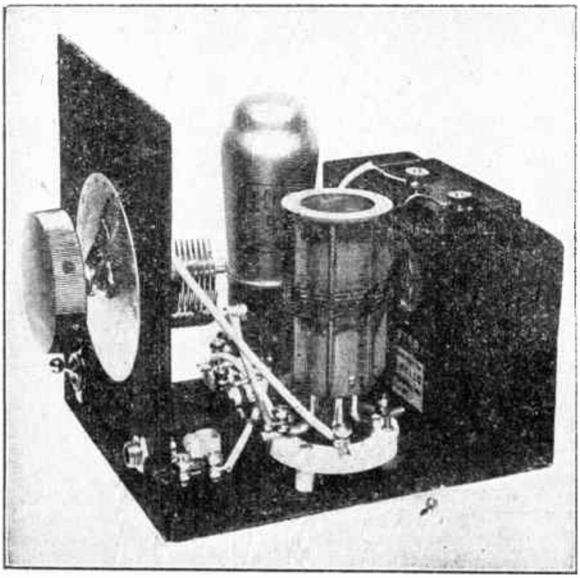


Fig. 25.

An easily constructed diode phone monitor employing a triode operating as a diode. A single 3 volt dry cell provides filament current and diode anode supply. A wire wound resistance is required to drop the filament voltage to a correct figure. Provision is made for head-phone monitoring.

Correction. Fig. 10. Page 120.

The fixed condenser connected between + 300 volts and earth should be shown connected between earth and the opposite end of the R.F.C.

World Radio History

Chapter Eight

AUDIO EQUIPMENT

Microphones—Carbon, Crystal, Condenser—Audio Amplifiers—Audio Frequency Transformers—Construction of Microphone Amplifiers—Power Supplies—Typical Design Features

MICROPHONES

Microphone Characteristics

THE link between the sound wave and the electrical apparatus in a telephony transmitter is the microphone. A microphone is really an instrument for the conversion of acoustic energy into electrical energy, and a full understanding of its function involves a study of complex electro-mechanical and acoustical theory. It will suit our purpose, however, to describe a few typical microphones which are available to the amateur, and to show how he can obtain the best results from them.

A satisfactory microphone must fulfil several requirements. In the first place it must be as sensitive as possible. That is to say the voltage or power output of the microphone into its electrical load must be as great as possible for a given sound intensity. Sound waves are generally measured by the magnitude of the alternating air pressure which constitutes them. This is of sine wave form for a single frequency tone and is generally measured by its R.M.S. value, as in the case of an alternating current wave. The unit used is the pressure in dynes per square centimetre. An alternative method is to measure the velocity of a particle of air as the wave passes. This is expressed as so many centimetres per second. For any medium such as air, the relationship between the acoustic pressure and the particle velocity is constant, and so it is immaterial whether our microphones respond to either quantity. Most microphones are operated by the pressure of the air wave upon their diaphragms, and since this is equal in all directions as in fluids, such microphones, generally called *pressure* microphones, are not very directional, that is to say they give some response, not necessarily perfect, to sounds arriving from the back and sides of the microphones as well as the front. In the case of *velocity* microphones, where the movement of the diaphragm depends upon the velocity of the air rather than the pressure, the microphone generally has a much more pronounced response to sound waves arriving in the direction perpendicular to the diaphragm than for a direction in the plane of the diaphragm. An example of this type is the ribbon microphone which has practically no output for sound coming from "sideways" positions. The directional characteristics of a microphone can be plotted as a polar diagram in exactly the same way as that of an aerial system.

Another very important characteristic of a microphone is its frequency response. For most purposes, a good microphone should give the same output for any frequency in the audible range. This may be from, say, 30 to 15,000 c.p.s. for high quality music reproduction, but 100 to 5,000 c.p.s. would be adequate for good speech. If, as is the case in many amateur transmitters, intelligibility rather than faithful reproduction is all that is aimed at, then a range of about 200 to 3,500 c.p.s. would be sufficient. It may actually be an advantage to have a rising characteristic at the high frequency end of the range. This may in practice increase the intelligibility at the receiving end in the face of interference, particularly when highly selective receivers are used.

It is most desirable, however, to strive to achieve as much fidelity as possible in any transmission when conditions allow, and for this reason all the audio-frequency equipment in a telephony station should have as good a performance as possible. It is perhaps unfortunate that high quality microphones are rather expensive and also invariably of low sensitivity. This means that a high amplifier gain is necessary before sufficient audio-frequency energy is available to modulate the transmitter. There are, however, several types of microphones now available to the amateur which strike a compromise and give very satisfactory quality, perticularly for speech, with only a moderate amount of amplification.

Carbon Microphones

The simplest type of microphone and the earliest to be invented, consists of a number of granules of carbon in loose contact, carrying the electric current from a D.C. supply of low voltage. When these granules are jostled by means of a diaphragm which is set in vibration by a sound wave, the resistance of the contacts between the carbon granules is varied and consequently the current in the circuit will vary more or less in sympathy with the sound pressures. There are two general types of carbon microphones in use ; first, the type used in ordinary commercial telephony, which includes the common solid back type. The great advantage of this instrument is that it gives a high electrical output, but the quality of reproduction obtained from it will not generally exceed that of commercial telephony and it is necessary to speak close to the instrument, which is normally held in the hand. A battery supply of two to six volts is usual for polarising, and a step-up transformer with a ratio of 1 : 50 used in conjunction with such a microphone will usually produce enough to operate the modulator grid direct.

The main reason for the high output is that the diaphragm, which is generally metallic, has several mechanical resonances in the audible range which cause the output to be very high at these frequencies but low elsewhere. The response is therefore "peaky" and cannot be considered to be of high quality.

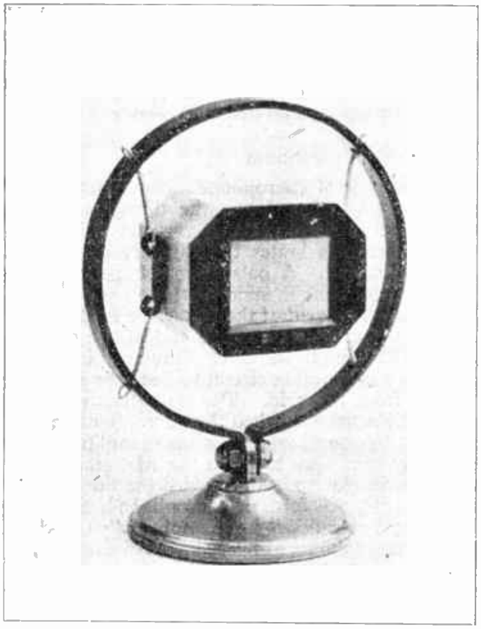


Fig. 1.

A transverse current carbon microphone built in accordance with the details given in Fig. 2.

The other class of the carbon type is the "transverse" current microphone. In this case a mica diaphragm is employed, behind which is a very thin layer of fine carbon granules. Current is passed from one edge of this layer to the other in a direction at right angles to the direction of vibration of the diaphragm. The frequency response is very much better than that of the solid-back or button type, but the output obtainable is much less. It is usually necessary to use either two or three resistance-coupled stages of amplification in order to drive fully, for example, a PX25 modulator valve. An input transformer for such a microphone must have a primary suitable for a 300–500 ohm circuit and a ratio of about 1 : 20 is common. Using a polarising voltage of 6 volts, feed currents of 15 to 20 mA are usual.

In all carbon microphones "blasting" is generally troublesome with loud speech or music, and for this reason they are not generally used for very high quality reproduction. The transverse current type of microphone is, however, probably the cheapest which will give satisfactory quality, and is therefore in very common use among amateurs. A large number are on the market, the cost ranging from about £2 upwards. Fig. 1 shows a home-made transverse current carbon microphone. Such a task is not beyond the capabilities of most amateurs, and constructional details have appeared from time to time in several radio journals. Fig. 2 gives the salient details required for the fabrication of this type of microphone. The main body, although frequently cut out of solid marble, can very well be made of a block of hardwood, the carbon cavities being built up by fixing several frames of very thin plywood or $\frac{1}{16}$″ paxolin to the face of the block. The electrodes are made of carbon rods taken from old dry cells, which can be drilled to take the terminal rods. The rods should be very smooth and are better if polished, although this is not essential. The diaphragm consists of an unblemished piece of mica, about ·002″ thick, which is cemented to the paxolin frame. The microphone must be filled with special carbon granules of about 100 or 150 mesh. These can be purchased from *Messrs. Siemens* or the *Morgan Crucible Co.* of Battersea. An ounce will fill several microphones, but they must be kept in the bottle until required in order to be absolutely dry. The microphone is filled through the two holes above the electrodes which are finally plugged and waxed over. The whole of the front cavity should be full.

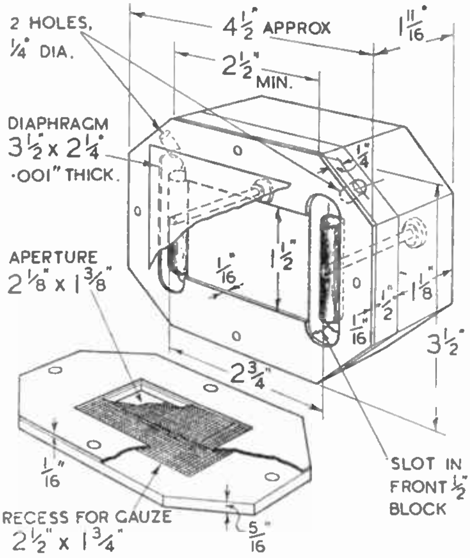


Fig. 2.

Constructional details of a transverse current microphone.

The polarising current can conveniently be drawn from a dry battery, or a potential divider circuit can be included in the speech amplifier to use the H.T. supply for this purpose, thus avoiding the need for a battery altogether. This method is used in the speech amplifier described at the end of the Chapter, to which reference should be made (Fig. 13).

After some use, the microphone may " pack " and become insensitive, in which case it should be thoroughly shaken with the polarising current switched off, and then gently tapped in its operating position to settle the granules back into place.

The carbon microphone made by the *General Electric Co.*, illustrated in Fig. 3, is a very popular type on account of its low price. This is not of the transverse current type, but it will give satisfactory speech quality for an inexpensive telephony station.

Most microphones will tend to pick up floor vibrations if rested directly on the table. For this reason they should preferably be placed on a piece of sorbo rubber, or suspended in a stand by means of springs or rubber rings.

Fig. 3.
A popular type of carbon microphone, manufactured by the General Electric Co., Ltd.

Crystal Microphones

Another type of microphone which has become popular of recent years is one which employs a piezo-electric crystal as a source of voltage. The crystal employed is a form of Rochelle salt which, when vibrated by means of a diaphragm, produces a piezo-electric voltage in a similar manner to the quartz crystal used for stabilising transmitters. It is, however, a much more sensitive material than quartz and with two stages of amplification, adequate output is obtained for driving small modulators.

A crystal microphone suitable for amateur use is illustrated in Fig. 4 and can be purchased at a reasonable price. For high fidelity work a better type of instrument is available, known as the " cell " type, in which the diaphragm is dispensed with, the sound acting directly on the crystal. Such types are less sensitive, however, and are much more costly. Crystal microphones do not require an input transformer nor any polarising voltage. They should be connected to the amplifier by means of a screened lead. The case is earthed *via* the screening to the earth lead of the amplifier while the " live " terminal of the microphone is taken direct to the grid of the first valve. A grid leak which should be of about one megohm is taken to a bias potential in the usual way. The capacity of the microphone is sufficiently high to allow the use of quite a long microphone lead without any appreciable loss of sensitivity. The capacity of the lead will not affect the high frequency response as is often imagined but will reduce the overall sensitivity if too large. This comes about because the microphone impedance itself is a capacity and not a resistance.

Condenser Microphones

In this type of microphone a condenser is used, of which one plate forms the diaphragm. The spacing between the plates is very small and when the diaphragm vibrates the capacity of the condenser is varied. A polarising voltage is applied to the microphone in series with a very high value grid leak. The grid of the first valve in the speech amplifier is connected to one end of the grid leak and the cathode to the other, using a suitable grid bias and a decoupling circuit to keep the polarising voltage from the grid. The potentials developed across the resistance when the microphone capacity is varied by sound waves are thus amplified. It is generally necessary to place the first stage of the amplifier in close proximity with the microphone ; consequently this form of microphone is commonly built into a so-called " head amplifier." Good condenser microphones are very expensive to buy, but it is not beyond the capabilities of a mechanically minded amateur to manufacture quite a successful one.

Fig. 4.
A diaphragm type crystal microphone suitable for amateur equipments.

Ribbon Microphones

All the microphones so far described are operated by the pressure of the sound wave upon a diaphragm or its equivalent. The ribbon microphone, as its name implies, consists of a small strip of aluminium foil suspended between the pole pieces of a powerful magnet. The aluminium ribbon is extremely light being generally not thicker than one ten thousandth of an inch. It thus follows the movement of the air exactly and in this way responds to the velocity of the air wave. No movement will result at all from a sound wave travelling in the plane of the strip but only when the wave strikes the front or back of the strip. The polar diagram is in fact identical with the radiation diagram of an horizontal dipole, *i.e.* a figure of eight. The strip has a very low resistance of the order of 0·5 ohm. The output from the strip is stepped-up by means of a transformer (ratio about 1 : 20) to say 200 ohms which is an impedance suitable for operating into a line. The primary of the transformer must match the strip resistance and consequently usually has only some 20 to 50 turns. The amplifier can be placed in any convenient position at the other end of the line, and should have a grid input transformer similar to that used for a transverse current carbon microphone. The output, however, is much less than with this type and three stages of high magnification are generally required in the amplifier.

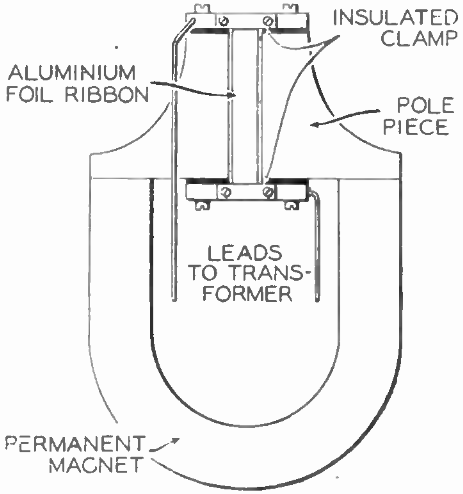


Fig. 5.

A diagrammatic view showing the construction of a simple ribbon microphone.

These microphones give exceptionally good quality and are easier to make than a condenser microphone. A full description is not possible here, but Fig. 5 shows in outline the principle of construction. Sometimes two magnets are used with their similar poles placed opposite, the strip being mounted in the centre. An amateur-built example on these lines is shown in Fig. 6. The transformer which is generally built on a small *mu-metal* core, should always be very close to the microphone. In the photograph referred to it is seen just below the microphone. Ribbon microphones are rather susceptible to draughts and for this reason a cover made of thin silk is generally placed over the ribbon and pole pieces.

One further point remains to be mentioned with regard to the use of ribbon microphones for speech. It will be found that if the speaker is too close to the microphone the quality will tend to be "boomy." This is an inherent trouble and can best be avoided by the use of sufficient gain to enable the microphone to be placed about 18" from the speaker.

Moving Coil Microphones

Another type of pressure microphone which is used extensively for broadcasting consists of a very light aluminium diaphragm carrying a small coil which vibrates in the annular gap of a magnet. The construction follows the general principles of the moving coil loudspeaker, indeed such a loudspeaker can be used as a microphone. The quality will not be very good owing to the mass of the diaphragm and coil being too great. This reduces the high frequency output giving a woolly or boomy tone. To overcome this defect the diaphragm of a proper moving coil microphone is made very small and the coil is generally wound with aluminium wire. Such microphones are usually very expensive and are not common in amateur stations, although less perfect but cheaper instruments are now becoming available.

Microphone Sensitivity

It has already been stated that the higher quality microphones are generally the least sensitive. The table which follows is intended as a rough guide to the relative sensitiveness of several types, but it should be borne in mind that individual makes may vary considerably.

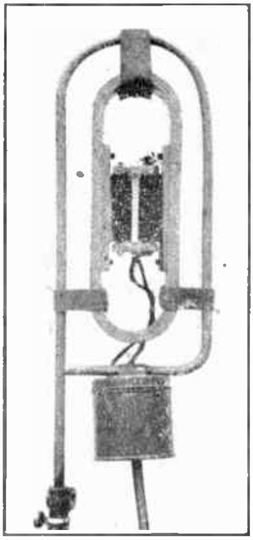


Fig. 6.

An amateur constructed ribbon microphone.

It is usual to specify the sensitivity of a microphone as the e.m.f. developed to a sound wave pressure of 1 dyne/cm². This e.m.f. is often expressed as the voltage level in decibels below one volt, but this is likely to be misleading to the amateur, as various microphones are used with transformers of different step-up ratios. For this reason, the table gives, very approximately, the voltage to be expected on the grid of the first valve when using a typical input circuit for average speech close to the microphone. These figures will naturally be less if the microphone is placed at a greater distance from the speaker. This latter procedure is to be recommended with any type of microphone for good quality.

Microphone Sensitivity

Type of Microphone.	Grid Voltage.	Transformer Ratio.
Solid back (carbon)	20	50
Transverse current (carbon)	·2	20
Condenser	·05	none
Ribbon	·03	10*
Moving coil ..	·05	30
Crystal (diaphragm type)	·05	none
Crystal (cell type)	·01	none

The voltages are approximate figures for normal speech close to the microphone.

*** In the case of the ribbon microphone it is assumed that the first transformer is included in the microphone. The ratio quoted is suitable for the amplifier input transformer.**

AUDIO AMPLIFIER DESIGN

In the previous chapter it has been seen that the modulator is required to deliver to an anode modulated stage an audio power of approximately one half the carrier power output. In order to obtain such an output, a large valve may be required in the modulator stage, and the output of the microphone must be amplified until it is sufficient to drive such a stage. Thus the required gain of the audio amplifier will depend upon the output of the microphone in use and the size of the modulator. It is always advisable to have a little more gain in hand than is actually required for normal speech in order that a speaker can fully modulate the transmitter even if he is not very close to the microphone. A volume control can be provided to adjust the gain according to the conditions.

The requirements of a speech amplifier can be summarised as follows :

(i.) The gain should be adequate and adjustble.

(ii.) The gain should be constant over the audio-frequency range (except in special circumstances).

(iii.) The harmonic distortion should be kept to a minimum.

(iv.) Valve noise and hum should be as low as possible.

Circuits

The circuits are generally of simple design on the lines of any other audio amplifier. Receiving valves of the battery type are sometimes used, but mains valves are more popular even for the first stages. The amplifier can generally be considered as a voltage amplifier, the output of which provides the grid voltage swing for the modulator, which is usually built into the transmitter. Sometimes, however, the modulator valve is fitted as the final stage of the speech amplifier, and this is the preferred arrangement where grid or suppressor modulation is employed, in which case the modulator power required is considerably less than for anode modulation.

Any of the well known methods of interstage coupling may be employed but resistance-capacity is commonest. The choice of component values is governed by requirements (ii.) and (iii.) above. Although a detailed account is not possible here, it may be useful to indicate the general procedure to avoid loss of amplification at the high and low ends of the frequency range.

In Fig. 7, V_1 and V_2 represent two stages in an amplifier. R_1 and R_2 are the two anode resistances, C_1 the coupling condenser and R_3 the grid leak. The condenser C_2 shown dotted represents the effective input capacity of the valve.

Assuming that a triode is in use, this will consist of the grid-cathode capacity plus the grid-anode capacity multiplied by the effective amplification of V_2. This latter part usually forms the bulk of C_2, and for most purposes the grid-cathode capacity can be neglected, but any stray capacities due to wiring and valve-holder should be included.

Considering first the performance at frequencies in the middle of the range, the effect of the grid condenser and leak and the input capacity can be

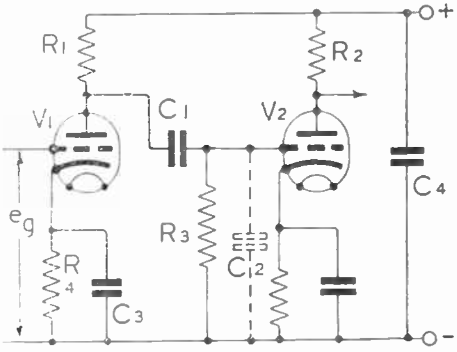


Fig. 7.

Two typical resistance-capacity coupled audio amplifier stages. The method of calculating the stage gain and frequency distortion is described in the text.

World Radio History

neglected. The equivalent circuit of V_1 then become that shown in Fig. 8A. The valve V_1 has been replaced by a resistance equal to its anode impedance (R_a) in series with a voltage equal to the signal voltage on the grid (e_g) multiplied by the magnification factor of the valve (μ). The load on the valve is R_1, which is connected between anode and earth through the H.T. by-pass condenser C_4 of Fig. 7, which is assumed to be large enough to be neglected. R_3 will generally be very high compared with R_1, and C_2 will be small enough to be neglected at medium audio-frequencies. The output voltage V in Fig. 8A is developed across R_1, and it is easy to see that:

$$V = \mu\, e_g \times \frac{R_1}{R_1 + R_a}$$

Now the voltage amplification of the stage is the output voltage divided by the input voltage, *i.e.*:

$$\frac{V}{e_g} = \frac{\mu\, R_1}{R_1 + R_a}$$

This quantity is the effective voltage amplification of the stage.

In order therefore to keep the stage gain high, R_1 must be kept high compared with R_a. If it is made excessive, however, too much D.C. voltage will be dropped across it, and the H.T. voltage must be very high in order to maintain a suitable working D.C. voltage in the anode. For this reason the value of R_1 is rarely made greater than about four or five times R_a.

At very low frequencies, the reactance of C_1 may become appreciable and the equivalent circuit now becomes that shown in Fig. 8B. The output voltage now appears across the grid leak R_3. This is actually always the case, but in Fig. 8A the reactance of C_1 was considered to be too small to have any effect, and as the grid leak is too high to shunt R_1 appreciably, the voltage V was considered to appear directly across R_1.

As the frequency becomes lower, however, the reactance of C_1 rises and the output voltage is reduced, owing to the fact that the grid of V_2 receives only the voltage across R_3. The amplification at low frequencies is reduced to:

$$\frac{R_3}{\sqrt{R_3^2 + \frac{1}{\omega^2 C_1^2}}} \times 100 \text{ per cent.}$$

of the amplification at medium frequencies. The low-frequency loss at any particular frequency can be calculated in this manner for any given values of R_3 and C_1. The amplification should preferably not fall below 70 per cent. at about 100 c.p.s. for speech or 50 c.p.s. for music.

To ensure this, the value of condenser and grid leak should be chosen so as to make $\frac{1}{\omega C} = R_3$ at the lowest frequency required. In these equations, it is understood that ω is equal to 2π (*i.e.* 6·28) times the frequency considered.

Turning now to the high frequency end of the range, the effect of the grid leak and condenser will be negligible, but the reactance of C_2 may fall low enough to produce an appreciable loss. The equivalent circuit for this case is shown in Fig. 8C. The condenser C_2 is effective across R_1 and R_a in parallel. Let R_0 be the value of R_1 and R_a in parallel, *i.e.*:

$$R_0 = \frac{R_1\, R_a}{R_1 + R_a}$$

Then the amplification at the high frequencies will be reduced to:

$$\sqrt{\frac{1}{1 + \omega^2 R_0^2 C_2^2}} \times 100 \text{ per cent.}$$

The values of R_1 and R_a (giving R_0) and C_2 should preferably be such that the amplification is not reduced below 70 per cent. at, say, 4,000 c.p.s. for speech or 7,000 c.p.s. for music.

It should be noted that the losses suggested should apply to the complete amplifier, and where more than one coupling is used, as in a three or four stage amplifier, the components should be so chosen that the product of them all does not exceed the suggested figure.

Where sufficient resistance cannot be put in the anode circuit without producing too much reduction in anode voltage, a choke is sometimes used. In this case, the inductance must be of such a value that its reactance at low frequencies is large compared with the anode impedance of the valve.

Transformers are sometimes used as interstage couplings, but with the gain available from modern valves it is usual to employ a transformer only when a push-pull stage is required.

Input transformers are often required to step up the microphone output voltage, while a transformer is also commonly used to couple the last valve of the amplifier to the modulator, particularly when a length of line intervenes. Further information on transformers will be found in a latter part of this chapter.

When using indirectly heated cathode valves, grid bias is generally obtained from a cathode resistance. This is shown as R_4 in Fig. 7 and should be shunted by a condenser C_3. The

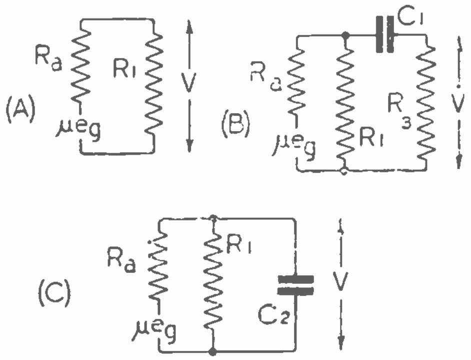


Fig. 8.

The equivalent circuit of V_1 in Fig. 7.

A. At medium frequencies.

B. At low frequencies showing the effect of the grid leak and condenser.

C. At high frequencies showing the effect of the input capacity of V_2.

World Radio History

reactance of this should be small compared with R_4 at the lowest working frequency, or the resistance will produce a negative feedback at these frequencies with consequent bass loss. Electrolytic condensers are usual for this position. The positive terminal of such a condenser is connected to the cathode.

To prevent the variations in anode current of the last valve from introducing signals back into the earlier stages with the likelihood of " motorboating," anode decoupling is generally necessary. A resistance is connected between the H.T. positive terminal and each of the anode resistances of the valves. A large condenser is connected between the junction of the resistances and earth.

A volume control should be incorporated in all speech amplifier circuits to obtain a suitable degree of modulation with any reasonable speech level. The commonest type consists of a potentiometer which is used as a grid leak to one of the stages. The resistance R_3 of Fig. 7 could very well be substituted by a potentiometer of the same value, the slider being connected to the grid of V_2. It is as well to avoid the use of potentiometers having resistances higher than $0{\cdot}25\text{M}\Omega$ where possible, or there may be a tendency for the frequency characteristic to vary with various settings of the volume control.

A potentiometer is sometimes connected across the secondary of the input transformer, but care should be taken that the transformer is suitable for operating into such a load. It is desirable to put the volume control in an early stage of the amplifier, or overloading may occur in stages preceding the potentiometer when high sound inputs are encountered. The lead between the grid and the volume control should be kept as short as possible. It is sometimes advisable to mount the potentiometer close to the valveholder in question and to use an extension to the knob on the panel. Flexible extensions are now available for this purpose, which may be useful when the potentiometer must be mounted in an awkward position.

Variable-μ valves can be used in the first stages of audio amplifiers, but unless great care is taken there is a tendency for harmonic distortion to occur.

The various types of tone-control met in broadcast receiver practice can be applied to speech amplifiers where necessary, but on the whole amateurs are advised to use a microphone with a good characteristic followed by amplifiers with a flat frequency response.

Harmonic Distortion

The choice of circuit components has been dealt with so far from the point of view of frequency distortion. The introduction of harmonics in a speech amplifier can produce distortion much more destructive to speech quality than the lack or over-accentuation of certain frequency bands.

The most fruitful source of harmonic distortion is the overloading of one or more valves in the amplifier. Considering the modulator valve itself, this is the most likely to become overloaded, but various types of circuit for the production of large outputs have already been described in a previous Chapter, and providing the recommendations therein are followed, no serious trouble will be encountered. It is equally necessary that the valve prior to the modulator shall be capable of supplying a sufficient output voltage to drive the modulator without itself being overloaded. This should not be difficult with the Class A type stages employed in speech amplifiers. The use of too low an anode resistance tends to produce distortion of a heavily loaded stage, but this circumstance will probably not be met in practice, as the gain would be reduced considerably by using such a low value.

Where the modulator is of the Class B type, particular care should be directed to the previous valve, which is generally called the driver stage. The latter should be of a low impedance type, and a good driver transformer will be required to couple it to the Class B stage. The ratio will be 1 : 1 or perhaps even a step-down ratio, in order to provide a low impedance facing the Class B grid circuit. The object of this is to enable the Class B valves to be driven into grid current without distorting the input waveform.

Another source of harmonic distortion is the iron employed in the cores of chokes and transformers. Input and intervalve transformers are usually quite safe, but if the cores of output transformers and chokes are too small, considerable third harmonic distortion of the low speech frequencies may result. This remark applies particularly to transformers and chokes coupling the modulator to the modulated R.F. amplifier. It is perhaps fortunate that although the presence of D.C. passing through such chokes reduces their inductance, it does tend to reduce the harmonic production, particularly if an air gap is used.

Feedback (Degenerative) Amplifiers

A method of reducing both frequency and harmonic distortion in amplifiers, which has come into prominence recently, is the use of negative feedback.

Imagine an amplifier which has an output of, say, 10 volts for an input of 1 volt. Suppose that for 10 volts of output, 0·5 volt is fed back to the input circuit in the reverse phase. That is to say, when a positive signal of 1 volt is applied to the input, a negative signal of 0·5 volt is also fed back to the input from the output circuit. The nett voltage on the input will now be $1 - 0{\cdot}5 = 0{\cdot}5$ volt. Thus an extra 0·5 volt must be supplied from the source to maintain the output at its previous value. This means that the gain of the amplifier will have been effectively reduced, actually by 2 : 1 in the case cited. The harmonics produced in the output stage are also fed back in the reverse phase, which reduces the harmonic content in the same ratio as the gain. There are two types of circuit in use. In one the feedback voltage is proportional to the output voltage. In Fig. 9A, a potentiometer is shown connected across the output load, and a fraction of the output voltage is connected in series with the input. In Fig. 9B, a resistance is connected in series with the load, and the voltage developed across it is connected in series with the input. In this case the feedback voltage is proportional to the output current. As feedback circuits are often applied to voltage amplifiers where there

World Radio History

is little or no load current the first arrangement is rather more popular. It is not proposed to add any detailed description of feedback amplifiers at this stage as the valves which are now commonly available are able to provide sufficient power with low harmonic introduction for most amateur purposes.

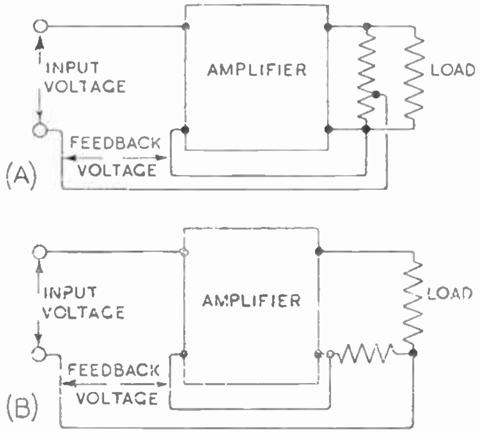


Fig. 9.

Illustrating the principle of the feedback amplifier. In (A) a voltage proportional to the output voltage is fed back to the grid circuit. In (B) the feedback voltage is proportional to the output current.

AUDIO-FREQUENCY TRANSFORMERS

General Theory

Transformers are required for connecting most types of microphone to the first valve of a speech amplifier, for intervalve coupling, and for connecting the load to the output of the last valve. The usual function of a transformer is that of an impedance changer.

Assuming that there are few or no losses in a transformer, the watts in the secondary circuit must be almost the same as the watts in the primary. If, therefore, the transformer steps-up the voltage in a circuit, the current must be reduced in the same ratio. This means that the nature of the circuit has been changed such that its voltage is higher and current lower, *i.e.* its impedance has been raised. In the design of power transformers, it is the changes of current and voltage which are important, but in audio transformers the change in impedance may assume the major rôle. A further difference is that the power transformer is generally required to operate at a single frequency only, while the audio transformer must work equally well over the whole audio frequency range. This means that the effective step-up ratio must remain constant. It will be seen later that step-up ratio may not be exactly equal in practice to the turns ratio at the upper and lower ends of the frequency range.

The voltage is stepped up by an amount equal to the turns ratio, and the current is stepped down by a similar ratio. Since impedance is measured as the ratio of voltage to current in a circuit, it is clear that the impedance ratio is equal to the square of the turns ratio. In Fig. 10, the primary of an audio transformer has T_1 turns and the secondary T_2 turns. Across the secondary terminals is connected a resistance of R_2 ohms. If the effective resistance is measured across the primary terminals at an audio-frequency, a value of R_2 times the square of the turns ratio will be obtained. This resistance has nothing to do with the copper resistance of the windings, which is assumed to be small. It is termed the " referred resistance " or the resistance " looking into " the primary. Thus:

$$R_1 = R_2 \times \left(\frac{T_1}{T_2}\right)^2$$

This property of the transformer is particularly useful in the case of output transformers. In Chapter 7, Fig. 14C shows a radio-frequency amplifier V_1 being modulated by a modulator V_2. It has been seen that the valve V_1 is equivalent to a resistance equal to its D.C. anode voltage divided by the anode current. This forms the audio load of V_2, but it may not be of a suitable value for the valve in use. The turns ratio of the transformer T must be chosen in order that the resistance seen looking into the modulator winding is a suitable load for V_2.

The usual load for best operation is about twice the anode impedance of V_2. Suppose that V_1 operates at 50 mA with an anode voltage of 500v, then the effective resistance of V_1 will be:

$$\frac{500}{50} \times 1{,}000 = 10{,}000 \text{ ohms.}$$

The valve V_2 may be a PX25 with an anode impedance of 1,250 ohms and will consequently require a load of 2,500 ohms. The impedance ratio required is therefore:

$$\frac{10{,}000}{2{,}500} = 4:1$$

The turns ratio must therefore be equal to:

$$\sqrt{4} \text{ or } 2:1$$

Hence the transformer must have twice as many turns on the winding connected to V_1 as it has on the modulator side. This means, of course, that the audio voltage applied to V_1 will be twice the anode voltage swing of V_2.

In the case of an input transformer coupling, for example, a transverse current microphone to the grid of a triode, it is required to use as large a step-up ratio as possible in order to get the maximum sensitivity. But in so doing the impedance of the microphone will be raised by the square of

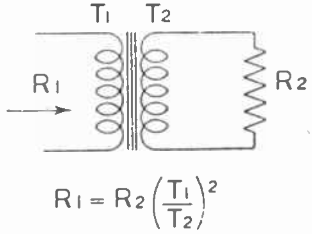


Fig. 10.

The effect of secondary resistance R_2 referred to the primary of the transformer.

World Radio History

this ratio. The maximum impedance of the secondary is limited by the inadvisability of using an impedance higher than about 100,000 ohms in the grid circuit of a high magnification triode. The microphone may be drawing a current of 23 mA at 6 volts, so that its resistance is :

$$\frac{6}{23} \times 1{,}000 = 250 \text{ ohms.}$$

The impedance ratio will therefore be :

$$\frac{100{,}000}{250} = 400.$$

Thus the turns ratio will need to be

$$\sqrt{400} = 20.$$

It is because microphones of the condenser and crystal types are already of very high impedance that it is not advisable to use a step-up transformer in conjunction with them.

It is now necessary to see why the step-up ratio of a transformer is not constant with frequency in practical designs. It must be understood that in a well-proportioned transformer the voltage ratio is very close to the turns ratio over most of the audio-frequency range, so that it is at very low and very high frequencies that its defects must be studied. Fig. 11 shows a transformer coupling a generator or source (R_1), such as a modulator valve, to a load such as a modulated R.F. amplifier (R_2). In order to make the calculation more easy the transformer is first considered to have its ratio changed to 1 : 1. In order to do this, the value of all impedances on one side, say that on the right, must be altered by the square of the turns ratio. This has been done in Fig. 11B. If the turns ratio in practice is 1 : n, then R_2 becomes R_2/n^2 in the equivalent unity ratio case.

A capacity C, which may be due to wiring and other strays, is shown dotted in A. This becomes n^2C in B, since the impedance of a condenser varies *inversely* as its capacity. The effect of the condenser will be neglected for the moment. The inductance of the primary is taken as L. The secondary inductance of the 1 : 1 ratio transformer in B will also be equal to L, as both windings now have the same number of turns.

Although the two windings are wound close to each other on the same core, the coupling between them will not be quite perfect. The number of lines of force generated by the primary which, due to this imperfect coupling, do not link with the secondary, give rise to a quantity known as the "leakage inductance," which can be called *l*.

Now it may be shown that a 1 : 1 ratio transformer can be replaced by an equivalent circuit as shown in Fig. 11C. Here the part of the circuit enclosed by the dotted rectangle replaces precisely the two windings of the transformer. The primary inductance L appears in shunt across the circuit, and the leakage inductance appears in series, one half on each side of L. From such a circuit, the frequency distortion of the transformer can be studied.

Over the larger part of the frequency range the reactance of L (*i.e.* ωL) should be so large that it can be neglected and the reactance of the leakage inductance (ω*l*) is sufficiently small to have no effect. Thus the effect of the transformer on the circuit is negligible. At very low frequencies, however, the reactance of L will become lower and some of the current from the source will flow through it, depriving the load R_2 of a certain amount of current. This is the cause of the so-called "bass loss" of a transformer. At very high frequencies ωL will become very great and will do no harm, but ω*l* will be large enough to put a series reactance in the circuit and cause a reduction in current through R_2. It is thus the leakage inductance which causes the high frequency loss.

Now it is an unfortunate fact that if the turns on the transformer windings are increased to reduce the shunt loss due to ωL, the leakage inductance will be increased and give rise to an increased "top" loss. Thus not only must the primary and secondary turns be in the correct ratio, but the actual number of turns must be carefully chosen so that the shunt inductance L is large enough to prevent a large bass loss without giving an unduly high top loss due to the leakage inductance.

If the capacity in the circuit is large enough, the condenser n^2C may cause a further distortion. It is possible that in some instances it may react with the leakage inductance to produce a resonant rise of voltage across the load at the higher frequencies. This is particularly the case with input transformers where the step-up ratio (n) may be large and the capacity C may be enhanced by the

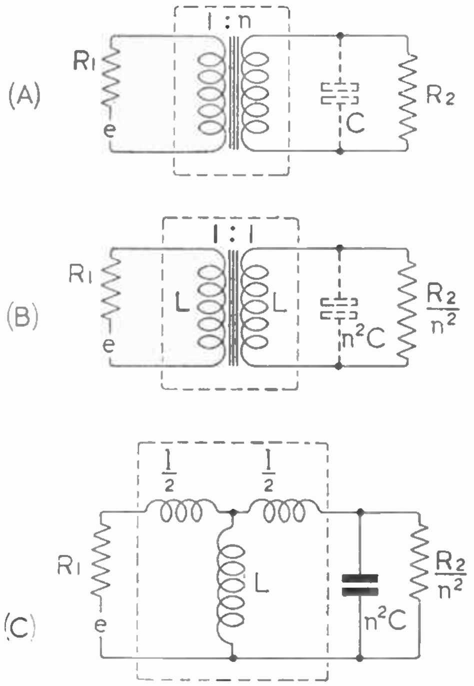


Fig. 11.

A. A transformer, ratio 1 : n couples a load R_2 to a source R_1.

B. The same circuit with the transformer converted to unity ratio.

C. Transformer replaced by its equivalent circuit.
Primary inductance = L.
Leakage inductance = *l*.

input capacity of the valve. This will give rise to a relatively large value for n^2C. It is for this reason that the ratio should not be made too great in such transformers.

The value of L depends largely upon the size and material of the core. Special alloys such as *Radiometal* and *Mumetal* are used to keep L high, but as they are very expensive their use will not be considered here. In order to keep the leakage inductance (l) small, the coupling between the windings must be kept high. This is frequently done by dividing the secondary (or high impedance winding) into two parts and inserting the primary between them. In this way, the leakage can be reduced to one half or one third of that obtained for a simple winding: Fig. 12 illustrates this point. Where a winding feeds a grid, this should always be connected to the outer end in order to reduce the capacity as much as possible.

Design and Construction

It will be realised that precise transformer design is somewhat complex, but the following procedure will enable the amateur to make the simpler types of transformer without any serious design errors.

The first point to decide is the turns *ratio.* Enough has already been said to enable this to be done quite accurately. Finding the actual turns for the windings is not so easy and depends largely upon the core available and the type of winding used. A few cores only, of the type likely to be available, are suggested here, and the windings are assumed to be of one of the two varieties illustrated in Fig. 12A and B. Knowing the impedance with which each winding is to operate the turns can be obtained from the table below. The figures have been calculated for the best results at frequencies between 50 and 7,000 c.p.s.

Core size.	Material.	Value of K.	
		For type A winding.	For type B winding.
Sankey No. 4 (square section)	Stalloy	575	315
Ferranti A.F.3	Armco	560	305
Ferranti A.F.5	Armco	760	415

The turns for any winding can be calculated from the formula :—

$$N = 1{,}000\sqrt{\frac{R}{K}}$$

Where N = Number of turns.
R = Resistance of circuit.
K = Constant from table.

The gauge of wire used should be such as to fill the winding space completely, and the primary and secondary should each be allotted approximately one half of the space. The turns should be laid up neatly, and it may be an advantage to place a piece of very thin paper between every few layers. The choice of a suitable gauge can be made by studying the directions and tables given in connection with power transformer design in Chapter 9.

Where a direct current is carried by one of the windings, the values of K given in the table are not very reliable. As a rough guide, it is suggested that these values might be increased by about 25 per cent. for currents which give a value of ampere turns not greater than about 500.

The design of intervalve and driver transformers is too complex to be considered here, and amateurs are well advised to purchase such transformers from one of the many firms who carry stocks of standard lines or who will make up special transformers to suit any particular requirements. When ordering such transformers, the information supplied should include the impedances between which the transformer is to work, the frequency range required, the audio power to be handled, and the value of direct current, if any, in the windings.

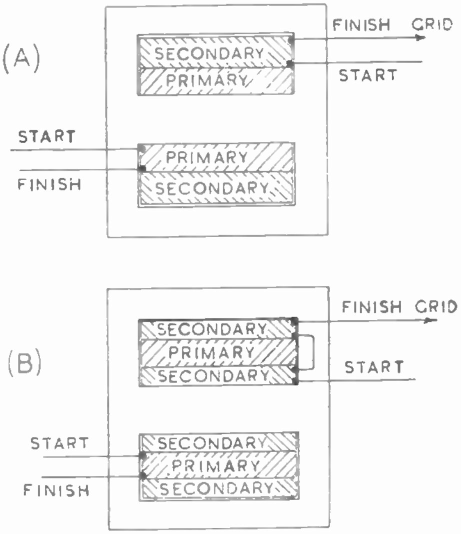


Fig. 12.
Two types of audio transformer winding. B. has a lower leakage inductance than A.

CONSTRUCTION OF MICROPHONE AMPLIFIERS

It must be admitted that the mechanical layout of an audio-frequency amplifier is not quite such an intricate problem as that of the radio-frequency stages of the transmitter itself. Nevertheless a number of points require careful attention.

Layout

It is usual to mount the valveholders in the sequence of the circuit on a metal chassis which also carries the various components. Such a procedure is not essential, however, and a wooden baseboard may be used if preferred. In the latter case, unless, as is strongly recommended, the whole amplifier is put in a metal box, it is a good plan to cover the baseboard with a thin sheet of copper before fixing the components.

Where A.C. heated valves are used, the heater leads should be twisted, or a small-sized lead-covered cable can be used. The heater circuit must always be earthed, either at the centre point of the L.T. transformer or by the slider of a potentiometer of about 30 ohms connected across the heater circuit. Care should be exercised, however, to avoid doing both.

Grid leads to volume controls and input transformers should be kept short and away from heater circuits. Power transformers should never be incorporated on the same chassis, to prevent induction hum in the audio transformers.

The location of the finished amplifier should be well away from any power transformers and also away from the transmitter itself as far as possible.

Where pickup is traced to induction between an amplifier transformer and a power transformer, it can often be reduced by changing the relative angle between them. Further, it is advisable to mount the output transformer well away from the input transformer, although the latter should always be on the chassis itself to keep the first grid lead short. Where feasible, it is good practice to mount these two transformers with their cores at right-angles to each other.

The valve holder of the first valve should preferably be of the anti-vibration type. A standard valve holder can sometimes be mounted on a piece of sorbo rubber, using a few inches of thin flexible wire to connect it to the circuit. This precaution is most necessary when very insensitive microphones are employed, *i.e.* where the gain of the amplifier is very high.

An anode current meter for the final valve is always an advantage, and a system of jacks or switches is sometimes used to insert the meter into the previous anode circuits at will.

Where electrolytic anode decoupling condensers are used, these should be capable of working at the full H.T. voltage, as the voltage across them will not fall to normal until the cathodes have warmed up. The screws fixing the laminations of output transformers and chokes, particularly in Class B stages, should always be quite tight, as a few laminations can make an appreciable noise if left loose enough to vibrate.

R.F. Pick-up and Feedback

One of the most difficult problems encountered when using insensitive microphones in a radiotelephony transmitter is the unwanted introduction of radio-frequency energy into the early stages of the audio equipment. When this happens, the radio-frequency current becomes rectified in the first valve, and the resultant output is fed back to the transmitter *via* the modulator. An audio-frequency oscillation then takes place. In severe cases it may be impossible to use sufficient gain to modulate the transmitter before this occurs.

On the R.F. side every precaution must be taken to prevent the stray radio field from spreading unnecessarily. Complete screening of the transmitter is expensive, but is strongly recommended wherever possible. The use of R.F. chokes in the power circuits is also recommended, while feeders of the balanced type rather than single wires help to minimise the stray field. The audio amplifier should be placed as far away from the final radio frequency stage and the aerial feeders as the station plan will permit. Wherever possible, an earth lead should be taken to the audio amplifier which is separate and distinct from that used to earth the frame and circuits of the transmitter. This prevents the application to the amplifier of R.F. potentials due to R.F. currents flowing in the transmitter earth lead. Both of these earth leads are better made of a thin copper tape than a wire.

There are also a number of precautions which can be taken in the design of the audio amplifier itself for the purpose of preventing R.F. feedback troubles. As has already been mentioned, the latter should be completely screened in an aluminium or copper box. The screening of all leads, such as the microphone and output leads and preferably even the supply cables, is helpful, the screens being connected to the amplifier case where they enter it.

It must be remembered that R.F. feedback trouble can only occur if rectification takes place. Since this can only be effected in the valves themselves it is more important to prevent the R F. energy from reaching them than any other parts of the circuit. Some R.F. energy may creep into the audio circuits in spite of all the screening measures recommended above.

In this case "grid-stoppers" are a useful remedy. A resistance of from 1,000 to 5,000 ohms is suitable, but it must be of the metallised or carbon type; the half-watt size is preferable. These grid-stoppers must be mounted directly on the grid connection of the valveholder. A wire connection from a separately mounted grid stopper would allow a small amount of pickup to reach the grid directly. In extreme cases, a resonant choke can replace the resistance, but this must be small in dimensions, or well screened, in order to prevent direct pickup by the choke. The chôke should be resonant to the transmitter frequency with both ends free. This can be checked by absorption with a simple oscillating receiver. A choke suitable for the 14 Mc band, for example, can be made on a $\frac{5}{16}$" former using 46 S.W.G. enamelled wire wound to a length of about $\frac{11}{16}$".

When the power supply leads to the amplifier are long, they can be filtered at the point of entry, inside the amplifier screening box. A small choke, capable of carrying the current of the circuit employed is put in each lead and a condenser of about 0·01 μF connected from the amplifier side of each choke to the earthed chassis. By-pass condensers of this size are also helpful when connected from the heater or filament terminals of the first valve to the chassis, and also across the microphone terminals in the case of low-impedance microphones, such as the carbon and ribbon types.

POWER SUPPLIES

There are few unusual features in the design of the power supply for audio-frequency amplifiers, most of the well-known circuits being suitable. It should be noted, however, that the smoothing required is greater than for any other part of the transmitter, since considerable gain may exist at the ripple frequencies. Anode circuit decoupling naturally assists in this respect. In the case of a

World Radio History

Class B stage, particular care must be taken to ensure good voltage regulation. This generally means the use of mercury vapour valves with choke input filters. Full design details will be found in Chapter 9.

The final smoothing condenser of any rectifier circuit should always be as great as possible; since trouble in the form of motor-boating may be encountered if this capacity is insufficient.

TYPICAL DESIGN

By way of illustrating some of the ideas discussed above, a practical circuit will be described.

Fig. 13 shows the circuit of an amplifier which is suitable for use with a transverse current carbon microphone. The maximum output obtainable is about 3 to 4 watts, which would be sufficient for anode-modulation of a lower power transmitter directly for carrier powers up to about 10 watts. For larger transmitters, the output is enough to drive a Class A modulator dissipating up to 100 watts. The amplifier is also quite suitable for suppressor grid modulation of transmitters up to 70 watts. The output transformer incorporated (Type TR1—*Partridge*) is designed for this purpose.

The circuit is seen to be of conventional resistance-coupled design with an input transformer (Type MR300/500—*Partridge*) to suit the microphone. The secondary load R_1 can be omitted with some transformers.

In the grid line to the first and subsequent valves, a grid stopping resistance is inserted as a precaution against R.F. feedback. These resistances have a value not exceeding 5,000 ohms and are of the ½ or 1 watt class.

Automatic biasing is employed for all stages.

To prevent bass cut, each bias resistor is bypassed to earth through a 50 µF electrolytic condenser. A high value of by-pass is desirable (so that its reactance is very low compared with the bias resistance) to avoid negative feedback to the grid at the lower frequencies. For the first two stages a 12 volt type is satisfactory, but for the third a 50 volt type is recommended.

De-coupling in the first stage is obtained by the use of a 50,000 ohm resistance and an 8 µF condenser; in the case of the second stage a 4 µF condenser is used in conjunction with a 10,000 ohm resistance.

The values of capacity and resistance specified for inter-stage coupling have been chosen to suit the circuit arrangement. The de-coupling condensers C_2 and C_3 are incorporated to prevent feedback and hum, the former having double the capacity of C_3 as these dangers are more likely to occur in the first stage.

If feedback should occur in this stage, it is permissible to use two 25,000 ohm resistances in place of R_5, in which case a by-pass condenser of 4 µF capacity should be connected between the junction of R_4 and the lower 25,000 ohm resistance. C_2 should then be connected between the centre point of the two 25,000 ohm resistances and earth.

It will be noticed that the gain control R_{13} is fitted to the input of the last stage; this position is recommended as it controls not only audio gain but also the valve noise of the early stages. If the gain control is inserted in the first stage, control of input level only will be affected. The control takes the form of a ·25 megohm potentiometer of the logarithmic type.

The automatic bias for the last valve is obtained by the use of a 50 ohm centre-tapped resistance R_{16} the middle point of which is taken to the bias resistance R_{15}, and this in turn is by-passed to earth *via* C_6.

The output transformer has a ratio of 1 : 1. When used for suppressor-grid modulation, a resistance of about 10,000 ohms should be connected as a secondary load. The necessity of a

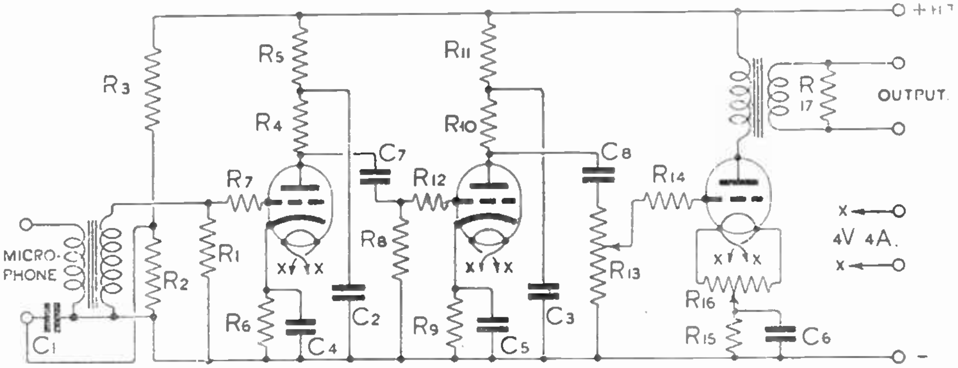


Fig. 13.

Circuit diagram of 3-stage resistance capacity coupled speech amplifier, giving 3 watts audio output.

C_1, C_6	50 µF, 50 volts.
C_2	8 µF, 500 volts.
C_3	4 µF, 500 volts.
C_4, C_5	50 µF, 12 volts.
C_7, C_8	.1 µF, fixed.
R_1	.25 megohm.
R_2	2,000 ohms, 1 watt.
R_3, R_{17}	30,000 ohms, 3 watts.
R_4	50,000 ohms, 1 watt.
R_6	1,000 ohms, 1 watt.
R_7, R_{12}, R_{14}	5,000 ohms, 1 watt.
R_8	.5 megohm.
R_9	500 ohms, 1 watt.
R_{10}	30,000 ohms, 1 watt.
R_{11}	10,000 ohms, 1 watt.
R_{13}	.25 megohm potentiometer
R_{15}	900 ohms, 1 watt.,
R_{16}	50 ohms, centre tap.
Valves	2 HL4+ or MH4. 1 015/400 or PX4.

polarising battery has been overcome by using a potentiometer consisting of a 3 watt 30,000 ohm resistance R_3, in series with a 1 watt 2,000 ohm resistance R_2. These resistances are connected across the main H.T. supply, and the polarising voltage for the microphone appears across R_2. In the particular amplifier under discussion this voltage is in the order of 4 volts when the H.T. supply is 350 volts. To avoid any possibility of hum being introduced into the grid of the first stage, a 50 μF 50 volt electrolytic condenser (C_1) is connected across R_2.

The amplifier is housed in an aluminium cabinet, and the chassis is raised 1" from the base to allow the small components to be mounted on the under side. On top of the chassis are mounted the electrolytic condensers C_2, C_3, C_4 and C_5, the three valves and the transformers. All other components are mounted or wired-in on the under side.

The output and supply terminals are mounted at the back of the cabinet, whilst the microphone jack is fitted at the left-hand side.

The gain-control potentiometer is mounted centrally in the front of the cabinet, and ventilation holes are drilled in the lid.

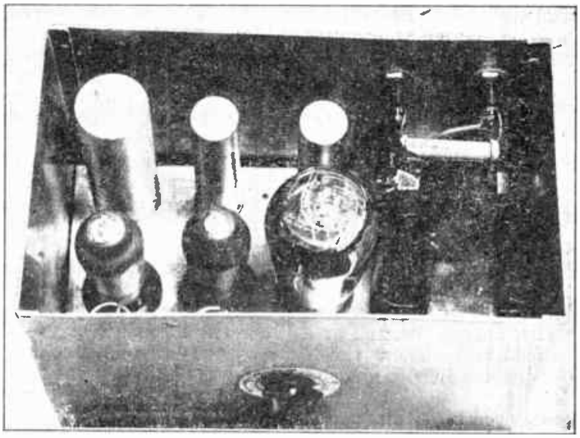


Fig. 14.

Lay-out of a three-stage resistance capacity coupled amplifier giving 3 watts audio output.

The grid stoppers, R_7, R_{12} and R_{14}, should be fitted as closely as possible to the grid pin of their associated valve holders. It should not be found necessary to employ screening for individual components, but the leads to the heater terminals should be twisted and kept clear of the grid wiring.

The amplifier has been designed to work from a 350 volt 60 mA power supply, but voltages up to 450 volts can be used without encountering danger. A 350 volt supply will give, with the valves specified, an audio output of about 3 watts, which will be increased to about 4 watts if the H.T. is raised by another 100 volts. By changing to a suitable type of output transformer it would be possible to use the amplifier for plate modulation of a 10 watt power amplifier.

The filament supply should give 4 volts at 4 amps.

It will be of interest to calculate the voltage amplification of the amplifier on the lines indicated earlier in this Chapter. It will be assumed that the valves specified are used.

For the first stage, the following conditions hold:

$$\text{Effective amplification} = \frac{\mu R_1}{R_1 + R_2}$$

where R_1 is the anode load $= 50{,}000$ ohms,
$R_2 = 11{,}000$ ohms,
$\mu = 33$.

Therefore, the voltage magnification of the first stage is:

$$\frac{33 \times 50{,}000}{50{,}000 + 11{,}000} = 27 \cdot 1.$$

Similarly, the amplification of the second stage will be:

$$\frac{33 \times 30{,}000}{30{,}000 + 11{,}000} = 24 \cdot 1.$$

Assuming that the amplifier is to be used with the 10,000 ohm load for suppressor grid modulation, the load on the third valve will be 10,000 ohms, since the transformer ratio is 1 : 1.

For the third valve, therefore, the voltage amplification is:

$$\frac{8 \times 10{,}000}{10{,}000 + 1{,}600} = 6 \cdot 9.$$

Thus the total voltage amplification from the first grid to output load is:

$$27 \cdot 1 \times 24 \cdot 1 \times 6 \cdot 9 = 4{,}340.$$

Now from the table given earlier in this Chapter the peak voltage for a transverse current microphone with suitable input transformer is quoted as approximately 0·2 volts for very close speech. When speaking at a normal distance of, say, 12", this would be in the order of 0·02 volts. Thus the output voltage with the volume control at maximum will be 0·02 × 4,340 = 86·8 volts. This is more than adequate for suppressor modulation of pentodes up to the 50 watt class, and will allow some reserve in the volume control.

If greater gain is required in order to use a less sensitive microphone, such as a ribbon or "cell" type crystal microphone, a screen grid or small tetrode valve can be used in the first stage. A suitable input transformer must be used for a ribbon microphone, but the crystal type can be connected directly into the grid circuit.

Owing to the higher gain it may be necessary to use two stages of anode decoupling. Triodes should preferably be used for later stages in the amplifier unless an output tetrode or pentode is used as the last valve.

A 10 WATT AMPLIFIER

Figs. 15 and 16 show the constructional details of a four-stage 10-watt resistance capacity coupled amplifier, the design of which includes optional

World Radio History

negative feed-back and separate controls for treble and bass attenuation. The first valve can conveniently be a 6J7 R.F. pentode connected as a triode, whilst a 6F5 high impedance triode is a suitable valve for the second stage. The coupling between this stage and the next can be made the basis of the "bass-cut" control. This may be achieved by the simple expedient of arranging for different values of coupling condenser to be switched into the grid line to the third valve. Under normal conditions a value of ·25 μF alone is coupled to the grid, but by the aid of a five-position switch, capacities of ·25 μF, ·1 μF, ·01 μF and ·001 μF can be joined in series with the fixed coupling condenser, thereby giving varying degrees of "bass cut." Using the fixed coupling condenser only, the bass will be fully reproduced, whilst in the fifth position of the switch, when the ·001 μF condenser is joined into circuit, all frequencies below about 200 cycles are attenuated.

Volume control is provided by means of a potentiometer connected between the output of the 6J7 and the grid of the 6F5.

The third valve can be a 6C5 low impedance triode. In this stage negative feed back is arranged by connecting 5,000 ohm and 500 ohm resistances in series with the cathode lead, the latter being nearest to earth. A proportion of the output is fed back from the output valve anode *via* a 15,000 ohm resistance and a 1 μF condenser to the junction of the 5,000 ohm and 500 ohm resistances. The negative feed back arrangement can, however, be made inoperative by connecting the junction to the centre point of a two-way switch, the second position of which places a 25 μF electrolytic condenser between the junction and earth.

Although the application of negative feed back considerably reduces both frequency and harmonic distortion, it also reduces the gain of the amplifier. The advantages are that quality is greatly improved and background noise is almost non-existent.

A series of condensers of different values connected across the anode of the third valve, and earth *via* another five-way switch can be used to provide a "treble-cut" control. A large value of capacity here produces a low impedance shunt which will attenuate high frequencies much more than the low, the amount of attenuation being dependent on the size of the condenser. In the first position of the switch no capacity is in circuit, therefore maximum high note response is obtained. The remaining four positions will give varying degrees of "top-cut," the most severe, cutting off at about 3,000 cycles.

The coupling condenser used between the anode of the third valve and the grid of the output valve should be of the oil-filled type as its very high insulation resistance makes it specially suitable for this position.

Cathode bias is provided for the first three stages. Suitable values of resistance being 2,000–3,000 ohms for the 6L7 and 6F5 and 5,000 ohms for the 6C5.

The output valve can be a 6L6 (the well-known beam power tetrode), operated at the full rating of 375 volts on the anode, and 250 volts on the screen. The 6L6 is listed as delivering 11·5 watts audio output under these conditions, but this figure will not be obtained unless the loudspeaker or modulation transformer is very accurately matched. Even a small error in matching the anode load to the valve results in quite a large drop in audio output. As the anode load of the 6L6 is 4,000 ohms no difficulty should be met in matching a speaker or modulation transformer.

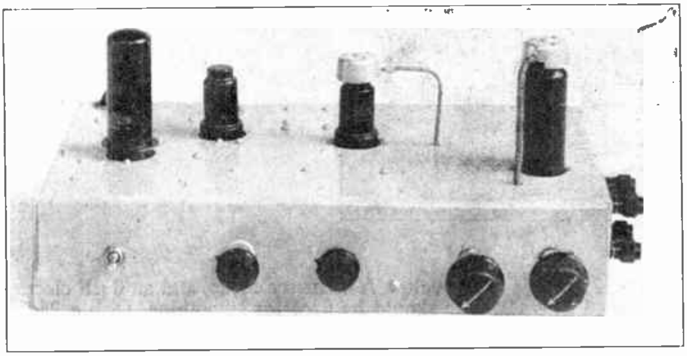


Fig. 15.

Front view of a 10-watt audio amplifier employing optional negative feed-back, and separate controls for bass and treble attenuation. Metal valves are used.

It is essential to use fixed grid bias for the 6L6 if the full audio output is to be obtained, a value of 18 volts being satisfactory. Cathode bias resistance will probably lead to severe distortion on the peaks which will thus cause the valve to overheat. The grid circuit resistance should never exceed 100,000 ohms where fixed bias is used.

The total current required for an amplifier of this type is 65 mA at 400 volts for H.T. and 6·3 volts at 2 amps for the valve heaters.

The photographs show the general method of construction and assembly. The chassis can be made from 18 s.w.g. sheet steel folded over on all four sides, a suitable size being 15 in. × 9 in. × 3 in. deep. It is convenient to divide the right-hand of the underside of the chassis into two compartments, the first can then be used to accommodate all the components of the first stage and the volume controls, whilst the rear compartment can be used to house the two 9-volt grid bias batteries. An advantage of this arrangement is that by screening the first stage inter-action with later stages is avoided.

World Radio History

A multiple electrolytic condenser block can be used for the decoupling circuits. This is shown at the bottom edge of Fig. 16.

A 20-watt 2,000 ohms adjustable resistance is connected in the anode of the 6L6 valve, and is used to set the anode voltage to that stage to the maximum allowable value of 375 volts.

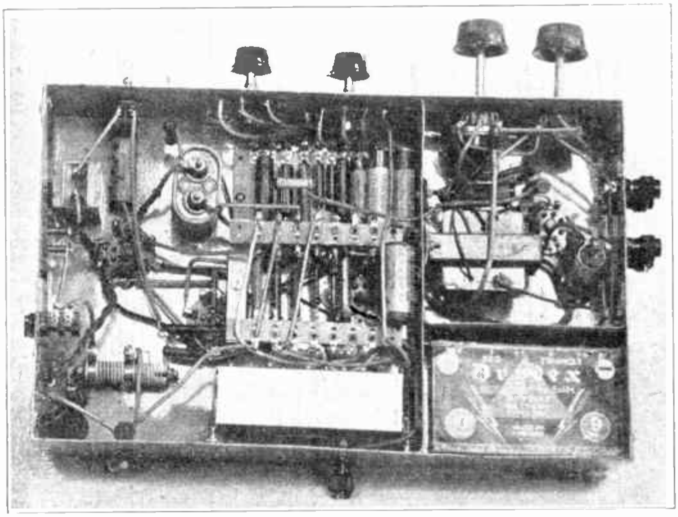


Fig. 16.

Underside view of a 10-watt amplifier. The screened compartments mentioned in the text can be seen on the right.

Grid stoppers which can be 5,000 ohms ·25 watt types should be mounted inside the screened caps which connect to the top caps of the first and second valves.

The fixing bush of the "bass cut" switch must be insulated from the earth by means of two insulating washers because the moving contact does not work at earth potential, whilst to ensure a perfectly hum-free output it is advisable to place the amplifier on a sheet of metal connected to earth.

A suitable power pack would comprise a 5Z4 rectifier and a mains transformer delivering 150 mA at 350–0–350 volts, 3 amps at 6·3 volts and 2 amps at 5 volts. A 40 henry choke, and an 8 μF electrolytic should be used for smoothing, with a 25,000 ohm bleeder resistance across the output.

A full description and circuit diagram of this amplifier appeared in the April, 1940 issue of *The T. & R. Bulletin*, but this issue is now out of print.

RESISTANCE COLOUR CODE

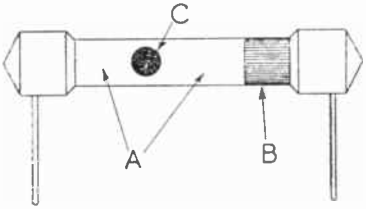
The R.M.A. Colour Code for indicating the value of resistances is set out below :—

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

Resistances under this code carry three colours placed in the three positions as indicated in the diagram, and denoted by the letters A, B and C.

Colour A gives the first significant figure of the resistance value, colour B the second significant figure, and colour C, which is a dot, indicates the number of "noughts" which follow B.

If the dot is omitted it is the same colour as A, the same arrangement applies when B appears to be missing. Where only one colour appears, A, B and C are the same colour and therefore have the same figure value.



The colours must always be read in their proper order, *viz.*, Body, Tip, Dot. Examples are as follows :—

A (Body)	B (Tip)	C (Dot)	Ohms.
Blue	Black	Black	60
Blue	Black	Brown	600
Violet	Blue	Red	7,600
Red	Blue	Orange	26,000
Brown	Brown	Yellow	110,000
Blue	Blue	Blue	66 megohms

World Radio History

Chapter Nine

POWER SUPPLY

Power Sources—Convertors—Rectifiers—High Vacuum and Mercury Vapour Valves—Transformer Design and Construction—Filters—Power Units—Circuits—Voltage Stabilisation—Voltage Dividers—Switching—Safety Devices

Introduction

In the ordinary amateur station, power is required for a variety of purposes including cathode heating, H.T. anode supplies, and possibly also grid bias supplies, battery charging, microphone circuits, relays and other auxiliary devices. The problems which confront the amateur are usually those relating to providing the necessary anode, grid and cathode voltages in transmitters and receivers, and only these problems will be considered here.

No amateur can afford to take risks when dealing with power supply systems. It should be remembered that several fatal accidents have occurred in various circumstances due to contact with wires carrying only a few hundred volts. Even the simplest apparatus may quite easily be a danger to life. High voltages are so readily obtainable that there is a great temptation to treat them carelessly. Moreover, it is vitally important to remember that a part of a circuit which may be "safe" in the normal way, may become just as dangerous as the high-voltage supply itself if there is a fault somewhere in the system. Further, there may be two or more faults, and it is dangerous to assume that the circuit is again safe when one fault has been remedied. Such faults may be found to occur in a broken-down blocking condenser or transformer insulation, which may convert a "dead" part of the circuit into a "live" part. Safety devices, designed to avoid the dangers associated with high-voltage systems, are described at the end of this Chapter.

DANGER The voltages used in transmitting apparatus are dangerous if proper care is not taken. Suitable safety precautions are described at the end of this Chapter.

Generally speaking, where no public supply is available the amateur must content himself with a low-power outfit. There are several courses open in such circumstances, depending chiefly upon the expenditure permissible. For the very simplest low-power sets, the ubiquitous dry battery holds its own as a source of H.T. current. For example, with dry batteries totalling 300 volts from which a drain of 20 mA or so is possible, six watts are available as input power, and with an efficient low-power set an amazing amount of work can be done using such a power. H.T. accumulators have the advantage that, during discharge, they maintain a steady voltage very much better than the dry battery.

The problem of accumulator re-charging in places remote from public supply mains calls for the use of some local generator, such as a petrol engine or wind generator.

In this country, supply mains are mostly derived from the National Grid at 230 volts, 50 cycles per second (the frequency being accurately controlled by a master clock), although there are still some localities which are fed with D.C. or with A.C., the frequency of which is usually nominally 50 c.p.s. but is uncontrolled. Throughout the country, the voltage of the public supply mains will be found to have a number of different values. These can be roughly divided into two groups, namely, high voltage, 200–260 volts, and low voltage, 100–140 volts.

Petrol Generating Sets

One does not usually turn to petrol-electric generators unless a considerable amount of electricity is required. Few petrol engines are made with a horse power below unity, hence an electrical output of about 300 watts is generally available. It is, of course, quite possible to run almost any size dynamo, even a small one delivering comparatively few watts, off a 1 h.p. petrol engine but the efficiency will be low and the operating costs unduly high. Maximum efficiency is not secured unless an engine is driving a load compatible with its size.

Wind Generators

Wind generators do not appear to be so popular in Great Britain as is the case abroad. The cost of an installation will vary considerably according to the size of the plant but should not prove excessive, especially in cases where the owner is a "handyman."

World Radio History

It is, of course, necessary to erect a wind-driven installation in a position where a wind of good velocity blows frequently or regularly. The majority of generators commence producing a reasonable output at 300 revolutions per minute, whilst the number of revolutions for maximum output is in the region of 1,500. The actual speed is dependent on the load taken from the dynamo as well as upon the velocity of the wind. In exposed positions, where winds of gale force are likely to be encountered frequently, special provision must be taken to prevent damage to the installation as a whole, this usually taking the form of an automatic brake.

The first essential is a support for the propeller and dynamo. This can well take the form of a lattice mast, which need not be more than 20 ft. in height, unless the location is particularly badly screened by trees or buildings. A well stayed tubular steel mast would form a convenient substitute where only a small installation is intended.

The size and type of the propeller will depend on the output required and on the type of dynamo employed. Two-bladed propellers are usually fairly long—between three and four feet for a 50 watt load—and rotate at a comparatively low speed, necessitating gearing up the shaft to the dynamo, at a high ratio. Probably more suitable, but also more expensive, are the multi-bladed propellers, of small diameter and revolving at a much higher speed. The starting momentum of the latter type is low but this is of little importance since no electrical load will be applied until the cut-out operates.

Some means of bringing the propeller into a position facing the wind must be included and this usually takes the form of a "wing" mounted behind and at right angles to the propeller. A suitable size would be two feet by three feet, set three to four feet behind the propeller.

D.C. Mains

If D.C. mains are installed, plenty of current is available but at an inconvenient voltage—too high for cathode heating, and too low for supplying the anodes of anything except low-consumption equipment, like receivers and very low-power transmitters. For supplying low-voltage circuits such as cathode heaters and accumulator-charging units, the simplest arrangement for using D.C. mains is to employ a series resistance capable of passing the desired current; a lamp of suitable size can usually be found which meets the requirements. For obtaining high-voltage supplies for transmitters, or heavy currents at low voltage, a motor-generator is the best solution of the problem. Where D.C. mains are used directly for feeding the anodes of a receiver or a transmitter and where the positive wire is earthed, special attention must be given to the question of insulation, for all the points in the circuit which are usually earthed will be at high voltage to earth. In either case, whether the earthed side of the mains is the positive or the negative side, it is generally forbidden to earth the mains locally. Therefore a non-inductive condenser of, say, $0 \cdot 1\ \mu F$ capacity should be joined in the earth lead of any receiver or transmitter connected to D.C. mains.

Although D.C. mains give current which is always in one direction, there is generally an appreciable ripple in the voltage, and this will be audible as a medium-pitched tone in a receiver, or will cause audio modulation in a transmitter connected to such a supply. This ripple must be removed by means of a filter, as described later in the chapter.

A.C. Mains

A.C. mains are by far the most common form of supply nowadays, and this is very fortunate for the amateur, for it enables him to obtain the requisite power for his receiver or transmitter at any desired voltage, economically and with practically no maintenance. In general, the energy taken from the mains is converted from the supply voltage by one or several transformers to the various voltages that are required, rectifiers and filters being employed where a steady direct current is necessary.

The greater part of this chapter is devoted to the consideration of power supplies operating on A.C. mains on account of their widespread application.

Rotary Convertors

The rotary convertor consists essentially of a rotating armature system which is driven from either D.C. or A.C. and provides either D.C. or A.C. at its output terminals, according to whether it is fitted with commutators or slip rings. The ratio of input to output voltages and currents depends on the windings, as in the case of the stationary transformer.

In general, the smaller sizes of rotary convertor have a single armature, with two windings and two commutators, or one commutator and one pair of slip rings. One winding acts as a motor and draws current from a low voltage source (usually D.C.) while the other acts as a dynamo and delivers either direct current at a much higher voltage or else alternating current, at possibly 230 volts.

Until recent years, the drawback of these machines was the very poor efficiency at which they operated—generally of the order of 30 per cent. to 40 per cent. Modern types, however, show a distinct improvement in this direction, although high efficiencies are only realised in high power machines. When choosing a rotary convertor, the output rating should be near to the value which will be required in normal circumstances, since it is under such a condition that the efficiency will be highest and the greatest economy secured.

Rotary convertors are manufactured in a great variety of sizes and types. The smallest is probably the 10-watt *M.L.* convertor, which operates from a six-volt accumulator and delivers a D.C. output of 240 volts, 40 mA. In the larger models, voltages of up to 1,000 are obtainable whilst the input may be arranged for 12, 24 or 32 volts, the latter values being particularly suitable for operation off country house and ship lighting sets. The employment of convertors giving an A.C. output has much to commend it and is finding increasing favour. The A.C. voltage—usually 230—can be stepped up or down by means of suitable transformers in the usual way and operating voltages varied to suit the need of the moment without the use of wasteful series resistances. Further, standard equipment can be used for portable work without extensive alterations being involved.

The regulation of modern machines is excellent—the output voltage is maintained practically constant

World Radio History

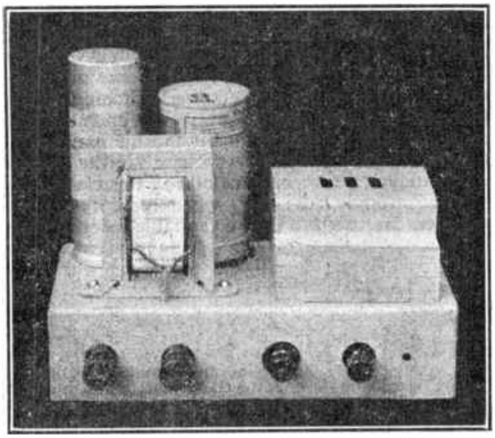
from a moderate load up to the maximum, the current in the primary winding of the convertor increasing as the load increases.

Where D.C. mains are available, rotary convertors may be employed to transform the current from D.C. to A.C.; thus enabling the user to derive all the advantages of the latter.

Vibratory Convertors

During the last two or three years, the vibratory convertor has been greatly improved, and must now be regarded as having great reliability and usefulness. It is gradually superseding the small rotary convertor as a means of obtaining A.C. from a D.C. source of low voltage. The reliability of a vibrator unit has now been raised to a degree which enables the manufacturers to guarantee the units for a life of at least 1,500 hours when used under proper conditions, whilst in many cases, the life may extend to as much as 3,000 hours. The efficiency is also quite high, being of the order of 60 per cent. or even greater at full load. It is worthy of notice that practically all modern car radio receivers employ the vibratory convertor as the source of high tension current.

Essentially, a vibrator consists of a synchronous reed, energised by a small internal electro-magnet and bearing two sets of contacts—one set to energise the primary of the associated transformer and the other to rectify the A.C. output from the secondary of the transformer. The unit transforms the current from a low voltage source (types are available for operation off 4, 6, 12, 24 and 32 volts) into alternating current of approximately two-thirds the D.C. voltage, the frequency being between 100 and 110 cycles. The A.C. is applied to the primary of the transformer and is stepped up to a value of 150, 250 or more volts. The high voltage D.C. output is taken from the centre tap of the secondary winding through a conventional smoothing circuit.



A typical Vibrator Convertor Unit. The Vibrator is contained in the cylindrical can seen between the electrolytic condenser on the left and the mains transformer on the right. It is fitted with a standard 5-pin valve base. The smoothing choke is in front on the left. Underneath the chassis are mounted the R.F. Chokes, condensers and resistances, which serve to suppress sparking on the Vibrator contacts and the consequent interference. The input to the Vibrator Unit is 18 watts at either 4, 6, 12, 24 or 32 volts. The output is of the order of 15 watts. The output voltage is held down to about 250 volts by the limitations of the Vibrator contacts.

The design of the transformer in a vibratory convertor requires special care, as the wave-form of the current is not sinusoidal. This point is dealt with in the section on Transformer Design.

It is very important to include a resistance-condenser filter across the vibrator H.T. contacts to prevent excessive sparking. If operated without buffer condensers it is probable that the unit will be rapidly and irreparably destroyed.

The sparking at the contacts is liable to set up interference at radio frequencies unless suitable precautions are taken. The first of these is thoroughly to screen all the components associated with the unit. All leads should be kept short in order to minimise radiation off them, and the metal case or chassis should be connected to earth with a short, heavy lead.

When very sensitive receiving equipment is employed, especially on the ultra-high frequencies, it may be found necessary to place the unit some little distance away, connections being made to it with screened leads. It may also be advisable to screen the aerial lead for a short distance near the set.

Rectifiers

A rectifier is always needed when A.C. is to be converted into D.C. It operates by reason of unilateral conductivity, *i.e.*, a rectifier conducts only when the applied potential is in a certain direction. When the potential is reversed, the rectifier is virtually an insulator. In amateur use, the rectifier for the H.T. supply is almost invariably of the full-wave thermionic valve type, although occasionally a half-wave rectifier is used. The so-called dry plate, or metal, rectifiers are rather widely used but generally for low-voltage supplies, on account of the inherent low voltage limit of this type.

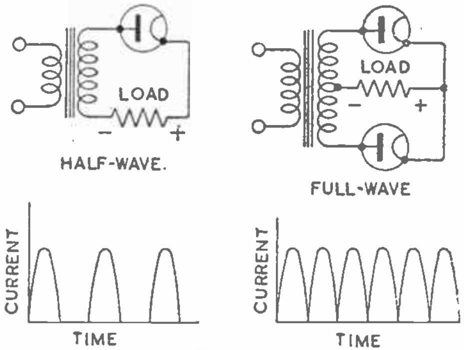


Fig. 1.

Skeleton circuits of half-wave and full-wave rectifiers. The curves show the corresponding wave-forms of the current delivered by the rectifiers into resistance loads.

Fig. 1 shows examples of the circuit connections of half-wave and full-wave rectifiers, together with curves indicating the form of current wave delivered by the rectifier in a simple resistance load. It should be noted that in the full-wave arrangement, the two valves have their cathodes connected together. In the case of voltages less than about 500 volts, the two valves are combined in one bulb containing a common cathode and two separate anodes : sometimes, two separate cathodes are used, having common connecting leads. For higher voltages, the valves are usually quite separate.

For voltages above about 1,500 volts, it is preferable to use a bridge type of rectifying circuit, known as the Graetz. This is shown in Fig. 2. Four separate valves are generally used, for which three separate filament transformer windings are essential. The circuit is more economical as far as the size of the H.T. transformer is concerned, and a very satisfactory degree of voltage constancy, or regulation, can be obtained. The current wave delivered is the same as that shown for the full-wave rectifier in Fig. 1. Moreover, twice as much voltage can be obtained, without exceeding the voltage rating of the valves.

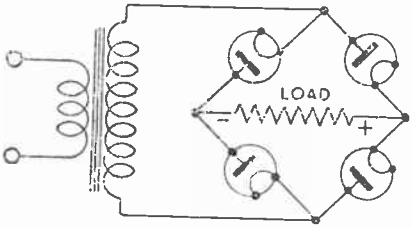


Fig. 2.
Skeleton circuit of Graetz bridge rectifier using four valves. Three separate filament secondary transformer windings are essential. This circuit is preferred where voltages above 1,000 v. are required.

Metal rectifiers of the full-wave type are built in one unit having a connection to the centre. Mercury-vapour rectifying valves are more efficient than the high-vacuum type, particularly at high voltages, due to the fact that the voltage-drop across them, in normal operation, is never more than about 15 volts.

High-Vacuum Valves

The most common type of small rectifier is probably that used in the ordinary mains-operated broadcast receiver, which is designed to give a current output of 40–120 mA at 350–500 volts. This is an excellent example of the full-wave type having two anodes and two cathodes in one bulb. The cathodes are usually of the filament type, but the alternative form, using indirectly-heated cathodes, is to be preferred for the reason that the filament type of cathode becomes operative within one second of switching on, and if a common transformer is used for feeding the anodes and the filaments, the H.T. is available at its highest value. If the load on this H.T. supply consists of one or more valves which do not become operative so rapidly after switching on, the voltage developed in the system may easily reach a dangerous value tending to break down the insulation of any condenser connected across the supply. On the other hand, if the rectifier has indirectly-heated cathodes, the high voltage is not available until perhaps 20 seconds have elapsed after switching on. By this time, the load on the supply will also have become operative, so that the voltage is prevented from reaching a dangerous value.

The high-vacuum rectifier rated at 120 mA and 500 + 500 volts is quite suitable for small transmitters, as it is capable of delivering 60 watts at a reasonably high voltage. Some amateurs find it practicable to use such valves with voltages above the normal rating, but this can be detrimental to the life of the valve unless the current is kept below the maximum rating.

Mercury-Vapour Valves

If higher voltages than about 500 volts are required, the most practical arrangement is to use mercury-vapour valves, such as the *Osram* GU1 or GU50 (which supersedes the GU5) or *Ediswan* MU1.

The GU50 and the MU1 are rated at 1,500 volts, while the GU1 is rated at 1,000 volts. These are all half-wave rectifiers, and therefore a pair should be used in a suitable circuit to give full-wave rectification. A pair can deliver up to 500 mA at these voltages. If still higher voltages are required, other types of mercury-vapour rectifiers are available.

It is important to see that the valves have adequate ventilation when operating, as excessively high temperatures may cause breakdown at heavy current loads or high voltages. The filament rating of the GU1 and GU50 is 3A. 4v., while that of the MU1 is 2·5A. 4v., and it takes about 30 seconds for the filaments to reach operating temperature. *The anode voltage must not be applied until the filaments have reached the full operating temperature.* Failure to observe this will almost certainly result in permanent damage being caused to the filament, appearing as a loss of emission if not a complete fusing of the filament.

In view of this important requirement, it may be desirable to use special time-delay switches, which are so designed that the H.T. circuit does not close until a fixed time has elapsed after switching on the filament current. If, however, the operator can rely on his own unfailing habit and his patience, a time-delay switch is not necessary : see the section on Switching Arrangements later in this chapter.

It is strongly advisable, when mercury-vapour rectifiers are used, to include suitable fuses in each

A mercury-vapour rectifier of the GU5 class. These rectifiers are half-wave types, and are used extensively in amateur and commercial power supply equipments. When in operation they exhibit a blue glow. The filament must always be switched on for about 30 seconds before the anode voltage is applied.

World Radio History

anode lead. This practice will save the transformer windings and the valves from being destroyed if the insulation of a filter condenser breaks down, or if there is any other short-circuit in the H.T. system. The reason underlying this is that the impedance of a mercury-vapour rectifier is negligibly small in the conducting stage, and therefore there is no restriction of the current offered by the rectifier itself in the event of a short-circuit.

Recently, grid-controlled mercury-vapour rectifiers (and other gasfilled types) have been introduced for various purposes. They are available in this country under such names as *gasfilled relay* and *Thyratron*, and the experimenter is well advised to investigate the many possible uses of these very versatile valves. (*See* Chapter 7.)

Metal Rectifiers

Metal rectifiers are best suited to low-voltage uses, such as accumulator charging and the operation of electro-magnetic relays. They become unduly expensive if an attempt is made to use them for H.T. supplies for several hundred volts. They are, however, extremely robust and reliable, and last almost indefinitely.

Transformers

In this section, consideration is given to transformers such as are required for supplying filament and anode currents at various voltages. The information is applicable, however, only to cases where the supply has a periodicity of 50 cycles per second, which is the frequency generally used in this country.

The efficiency of a transformer is high, being about 80 per cent. for the 100-watt size, increasing to about 90 per cent. for 250 watts, and rising still higher for larger sizes. The losses appear as heat developed in the iron core and in the copper windings. In the design of a transformer, an attempt is usually made to equalise the losses in the iron and the copper. The important thing, in practice, is to prevent the temperature of the transformer from rising to an excessively high value which may be dangerous to the insulation of the windings. It is therefore essential to provide adequate ventilation. It is also convenient to remember that a transformer usually has a high overload capacity for short periods, although as will be explained later, the output voltage is not maintained if the rated current is exceeded. In this event, more power than the normal rating may be taken from the transformer for short periods, but at a voltage somewhat below normal. It is dangerous to raise the primary voltage much above the rated value, as the iron can easily become saturated, with the result that the primary current increases out of all proportion to the primary voltage and excessive heating is thereby caused.

As an auxiliary piece of equipment, an auto-transformer is often useful. This consists merely of a single winding on the usual iron core, the winding being tapped at suitable points, after the manner of a tapped-resistance voltage-divider. In a good auto-transformer, the size of wire used between the taps is chosen to suit the current which may be obtained at the various voltages.

Transformer Design

All power transformers are designed from calculations based on the equation :—

$$E = \frac{4Ff\varphi T}{10^8}$$

where

E = R.M.S. value of induced E.M.F. in considered winding,
F = form factor of E.M.F. wave (1·11 for sine wave),
f = frequency of supply in cycles per second,
φ = total magnetic flux through core,
T = number of turns in considered winding.

For amateur purposes, where so many factors are already fixed, it is unnecessary to calculate every design from first principles. Instead, it is quite satisfactory to resort to tables wherein these calculations have been reduced to a convenient form. The tables take into account both the iron losses and the copper losses, and provided certain general recommendations are observed the constructor should have no difficulty in working out a satisfactory design for any transformer which he may need.

The starting point in the design is to decide what will be the total loading on the transformer, *i.e.*, the total power output when the full current is being taken from all the secondary windings. Approximately 10 per cent. should be added to this figure to obtain the power *input* to the transformer. Reference to Table A will show what size cross-section of the iron core will be suitable for a transformer capable of handling this amount of power. The same table also gives the "turns per volt" ratio. This factor is obtained directly from the cross-section of the core, and it will be observed that the following relation holds :—

TABLE A

Watts	Cross-section of core in square inches	Turns per volt
50	1·5	5·3
100	2·25	3·5
150	2·5	3·2
200	3·0	2·7
250	3·5	2·3
400	4·0	2·0
600	4·8	1·7
800	5·5	1·4
1,000	6·25	1·3

(Cross-section of core) × (Turns-per-volt) = 8. The number of turns per volt given by this table applies to all the windings on the transformer, including the primary.

The primary voltage is usually the same as the mains voltage, so that this is fixed, and the number of primary turns is fixed. The maximum power loading of the transformer has already been decided, and an approximate value for the primary

World Radio History

current can therefore be obtained directly from the relation—

$$\text{Primary current} = \frac{\text{Primary watts.}}{\text{Primary volts.}}$$

The smallest wire size capable of carrying this current should be used for the primary winding. The copper wire table in Chapter 23 gives wire sizes in relation to their current-carrying capacity, and also gives the winding data for various wire and various kinds of insulation. The number of turns per layer and the number of layers are calculated by simple arithmetic, and when 50 per cent. is added to the thickness of this number of layers, to allow for insulation between layers and a margin of safety, the total thickness of the primary winding is then obtained.

Using the same number of turns-per-volt, the numbers of turns required for the various secondary windings can be calculated directly, and the corresponding amounts of winding space can be deduced in the same way as for the primary. It is important, however, in the case of the filament or heater windings, to calculate the number of turns required to give the exact filament voltage on load. The simple ratio of the number of turns in the secondary and primary windings only gives the voltage when there is no load. Owing to magnetic leakage, and to the iron and copper losses, the voltage on load is lower than that given by the simple ratio. In practice, the necessary correction for low-voltage filament windings can be easily calculated with sufficient accuracy merely by taking into account the copper loss in the primary, *i.e.*, the primary resistance. This is obtained from the wire table referred to above, after making an approximate estimate of the average length of wire per turn and hence the total length of wire (which, incidentally, from the weight column in the table, will give the weight of wire required). The primary resistance causes a drop in the effective primary voltage in proportion to the primary current.

$$\begin{array}{c}\text{Primary volts}\\\text{lost}\end{array} = \begin{array}{c}\text{Primary}\\\text{resistance}\end{array} \times \begin{array}{c}\text{Primary}\\\text{current}\end{array}$$

This should be expressed as a fraction of the input primary voltage.

In the case of filament windings, the resistance is so low that there is no appreciable voltage drop in them, and consequently only the effect of the primary resistance need be considered. The effect of magnetic leakage is usually negligible in this calculation. Thus, the voltage across the low-voltage secondaries on load will be reduced by this same fraction, and therefore to obtain the desired filament voltage on load, the number of turns in the filament windings should be increased by the same fraction. In small transformers, this usually amounts to about 10 per cent.

The resistance of the high-voltage secondaries may be sufficient to cause a secondary voltage drop, and if it is desired to obtain exactly a certain voltage from the high-voltage secondaries, a further correction should be made to the numbers of turns in those windings, proportional to the voltage which is lost due to secondary resistance. Usually, however, such precision on the high-voltage side is quite unnecessary.

As with the primary, the smallest practicable wire sizes should be chosen for the high and low-voltage secondaries with due regard to the current which they have to carry. In the case of centre-tapped high-voltage secondaries for fullwave rectifiers using the circuit shown in Fig. 1, each half of the winding passes current for only half the time, but on account of the form factor of the current, the wire size required is approximately the same as that for the output current from the rectifier.

The wire insulation should preferably be enamelled and silk covered, or double-silk covered, for high-voltage windings, and double-cotton covered for low-voltage heavy-current windings, although it is reasonably safe to use enamelled wire for the latter if space and cost are limited. It is important to remember that a single short-circuited turn will cause a heavy current to flow in that turn, and this will almost certainly be sufficient to burn the insulation of the neighbouring turns, resulting finally in complete failure of the transformer.

In transformers for use in conjunction with vibratory convertors, the iron should be operated at a flux density about 30 per cent. lower than that recommended for transformers operating on sine-wave supplies. Accordingly, the turns-per-volt figures should be increased by about 30 per cent. in such cases, and it is also advisable to use slightly heavier wires and to make the size of the core somewhat larger, in order to allow for the form factor of the "rectangular" pulses of current passed by the vibrating contacts.

The above remarks regarding the number of turns relate only to the case where the transformer is well proportioned and well constructed. Cores of good shapes are indicated in Fig. 3. An elongated, wide, or shallow formed transformer will almost certainly have low efficiency, and extra secondary turns will be required to give the desired voltage on load. The calculation for the extra turns is very difficult, and in any case, such shapes should be avoided for the further reason that the regulation is bad.

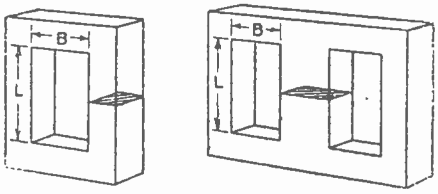


Fig. 3.

Examples of well-proportioned transformer cores. The shaded areas represent the cross-section of the core.

Transformer Regulation

The term "regulation" relates to the variation of output voltage with change in output current. When current is taken from a secondary winding, the voltage falls. The amount by which it falls, when expressed as a percentage of the voltage on no load, is known as the "voltage regulation." Good regulation, *i.e.*, when the fall of voltage is only very small, is obtained when the transformer, besides having a good shape, is compactly built. The window space of the core should be completely filled with the primary and secondary

World Radio History

windings, without using an unnecessary amount for insulation, and unnecessarily large wire sizes. Fig. 4 indicates a convenient way of arranging the windings in a multiple-secondary transformer. It will usually be found that the windings suitable for amateur requirements can be made to fill the core sizes, which are commonly obtainable, without any difficulty.

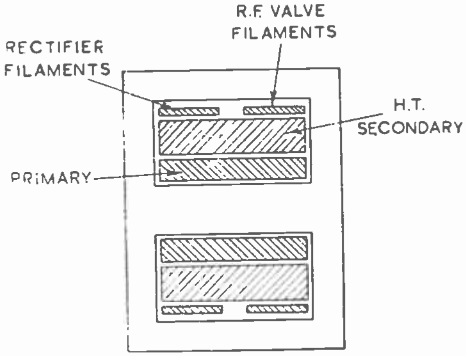


Fig. 4.

Typical arrangement of windings in a small power transformer. Rectifier filament and H.T. secondary windings should always be provided with ample insulation.

Transformer Construction

In making up a transformer, very thin but strong paper should be used between each layer of fine wire, or between every two or three layers if the wire is thicker than about No. 20 s.w.g. Suitable paper for this purpose may be taken from an old filter condenser of the rolled type.

The core laminations must be packed together as tightly as possible, with alternate placings of the stampings, so that there is practically no air gap anywhere in the core. Finally, the laminations must be clamped rigidly by stiff metal or wooden strips, in order to prevent any vibration which might otherwise occur due to the effect of the pulsating field on a loose stamping.

It is desirable to fit terminals to all the windings and to label them clearly with the voltage and current ratings, but if the transformer is to be installed in a permanent piece of equipment, there is no reason why the wire leads themselves should not be used for making the circuit connections directly.

The advice given above should prove useful in the case where it is desired to rewind a burned-out transformer, or to add windings to an existing transformer. In either of these cases, however, it is necessary to ascertain first the number of turns per volt. If a winding of known voltage is removed from the transformer, the turns can be counted from which the number of turns per volt can be obtained directly. This figure must be used in designing the new windings which are to be added or to replace old windings. Alternatively, a test winding of a known number of turns may be wound on, the core replaced, and the voltage of this winding measured without any load.

An important point in the construction of transformers is the insulation of filament windings for rectifying valves. Since the rectifier filaments are connected to the positive side of the H.T. supply, the full alternating voltage of the H.T. secondary will be present between the rectifier filament windings and the primary which is earthed at one side by the mains-earth. Special care must therefore be given to the insulation of such windings.

In mains transformers for transmitters or receivers, it is usually worth while to include a screen between the primary and the secondaries. This screen, which should be well insulated, may consist of a single turn of copper foil to which a flexible lead is connected for earthing, care being taken to see that the foil does not constitute a short-circuited turn. This screen is an effective stopper for preventing radio-frequency currents from passing across between the primary and the secondaries.

Example of Typical Transformer Design

Suppose the transformer is required to deliver 600 + 600 volts at 120 mA, and to have two separate 4-volt windings each capable of giving 6 A.

The secondary loads are—

600 v. × 120 mA = 72 watts
2 × 4 v. × 6 A = 48 watts
120 watts

Efficiency of transformer, say, 80 per cent.
Primary input = 150 watts approx.

A suitable core for a transformer of this size can be made from *Sankey's* No. 28 stampings, built to a thickness of 1·75″. This gives a cross-section of 2·19 sq. ins. so that the turns-per-volt ratio is 8/ 2·19 = 3·66. If the mains voltage is 230, the number of primary turns will therefore be 230 × 3·66 = 842. The maximum primary current will be 150/230 = 0·65A. approximately, for which the smallest wire size practicable, as shown in the wire table in Chapter 23, is No. 24 s.w.g., at the maximum rating of 2,000 amperes per square inch. From the same wire table, it is seen that this gauge occupies 40 turns per inch for double-silk insulation.

The length of the window space L (see Fig. 3) in the No. 28 stampings is 3″, while the window height B is 1·25″. The number of turns per layer of the primary winding will be, say, 110, allowing for imperfection in winding. The number of layers is therefore 8, giving a thickness of 0·2″. Approximately 50 per cent. is added for insulation, giving a total thickness of 0·3″ for the primary winding.

Similarly, the two halves of the secondary winding must have 2 × 600 × 3·66 = 4,392 turns. The smallest wire size for carrying 120 mA. at the same 2,000 amperes per square inch rating, is No. 34 s.w.g., giving 97 turns per inch if enamelled wire is used. Using this wire, the number of turns per layer is 280, say. The number of layers is therefore 16, and the thickness of these layers, allowing about 50 per cent. for insulation, is 0·375″.

The filament windings are to be wound outside the H.T. secondaries. The smallest wire size suitable for carrying 6 A. at the same rating is No. 16 s.w.g. Using double-cotton covered wire this gives 13 turns per inch. Taking the same turns-per-volt ratio of 3·66, 15 turns would be

World Radio History

required to give 4 volts. One extra turn in each 4-volt winding on this transformer should, however, be added to compensate for losses. Each filament secondary should therefore have 16 turns of No. 16 d.c.c. wire. These windings will each occupy about 1·3″ and may be wound side by side in one layer. The thickness of the two-part layer, allowing for sufficient insulation, will occupy about 0·15″.

The total thickness of all the windings, plus an allowance for insulation between primary and secondary and for the thickness of the bobbin, will be found to be a little less than the height B of the window space, 1·25″. If the total thickness had been greater than B, it would be necessary to use a core having a greater area of window space, or alternatively, more laminations of the same size, thereby permitting a lower turns-per-volt ratio, with a consequent reduction in the number of turns in all the windings. Conversely, if the height B would be far from filled by the calculated windings, modifications of the opposite kind should be made in the choice of the core shape or thickness in the interests of good efficiency and regulation.

Condenser-Input Filters

Filters for supplies obtained from D.C. mains should be of the condenser-input type as shown in Fig. 5 (*a*), since in this case the regulation is inherently good and there is no thermionic rectifier necessitating careful consideration. The choke L_1 must be capable of carrying the desired current without a substantial reduction of its inductance. If desired, a second choke may be inserted in the negative lead between the two condensers, as in Fig. 5 (*b*).

Filters for rectified A.C. supplies may also be of the condenser-input type shown in Figs. 5 (*a*) and (*b*). The action of the condenser on the input side of the filter is indicated by the voltage-wave shapes shown in Fig. 6. Curve A represents the primary voltage applied to the transformer. The voltage output of the rectifier is indicated by the dotted curve B, as already described in connection with Fig. 1. The charge contained in the input condenser, however, prevents the input voltage to the filter from falling to zero between the voltage peaks. A partial discharge takes place after each peak has been passed until the next peak occurs. The condenser voltage is shown by the full curve B. Finally, the effect of the further condenser and smoothing choke is to reduce this fluctuation, so that the output is substantially steady D.C. as indicated in curve C.

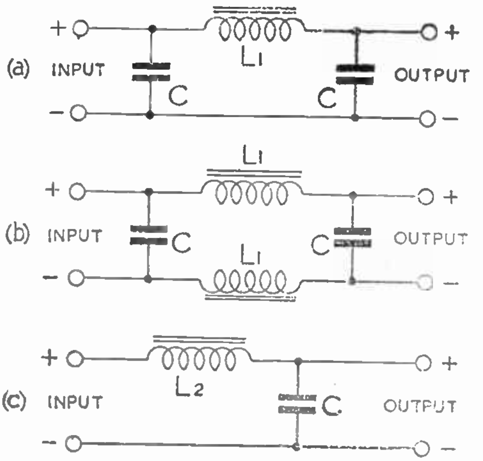


Fig. 5.

Examples of simple filter circuits: (a) and (b) are condenser-input filters, (c) is a choke-input filter. For more effective smoothing, a further choke should be connected in series and a condenser in parallel on the output side.

C = 4μF,
L_1 = 20 H. smoothing choke,
L_2 = 5–20 H. swinging choke.

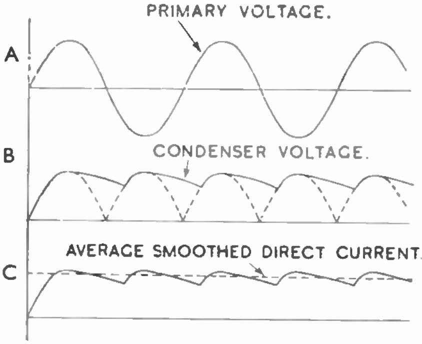


Fig. 6.

The voltage variations occurring in a rectifier-filter combination.

Choke-Input Filters

Unless the highest possible output voltage is required, it is often preferable to use the choke-input filter, shown in Fig. 5 (*c*). L_2 should be a swinging choke, which means that it has an inductance which varies greatly with the current and in the inverse sense, as distinct from the ordinary type of smoothing choke which is designed to have a constant inductance, independent of current variations. The choke-input filter has two advantages. First, the condenser-charging current is restricted by the effect of the input-choke L_2 to a substantially lower value, which improves the life of the rectifier valves. Secondly, the regulation of the rectifier-filter system is improved; that is to say, the voltage output is more nearly constant when the current load is varied. On the other hand, the voltage output is somewhat lower than that obtained from the condenser-input filter. The performance of the condenser-input and choke-input filters is shown comparatively in Fig. 7.

Regulation

The regulation of the complete system depends on the type of rectifier circuit which is used, and for good regulation it is always preferable to use a full-wave rectifying circuit, or better still, the bridge circuit rectifier shown in Fig. 2.

Ripple Elimination

Simple filters of the types shown in Fig. 5 are capable of reducing the ripple to quite small

World Radio History

amounts and are suitable for telegraphy working. For telephony, however, it is highly desirable to use a further filter section consisting of a series choke and a parallel condenser, in order to remove the last traces of ripple, or hum. This is particularly advisable in the early stages of a crystal-controlled telephony transmitter. A choke-input filter is shown in Fig. 8, for feeding the power-amplifier, while a condenser-input filter is used for feeding the oscillator, frequency-doublers, etc. If the filters are well designed, either type will give a satisfactory degree of smoothing for amateur purposes.

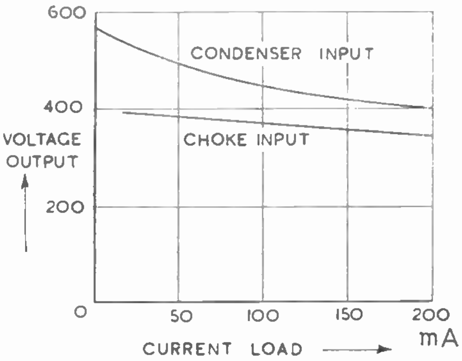


Fig. 7.

The comparative performance of condenser-input and choke-input filters. Higher maximum voltage is obtainable with a condenser-input filter, but the regulation is not very good. The voltage output of a choke-input filter is lower, but the regulation is much better; further, this arrangement is strongly recommended when mercury-vapour rectifiers are used.

Although the amount of ripple in the supplies used in amateur stations is not generally measured it may be remarked that a ripple of 5 per cent. is permissible for the H.T. supplies to R.F. amplifiers in a transmitter, 1 per cent. for R.F. oscillators, and 0·25 per cent. for telephony transmitters.

Filter Condensers

Filter condensers may be of the paper type, dry or wet electrolytic, or oil-filled types. Mica is not generally used on account of the comparatively high cost. Condensers in filter units should be mounted away from sources of heat, such as valves transformers and chokes, because the breakdown voltage of a condenser is seriously decreased if its temperature is allowed to rise appreciably.

Filter condensers usually have a capacity of between 1 and 8 microfarads, the voltage being chosen in accordance with the maximum surge voltage expected in the circuits. The cost of a condenser of any given capacity increases rapidly with the voltage rating, but it is false economy to operate condensers above their rated limit. The maximum surge voltage of the circuit may be much higher than the nominal voltage under steady operating conditions, and therefore due allowance should be made in deciding on a suitable rating. A condenser may successfully withstand an excess voltage for a time, perhaps a few minutes or a few hours, but not indefinitely.

It is impractical for the amateur to make his own filter condensers, on account of the nature of the materials and the special treatments which are necessary to produce a reliable condenser.

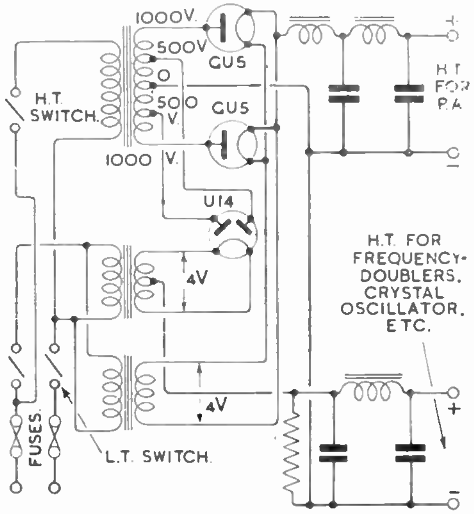


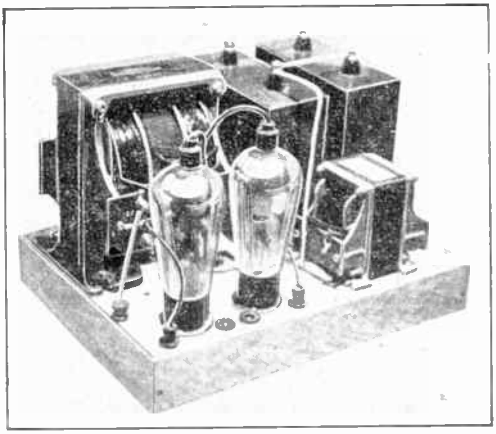
Fig. 8.

A typical power supply circuit for an amateur transmitter, providing high voltage for the power-amplifier stage and a lower voltage for the oscillator, frequency-doubler, etc.

Filter Chokes

Filter chokes are of two types: constant-inductance chokes and input, or swinging, chokes. The former usually have an inductance of some value between 10 and 30 henrys. The swinging choke has an inductance which varies, perhaps between 5 and 20 henrys, according to the instantaneous value of the current passing through it.

The maximum current which may be passed through a choke is determined by two factors; (i) the magnetic saturation of the iron core with



A power pack suitable for the Three Band 50-watt transmitter described in Chapter 6. Note method of changing output from 1,250 to 750 v. by means of plugs and all-in type terminals.

excessive current flow resulting in loss of inductance, and (ii) the heating of the windings due to electric resistance loss.

It is quite a simple matter to wind smoothing chokes of either type, if a suitable core and bobbin are available. The design involves many difficult calculations, particularly in the case of swinging chokes, but fortunately for the amateur the constructional characteristics are not critical.

In construction, there is no difference between a choke and a transformer, except that the core of a choke is always provided with a small air gap. This serves to prevent saturation of the core, which would otherwise occur due to the comparatively large amount of direct current flowing through the winding. In the case of the swinging choke, the air gap is quite small in comparison, but no simple instructions can be given for its calculation.

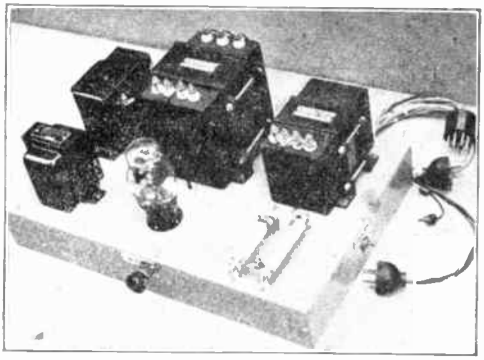
For smoothing chokes in general, it will usually be satisfactory for the amateur to dispense with calculations, and to follow the lines of the example set out below:

Inductance—About 10 henrys.
Core size—Sankey No. 4.
Window space—2 5/16" × 7/8"
Core cross-section—15/16" × 1"
Winding—5,600 turns No. 30 d.s.c. for 200 mA.
4,500 turns No. 28 d.s.c. for 250 mA.

Power Units for A.C. Supplies

In experimental work, separate units are desirable for providing various supplies for filaments and anodes. This may necessitate several separate transformers for the several purposes, but the extra expense is almost invariably well justified. Multiple-winding transformers giving separate outputs are readily available and are quite widely used. In permanent equipment, the saving in cost and space by the use of such a transformer may be worthy of consideration.

For general amateur purposes, however, it is convenient to have one common filament transformer of ample power rating with different windings giving voltages to suit the valves which may be used in the transmitter. Transformers for the different H.T. supplies should be separate from each other, in the interests of flexibility, with or without self-contained rectifier filament windings. If these windings are not included, separate small filament transformers having really good insulation will be required. By the use of individual transformers, it is easier to arrange the switching circuits for running indirectly-heated cathodes and the cathodes of mercury-vapour rectifiers which require to be heated before any anode voltage is applied.



A typical power supply suitable for a medium-power transmitter. The maximum output is about 250 mA. at 500 volts. The smoothing condensers are mounted underneath the chassis.

It is generally very convenient to have each H.T. secondary winding tapped at suitable intervals to give lower voltages, as this is by far the simplest way of obtaining reduced voltages, whether it be for feeding sub-amplifiers or merely for temporary test purposes. An auto-transformer, suitably tapped to give voltages above or below the input voltage, may also be used to feed an H.T. transformer as a means of obtaining supplies at various voltages. For test purposes, the voltage output of a transformer may also be reduced by inserting a resistance in the primary circuit, but in this case the regulation will not be as good as when an auto-transformer is used.

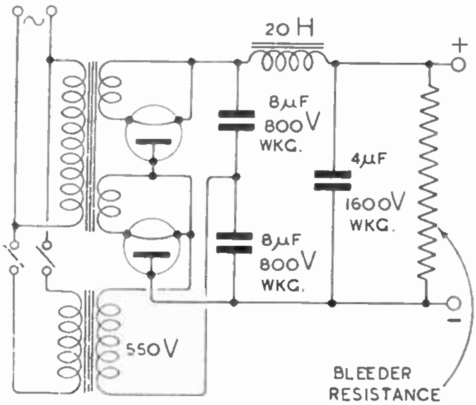


Fig. 9.

A voltage-doubling circuit suitable for supplying high voltage from a low-voltage transformer. The maximum voltage obtainable in the arrangement shown here is about 1,000 v. The capacity of the two condensers marked as 8 µF cannot be reduced without seriously reducing the efficiency.

Bleeder Resistances

In order to avoid the danger of filter condensers being left charged at a high voltage when the load is switched off, it is highly desirable to connect a bleeder resistance having a value low enough to ensure the proper discharge of the filter condensers when the circuit is switched off. Its value is usually chosen so that it passes a current of about 10 per cent. of the full load current. It is most important to make sure that the resistance element is capable of carrying the current which flows through it while the apparatus is in operation. A burned-out bleeder resistance is obviously a source of danger, and it is wise to install a resistance of considerably greater current carrying capacity than is actually required, and to use a resistance of the best quality obtainable.

World Radio History

Circuits

A typical circuit arrangement for power supplies for amateur transmitters is shown in Fig. 8. A common H.T. transformer, tapped at intermediate points, provides the H.T. supplies for both the R.F. power amplifier and the oscillator and frequency-doubler. Separate rectifier filament transformers are shown, but a common transformer having two separate filament windings could be used if preferred. In the interests of safety, a bleeder resistance should also be included in the filter circuit which feeds the power amplifier.

Another arrangement using a voltage-doubling bridge rectifier circuit, which is very useful where only low-voltage transformers are available, is shown in Fig. 9, together with the necessary voltage rating of the condensers in the bridge circuit. It is important to see that the bridge condensers have a sufficiently large capacity, otherwise the voltage output and the regulation will suffer.

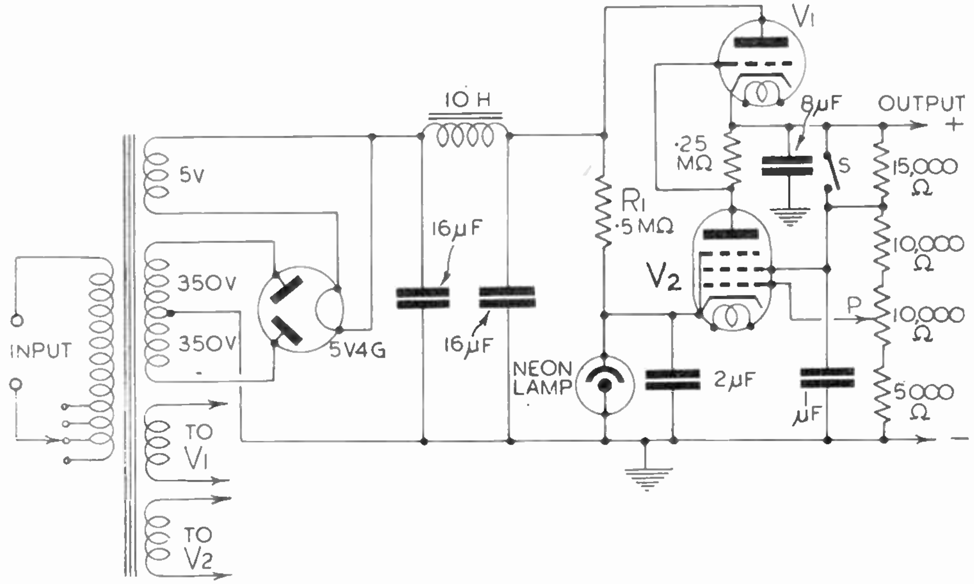


Fig. 10.

An effective voltage stabiliser circuit. The left-hand part of the circuit represents a conventional power supply, while the stabiliser section is on the right. A choke-input filter may be used instead of the condenser-input filter shown here, in which case even better stabilisation will be obtained.

Voltage Stabilisation

It is sometimes necessary to ensure that the voltage of a power supply is not affected by variations in the input voltage or in the output load. Typical cases where this condition may have to be satisfied are U.H.F. receivers, electron-coupled oscillators and frequency meters.

One of the most effective forms of voltage stabiliser is described here: it is very convenient to use and is quite inexpensive. As will be seen from the circuit diagram, which is shown in Fig. 10, the power supply proper consists of the usual transformer, rectifier valve, filter choke and condensers, while the stabiliser section consists of two valves in series with a high resistance and a neon lamp connected across the output from the filter. The stabilised output is obtained through the valve V_1, which must therefore be of comparatively low impedance. The valve V_2 acts as a D.C. amplifier and determines the regulating bias which controls V_1. The function of the neon lamp is to maintain the cathode of the controller valve V_2 at a constant potential of about 90-volts to earth. The resistance R_1 maintains a striking voltage on the neon lamp even when V_2 is biased to cut-off by the adjustment of the potentiometer P.

The screen voltage and grid voltage for V_2 are obtained from a potentiometer circuit connected across the output terminals. It is evident from the circuit that an adjustment of the potentiometer P will vary the grid voltage of V_2 with respect to its cathode; this variation is conveyed to the grid of V_1 by the drop across the anode resistance of V_2.

A variation in grid potential of V_1 will vary its impedance or voltage drop, hence varying the output voltage.

The potentiometer P is used to adjust the output voltage to the required value. When the output load, for example, increases and the output voltage tends to fall, the top end of P (which is designed to be maintained at about V_2 cathode potential at no load), will fall with respect to the cathode, giving an increase in grid bias on V_2. At the same time the screen voltage of V_2 will also tend to fall, both effects giving a decrease in anode current. This will produce a decreased bias on V_1 with a

World Radio History

consequent lower impedance and an increased compensating output voltage. Similarly, the reverse occurs with a decrease in load, and also when the input voltage from the rectifier alters, due to mains voltage variation.

The fixed potential of the cathode of V_2 fixes the lowest possible output voltage, since obviously the anode and screen voltage of V_2 cannot become lower than that of the cathode. If the lowest voltage required is in the order of 150–200 volts, an *Osglim* Beehive Neon may be used instead of a *Philips*.

The switch S when closed is used to lower the output to about 100 volts; when open, the minimum voltage is around 150 volts. The condensers of 0·1 μF and 2 μF serve to prevent parasitic oscillation. An additional condenser of about 0·1 μF may be required between the screen and grid of V_2 for the same purpose, depending on the layout. Oscillation, when present, is indicated by a jerky control by the potentiometer P or lack of any control at certain settings or at certain loads.

The potentiometer P may be at any distance from the unit, but the anti-oscillation condensers should be located close to the valve holder.

The *Philips* lamp is a 100 volts indicating neon and has a resistance in the base which must be removed. This is easily achieved by standing the neon in methylated spirits for a short time when the base can be removed. After the resistance has been taken out, the neon can be re-based with Plaster of Paris mixed up to a thick paste.

The table below shows the regulation obtained with various loads and settings of the output voltage, and with variations in mains voltage. The figures were taken using a *Brimar* or *Micromesh* valve, type PA1 as V_1 and a 6J7G as V_2.

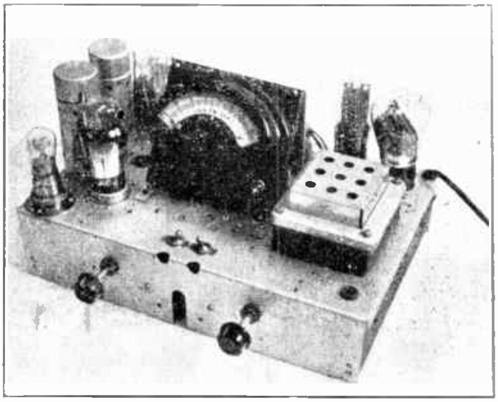
Output set to	Load Current (Milliamps)						
	0	30	50	70	90		
Volts	Volts	Volts	Volts	Volts	Volts		
300	300	300	295	280	255		
250	250	249	248·5	248	247		
200	200	200	200	198·5	197		
150	150	150	149	148	147		
100	100	99	98·5	98	98		
	Mains Input Volts at 50 mA. D.C. Load						
	Volts	Volts	Volts	Volts	Volts	Volts	
	180	200	220	240	260	280	input
250	243	245	249	250	251	252	output

The regulation at 300 volts output is not so good, due to insufficient voltage drop allowed in V_1. If voltages above 300 are required, the mains transformer should furnish at least 100 volts more than the output voltage required at full load.

A type PA1 valve or a *Standard* 4033A is the most suitable type for V_1, as it has a low voltage drop (impedance) and a high slope, giving good control.

For V_2, a 6J7G, 6C6 or 77 type valve is suitable, although old screen grid valves, such as an MS4B or AC SG, can be used. Other triodes for use as V_1 can be a 2A3, PX4 or *Mazda* PP3/250, but if these are used a separate centre tapped L.T. winding is required, and it may be necessary to increase the V_2 anode resistance from 0·25 to 0·5 or 1·0 megohm. For higher output currents, up to, say, 250 mA., or voltages up to 600, a valve such as the *Standard* 4300A is recommended; in this case an *Osglim* neon is preferable to the *Philips*.

The unit may be fed, quite satisfactorily, from some existing H.T. supply, *e.g.*, from a P.A. or F.D. supply of about 400 volts, the stabiliser both dropping the voltage and stabilising it for an E.C.O. Such a unit may also be used for obtaining a constant grid voltage for various purposes.



A voltage stabilised power supply suitable for low-power oscillators, etc. The circuit used is shown in Fig. 10, with the modification that two stabiliser sections are connected in parallel across the filter thereby providing two stabilised outputs which are independently adjustable. The screening cans contain the two controller valves.

Voltage Dividers

Voltages of lower value than the supply voltage may be obtained by the use of a voltage divider which is a form of potentiometer where the tapping points on the resistance are fixed or adjustable instead of being continuously variable. As many tapping points as desired may be used to give various voltages, but each additional point which delivers current affects the voltages of all the other intermediate tappings. The reason for this is that the voltage-drop across any given resistance varies directly with the current flowing through it. If this relation (Ohm's Law) is remembered, it is a simple matter to calculate the resistances of all the sections of the voltage divider if the voltage and current required at each tapping point are known. In Fig. 11, which shows a typical arrangement, these values are I_A, I_B, E_A and E_B. The resistance R_1 acts as a bleeder and determines the minimum current I_1 flowing through the divider, *i.e.*, when all loads are removed. This minimum current is chosen to suit the system, and forms the starting point for the calculation.

R_1 is calculated directly from I_1E_A. The resistance R_2 carries both the bleeder current I_1 and the first load current I_A both of which are known. The voltage-drop across R_2, *i.e.*, between the tapping

World Radio History

points B and C is also known, so that R_2 is given by

$$\left(\frac{E_B - E_A}{I_1 + I_A}\right).$$

Similarly, R_3 carries the current $(I_1 + I_A + I_B)$, and is given by

$$\left(\frac{E - E_B}{I_1 + I_A + I_B}\right).$$

The total resistance of the voltage divider is then obtained from $(R_1 + R_2 + R_3)$, the intermediate tapping points being located as determined by the values of the separate sections of the resistance. If the total resistance has an inconvenient value, a different value of the bleeder current I_1 should be chosen as a starting point for the calculation.

The regulation of a voltage divider is poor : that is to say, the voltages at the various tapping points will vary quite seriously when the current delivered by any tapping is changed, and this should always be borne in mind in making adjustments to apparatus which is supplied by a voltage divider.

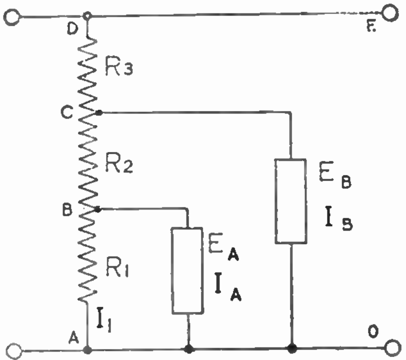


Fig. 11.
A voltage divider. The resistance is connected across the line AD, and is tapped at B and C to give intermediate voltage values. See text for the calculation of R_1, R_2 and R_3.

Switching Arrangements

Very little advice can be given on switching arrangements, as each amateur usually finds it necessary to devise his own switching circuits to meet his own special needs. A few points of general interest and importance, however, may be mentioned.

Double-pole switches should be used wherever possible, at least in the interests of safety. This practice often helps also in preventing induced hum in the receiver from the transmitter supply circuits. Switches should be connected in the primary circuits of transformers, and not in the secondary circuits, unless some of the secondaries are continuously loaded, as in the case of combined transformers supplying current for indirectly-heated cathodes or mercury-vapour rectifier filaments and the anodes of the rectifier. This is important in devising switching arrangements for the change-over from transmission to reception.

Time delay switches for use in conjunction with mercury-vapour rectifiers are quite simple to arrange, the switch winding being connected to the filament supply and the switch contacts in the H.T. circuit. It should be remembered, however, that they do not provide a complete safeguard against damage, for if the main supply circuit is broken for a short period, the characteristics of the time-delay switch may be such that the contacts will not open at all, or close again too early, so that the H.T. supply is connected to the anodes before the filaments have reached the proper temperature again.

Safety Devices

The dangers of high-voltage supplies have already been mentioned in an earlier part of this chapter, but it should be added here that there is no reason for the amateur to be unnecessarily perturbed, provided a few simple precautions are taken. It may also be remarked that while the H.T. supply may not give a fatal shock to the careless operator, the sudden muscular impulse which invariably accompanies the shock may cause him to do more damage to the apparatus or to his own person than the damage caused directly by the shock.

It is a wise precaution to connect a red pilot lamp across the primary of all H.T. transformers. This may be a neon lamp, or a filament type lamp of, say, 15-watt rating. In the latter case, the possibility of a failure of the filament may be greatly reduced by using a lamp of higher voltage rating than the voltage of the supply to which it is connected, *i.e.* by under-running the lamp.

Bleeder resistances should have a wattage rating twice as large as the power actually dissipated in them under the heaviest conditions, in order to minimise the risk of failure.

Fuses are desirable in all supply circuits. If fuses are used only in the mains input leads, a short-circuit will cause all the supplies to fail, which can be very annoying if there is any apparatus in operation, such as an electron-coupled oscillator, where the valve temperature is of importance. As an alternative to fuses, small overload circuit-breakers may be used. The Meccano type is quite suitable and is easily obtainable.

A patch of thick rubber floor covering in front of the transmitter will possibly prevent a serious shock if the positive H.T. terminal should accidentally be touched, but it is more desirable to acquire the habit of never touching any part of the circuit with the power on rather than that of using devices which make it safe to do so.

A further aid to safety is the practice of properly earthing all metal parts of the apparatus which are not actually part of the circuit. This applies for example to lead sheaths and metal conduits carrying wires, cores of smoothing chokes and transformers and the metal cases of all condensers.

The practice of using double-pole switches is strongly recommended, not only with a view to completely isolating the mains voltage but also to prevent a circuit remaining alive even with the switch open due to an earth contact at an unsuspected point.

A comprehensive list of recommendations for the guidance of amateurs on the subject of safety has been prepared by the Radio Society of Great Britain and is available on receipt of a 2½d. stamp from the Headquarters of the Society. The Institution of Electrical Engineers also issues Rules for the Safety of Electrical Installations in Buildings, price 1s. 6d., obtainable from the Secretary, I.E.E., Savoy Place, London, W.C.2.

World Radio History

Chapter Ten

TRANSMITTER INTERFERENCE

Telegraphy Interference—Keying Methods—Key Thump Elimination—Valve Keying—Telephony Interference—Wave-Traps—Television Reception—Harmonic Reduction—Co-operation with Broadcast Listeners

THE subject of Transmitter Interference although of no special importance to-day owing to the determination of British Amateur licences, is nevertheless of paramount interest to all who propose applying for a radiating permit after the cessation of hostilities.

The information given in this Chapter represents the results of numerous experiments carried out over a period of many years, and should be borne carefully in mind by all who are planning equipment for post-war use.

The details concerning third harmonic suppression have been included, as they are a consideration of the problems of television interference which were involved in pre-war days, and are likely to be of even greater importance when television transmissions are resumed.

The more general types of interference will be studied first, commencing with the transmitting station, from which the interference originates. Everything possible should be done at this point, since it is preferable to eliminate the trouble at the source, but the successful elimination of any interference depends largely on the co-operation of the amateur with the broadcast listener.

Types of Interference

There are three types of interference that may be caused in neighbouring receivers working on broadcast waves, by an amateur telegraphy transmitter.

First, the " wipe-out " effect, where the signal from the transmitter " blocks " the receiver due to either the excessive field strength of the transmitter, or the inselectivity of the receiver, or both. This effect may also be accompanied by bad hum due to insufficient smoothing in the transmitter.

Second, key " clicks " or " thumps," caused by the sharp change in aerial power from zero to normal, and *vice versa*, when the transmitter is keyed.

Third, the " hum effect " which is not necessarily accompanied by blocking in the broadcast receiver.

The first effect is normally curable at the receiver end, and will be dealt with in a later section.

The second effect must be cured at the transmitting station, and can usually be overcome by adopting various filter devices, or by changing the keying system.

The third effect can be troublesome, as it may be a form of interference that is not radiated as a wave, but which travels through the mains wiring. To test this, remove the aerial to at least 5 feet from the receiver. If the hum still persists, remove the earth lead and if the hum is still noticeable, then it is most probably being conveyed through the mains wiring. The solution of this trouble lies in the use of a suitable mains filter, possibly at the transmitter end as well as at the receiver.

It is always advisable to insert two ·1 μF condensers across the main supply lead to the transmitter, with the centre point earthed. These should be connected as close as possible to the main switch, where the mains enter the premises.

Fig. 1 shows a suitable mains filter circuit for the receiver end. The condensers are ·1 μF, and the chokes are of a size suitable for the frequency they are to reject. They must also be wound with a suitable gauge wire for the current carried. It is suggested that 50 to 250 turns on a 1" dia. former, of 20 D.C.C. S.W.G. be used.

It may be found that only one pair of condensers are necessary, or alternatively one condenser each side of the chokes, in which case the earth connection must be omitted.

The filter should be constructed in a metal box, which should be earthed. The components must be insulated from the box in a manner suitable for a mains circuit.

Precautions at the Transmitting Station

It must be realised that in order to cure interference due to a telephony transmitter, it is

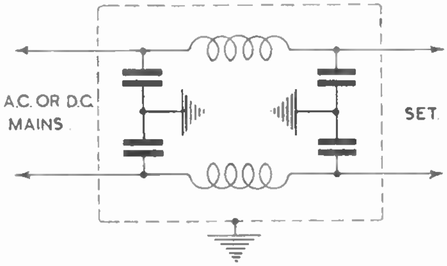


Fig. 1.

Interference suppressors in the mains leads to transmitter or receiver. The earthed metal box containing the filter is a precaution against direct pick-up or radiation by the chokes.

World Radio History

necessary to ensure first that no interference would be experienced were the transmitter keyed. Having produced a carrier free from A.C. modulation, it should be possible to key it without causing instantaneous changes in aerial power, which would produce transient sidebands, as explained later. When telephony is used, however, the carrier is modulated, and the aerial power continually varied. It is necessary, initially therefore, to take precautions against interference when using telegraphy.

If this system is employed, some form of frequency stabilisation, preferably crystal, should always be used, and steps taken to see that it is properly adjusted, and that the P.A. stage is correctly neutralised.

Power Supply

Even a crystal oscillator will generate modulated waves, unless great precautions are taken with the smoothing of the H.T. supply to this stage, which should, of course, be as free from ripple as possible. Similar care should also be taken with the L.T. circuit, the filaments or heaters being by-passed with the usual form of centre-tapped condensers, connected directly on to the valveholder.

When telephony is employed, even greater precautions must be taken with the smoothing arrangements.

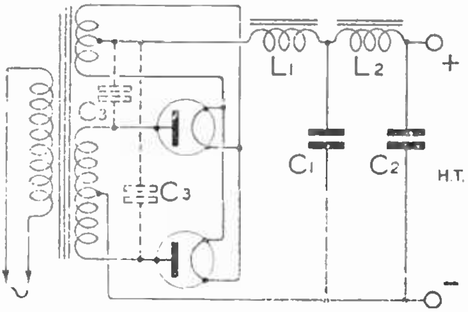


Fig. 2.

Methods of suppressing interference when using mercury vapour rectifiers for high tension supply.

If mercury vapour rectifiers of the GU1 type are used, interference may be experienced in neighbouring receivers, due to feed-back, through the mains, of the characteristic hum of this type of rectifier. This trouble may be cured by adding the choke L_1, to the smoothing circuit shown in Fig. 2. This is now usually incorporated in the design of modern power supplies in the form of a swinging choke, and is referred to in detail in Chapter 10.

As an alternative cure the condensers C_3 may be fitted. A capacity of ·01 μF, at a sufficiently high working voltage, will be suitable.

Aerial Coupling

This is an important matter, and the section of Chapter 12 dealing with the subject should be studied carefully.

In general it is always advisable to use loose coupled circuits and to avoid all forms of direct coupling.

Keying Methods

This subject is dealt with fully in Chapter 7, but certain methods will be referred to again here, owing to their importance in connection with interference.

The two methods of keying in general use consist of breaking either the primary of the power transformer, or the H.T. circuits.

Primary keying requires a simple filter circuit as shown in Fig. 3. The value of C_2 is not very critical. The chokes H.F.C. do not function at the frequency of the transmitter, but are intended to prevent the R.F. oscillations, caused by the spark at the keying contacts, from radiating. Any large choke is suitable, as these oscillations are of very indefinite frequency. It should be borne in mind that the chokes have to carry the current flowing in the primary of the transformer, and will therefore cause a voltage drop, which consequently limits their size. If a filter is not found to be necessary, keying may be effected across C_1.

Elimination of Key Thump

When a transmitter is keyed, and the aerial power suddenly switched on, a click or thump is often produced in nearby broadcast receivers. A weaker click is produced on breaking the circuit.

The reason for this thump or click being produced on broadcast frequencies when the transmitter is working on high, or ultra-high frequencies, is due to transient side bands caused by the sudden starting up of oscillations. These side bands cover a large part of the frequency spectrum, and although their duration is exceedingly short, their amplitude is great. Furthermore, even the most selective receivers will be unable to eliminate them, as they are transmissions which cover nearly all frequencies.

The cure is to arrange for the oscillations to commence and finish slowly, as the key is depressed and released. By "slowly" is meant a lag of about one-tenth to one-twentieth second, although this figure cannot be fixed at any very definite value.

Fig. 4 shows a conventional filter for keying in any D.C. feed, *e.g.*, in the H.T. supply to a frequency doubling stage. It is immaterial, so far as the effectiveness of the filter is concerned, whether the positive or negative H.T. lead is broken, *i.e.*, whether the lead to the anode of the valve is keyed, or the connection between H.T. negative and the centre tap of the filament of that stage. It is

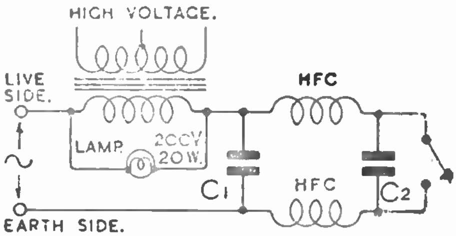


Fig. 3.

A filter for use with primary keying.
C_1 ·05 μF. C_2 ·001 μF. HFC 210 turns No. 30 D.S.C. on ¾" former.

World Radio History

frequently more convenient to key in the former position.

The condenser C may be 0·5 μF and the resistance R 250 ohms. The choke L requires to have a fairly high inductance with no D.C. flowing, 50 to 100 Henrys, but this may drop to quite a low value when current is flowing, since the choke is inserted to remove the thump at " make," the condenser-resistance combination operating at " break."

This system of keying should preferably be used on a low power stage ; when this is done, it may be found necessary to insert a further choke, similar to L, in the H.T. lead to the power amplifier stage.

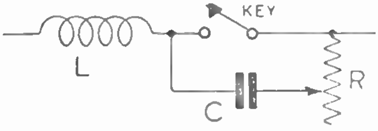


Fig. 4.
A thump filter for keying in D.C. leads.

It is always advisable to use a relay for keying, because a well-made relay gives a much firmer and quicker make and break than a key. Further, it is not advisable to employ H.T. or other leads in the wiring of the transmitter, of undue length, such as might be necessary if no relay were used.

Fig. 5 shows a relay operated by a key and battery. The condenser C across the coil of the relay prevents interference due to breaking an inductive circuit, and may have a capacity of ·25 or ·5 μF. If the distance between the key and the relay is considerable, a further condenser of similar capacity may be found necessary across the key itself. If thump still persists, two chokes, RFC, should be inserted in the leads to the relay contacts. These should be large, and 200 or 300 turns will be suitable.

Valve Keying

Several valve keying systems exist, which are generally satisfactory when applied to the higher-powered amateur stations, but there is no object in using them at low power stations. Fig. 6 shows a convenient example, which has several advantages.

The keying valve requires a separate filament supply, and must be capable of passing the total anode current to the keyed stage. If one valve is insufficient for this purpose, further valves may be connected in parallel. There will be only a small voltage lost in the keyed valve, due to the fact that the grid and anode of the keying valve are joined at " make " when the key is down. The 1μF condenser across the key removes last traces of click.

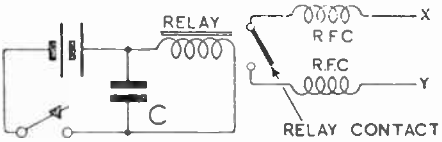


Fig. 5.
Interference suppressors in a relay keying circuit.

Although it may not be essential, it is always preferable to use shielded leads for power supply wiring, keying wires, L.T. and H.T. leads, and any other supposedly zero R.F. potential wires. If, however, a good earth is used on the transmitter, this point may not be quite so important.

Telephony Interference

The modulation equipment of a transmitter requires very careful attention if telephony is to be used during the hours of broadcasting. In this connection Chapter 7 should be carefully studied, and due attention paid to all the details.

Over-modulation must be avoided, otherwise severe interference will result. Care should also be taken to see that no frequency modulation is taking place. Again, aerial coupling plays an important part, and due attention should be paid to it. It is essential that, when feeders are used, they should be correctly matched to the aerial system ; bad telephony interference may often be due to radiating feeders. Chapter 12, dealing with this subject, should be read carefully.

If these points are attended to, the cure for telephony interference lies at the receiver end.

The Broadcast Receiver

The average broadcast receiver is reasonably selective, only suffering from interference when in very close proximity to the transmitter, and frequently then only when telephony transmissions are taking place.

The older types of receivers, of the detector and one L.F. class, are more subject to interference than the superheterodyne or multi-tuned circuit types, which require only small indoor or frame aerials.

Portable receivers with enclosed aerials are less subject to interference than the other types mentioned. Mains portables are equally good, although a mains filter of the type shown in Fig. 1 may be necessary. Care should already have been taken to keep R.F. out of the mains at the transmitting end.

A form of wave-trap can be used with this type of receiver, and is usually effective. The trap consists of a few turns of wire wound round the aerial frame and tuned to the frequency of the interference.

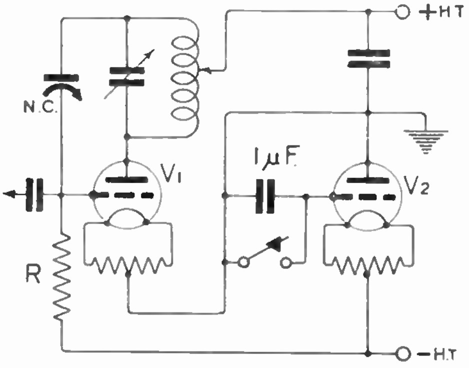


Fig. 6.
A method of valve keying developed by British amateurs.

In some cases a small R.F. choke connected in the grid lead directly next to the grid of the detector valve, will be found satisfactory. The choke should be wound as small as possible, physically, consistent with the frequency it is intended to reject.

Receiver Aerial Adjustments

With the older type of receiver, wipe out, or hum is the most common form of complaint, and applies equally whether telegraphy or telephony is being used.

It should first be ascertained that the receiving aerial is not too long. If this is the case it should be shortened if possible. An indoor aerial will be found to assist, and is often quite free from interference. The coupling from the aerial to the first tuned stage should be loose.

The simplest method of loosening the aerial coupling, is to insert a small fixed condenser in series with the aerial lead, close to the receiver. This condenser may vary in capacity according to local conditions, and may have a value between 300 µµF and 5 µµF.

In every case, steps should be taken to confirm that the interference is not reaching the receiver through the mains in the manner previously described.

Wave-traps

The wave-trap, which is often an effective cure for most forms of interference, should be connected in the aerial lead, as closely as possible to the receiver. If constructed in a screened box, which should be earthed, it will be still more effective, although screening is not always necessary.

There are three types of remedy which come under this heading. The untuned trap, the tuned trap, and the low-pass filter.

The untuned trap, Fig. 7A, is the simplest, and consists of a small R.F. choke in the aerial lead. It is usually more effective on the higher frequency bands, but will be satisfactory on the 3·5 Mc band if the interference is not too intense.

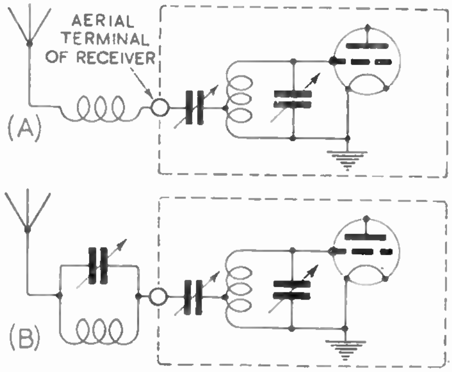


Fig. 7.

Showing how an untuned (A) or tuned (B) wave-trap should be connected between the aerial and the first tuned circuit of a broadcast receiver.

A choke of 100 turns of 36 D.S.C. wire wound on a ⅜″ former will be found suitable. In all cases chokes should be wound on small-diameter formers in order to keep the self-capacity to a minimum.

Fig. 7B shows the tuned trap, which is more selective, and should be adopted if the untuned trap is not quite effective. This trap is usually employed on the lower frequency bands, but can be used successfully on the higher frequencies.

For the 1·7 Mc and 3·5 Mc bands a ·0003 µF condenser is suitable. But for 7 Mc and above, a value of ·0001 µF should be used. The diameter of the former should be decreased from 1″ for the 1·7 and 3·5 Mc trap to ½″ or ⅜″ for the higher-frequency traps. For 1·7 Mc 50 turns will be approximately correct, and about half this number for 3·5 Mc. For 7 Mc 16–18 turns is suitable, and again about half this number for 14 Mc.

Where the trap is to operate on more than one band, a tapped coil may be provided, the turns being as indicated above.

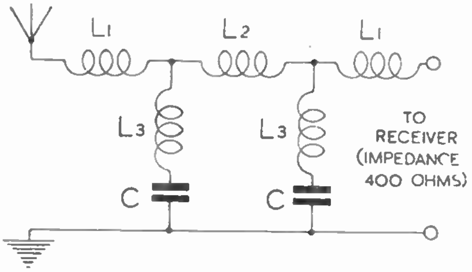


Fig. 8.

A low-pass filter which can be added to a broadcast receiver to eliminate interference.

The Low Pass Filter

Fig. 8 shows the circuit for a low pass filter, which should be fitted in a similar way to the ordinary tuned or untuned wave-trap. It provides a much greater degree of rejection than the simpler forms of traps, and will usually be effective where the others fail.

Since the lower frequency bands are apt to cause more trouble than the higher, the filter is shown with suitable size coils for the 1·7 Mc, 3·5 Mc and 7 Mc bands.

The filter comprises two " T " -type sections in series, forming an unbalanced filter with a sharp cut-off. The components are five coils and two condensers, the coils being wound on valve bases (1⅜″ diameter). It is essential that the coils be wound with No. 30 D.S.C. wire with the turns touching and secured in place with Durofix or similar cement, so that they do not become loose; the condensers must be of a reliable mica type and be reasonably accurate. It is recommended that T.C.C. type M be used.

The values of the coils and the turns required are given in the tables.

The coils L_3 are shown as different for the 1·7 and 3·5 Mc bands, although the filter for 1·7 Mc could be used for 3·5 Mc, but the one for 3·5 Mc would not be satisfactory for 1·7 Mc. The filter is arranged to have a characteristic impedance of 400 ohms at each end, as this figure is likely to suit most aerials and receiver input circuits. The curves of the filter using both 1·7 and 3·5 Mc coils are shown in Fig. 9, where the loss of the filter in decibels is plotted against frequency. As can be seen from the curves, the loss over the broadcast range of frequencies is negligible, but over the respective bands the loss is high and in the order of 40 decibels.

VALUES OF FILTER ELEMENTS

Band	L_1	L_2	L_3	C
1·7 Mc	20	40	35	·0002
3·5 Mc	20	40	10	·0002
7·0 Mc	10	20	5	·0001

L in microhenrys. C in microfarads.

WINDING TABLE

Coil	Turns. 1·7 Mc	Turns. 3·5 Mc	Turns. 7 Mc
L_1	20	20	13
L_2	30	30	20
L_3	27	13	9

It is evident, therefore, that the filters would give a reduction in the strength of interference of about 4 to 5 " S " points, which in most cases would reduce telephony interference to a negligible value. The losses due to the filters would be slightly modified in practice by variations of aerial and receiver impedance, and in general the cut-off points would be at a slightly lower frequency.

The use of one of the above forms of filter in the aerial coupling to the broadcast receiver, when employed in conjunction with a short and loose-coupled aerial, should remove all interference *picked up by the aerial.* It is not usually practicable to redesign the tuning system of a neighbour's receiver, though the point may be borne in mind. Where the older type of screen grid valve is in use, a slight increase of grid bias will often relieve the interference.

It is always advisable to use a good earth to the receiver, but, if only a poor earth, with a long lead, is available it may be advantageous to discard it.

In certain cases a change from leaky grid detection to anode bend will effect a cure where the interference is not necessarily reaching the receiver *via* the aerial. The use of a small R.F. choke in the grid lead, as mentioned previously, is usually of great help.

Interference to Television Reception

The third harmonic of a transmitter in the 14 Mc amateur band must fall between 42·0 and 43·2 Mc. The frequencies allotted for the London Television Station were in pre-war days 41·5 Mc for the sound and 45 Mc for the vision carrier frequency. Owing to the wide modulation frequency band width required, the vision signals occupied approximately from 42 to 48 Mc. A commercial television receiver should be capable of receiving signals say between 43 and 47 Mc when normally tuned to 45 Mc. Consequently harmonics from a 14 Mc amateur station could cause considerable interference to a television receiver tuned between 43 and 47 Mc.

Reduction of Third Harmonic Radiation

It must be recognised that if any form of R.F. power amplifier is to be worked efficiently, a large amount of harmonic energy must necessarily be produced in the anode circuit. The use of push-pull final stages will reduce the even harmonics considerably, but not, unfortunately, those which fall outside the amateur bands, *i.e.* the odd harmonics, in particular the third. It is true that a linear Class B final stage will probably produce less third harmonic than an efficient, well-driven Class C amplifier, but even so there will always be sufficient harmonic energy to cause trouble if it is radiated.

Two further difficulties present themselves. First, the P.A. anode circuit is generally made with a high L/C ratio for efficiency which allows more harmonic current to pass into the load than would a low L/C circuit. Second, most forms of short-wave aerial systems will radiate quite efficiently on a frequency three times that for which they were intended. All told, it would appear that the more efficient a station is designed the worse offender will it be.

Although the *generation* of third harmonics may be a sign of an efficient final stage, there is no

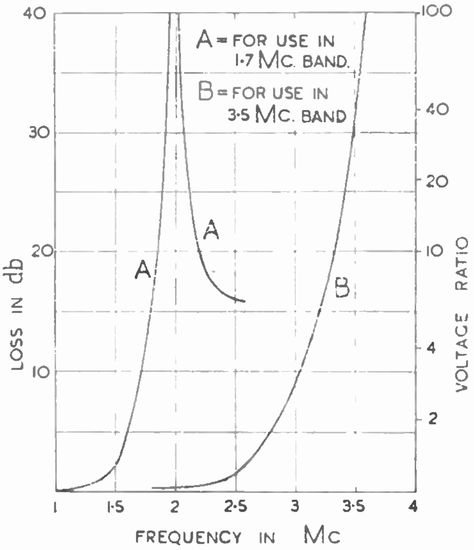


Fig. 9.

Curves showing losses in decibels through a low-pass filter. The curves were obtained by terminating both ends with 400 ohm non-inductive resistances and with a variable frequency across the input.

reason why they should be *radiated*. Indeed, the latter would be a sign of inefficiency, quite apart from the question of interference.

Several methods of reduction of third harmonic radiation are presented herewith, one of which should be successful in eliminating the difficulty no matter what type of 14 Mc apparatus is in use.

The simplest method of attack seems to be the prevention of any 43 Mc R.F. current from reaching the aerial itself. It is doubtful, except possibly in the immediate vicinity of the transmitter, whether enough energy would be radiated from the circuits themselves to cause serious interference. If this was the case, then nothing short of very effective screening of the complete transmitter would be of much use.

If the load on the P.A. is reduced at these frequencies and the harmonic current is prevented from reaching the aerial so much the better.

The following devices will be described:

(*a*) Filters in the feeder.
(*b*) Resonant stubs on the feeder;
(*c*) Modifications to the aerial coupling circuits.

Filters for Harmonic Reduction

Feeders found in amateur stations are generally of either approximately 600 ohms impedance or 80 to 100 ohms.

In the former class is the balanced feeder with 16 s.w.g. conductors spaced about 5″ apart, matched into the aerial with a Y connection or the Windom, which is a single wire or unbalanced type. The commonest example of the lower impedance feeder is the twisted pair type connected directly in the centre of the aerial (usually called the doublet).

With any of these three aerial arrangements a filter can be constructed which will attenuate the third harmonic very severely, while giving practically no loss of the fundamental. At the same time quite a useful reduction of second harmonic will also be achieved. Several types of filter are possible, but those shown are easiest to build in practice. The basic circuit is shown in Fig. 10, together with the approximate shape of the transmission characteristic. Such a filter can be converted for use in a balanced circuit as shown in Fig. 11. The values of L_1, C_1 and C_2 are the same in each case, but it will be seen that the series arm has been divided so that one half of it is put in each line.

The design of two filters are given, one for 600 ohm circuits and the other for 80 ohms. The values of the components are given in Fig. 12A for a 600 ohm balanced feeder which has a cut-off frequency of 22·5 Mc with a loss at 28·4 Mc of 15·6 dB, *i.e.*, a current reduction of about 6 to 1, while its attenuation is a maximum at 42·6 Mc. The actual loss at 42·6 Mc will depend upon the Q of L_1 and C_1, and should be well over 100 to 1, using the coils described, at the third harmonic of any frequency in the 14 Mc band.

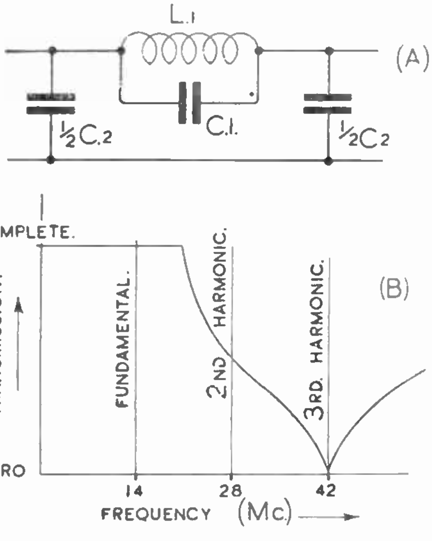


Fig. 10.
Filter circuit showing transmission characteristic.

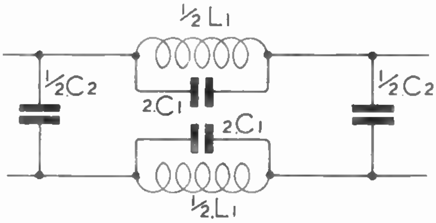


Fig. 11.
Filter for use in balanced circuit.

If means are available it is advisable to measure the values of the condensers before assembling the circuit. Small condensers of 2·5 μμF capacity are available in ceramic dielectric types.

The resonant circuits in the series arms should tune to 42·6 Mc. If a simple receiver is available on which television signals can be received, these can be checked by noting where the circuit absorbs energy when it is held near the receiver coils. If necessary, vary the spacing of the turns on the coil slightly until the coil and condensers by themselves resonate about half-way between the vision and sound carriers. The complete filter can be inserted in the feeder line at any convenient position, although if placed very near the transmitter care should be taken to see that the coils are not too close to the tank circuit. If a single wire feeder is in use the two coils can be put in series as shown in Fig. 12B, using exactly the same components as for Fig. 12A. The earth returns of the shunt condensers must be kept short and connected to the chassis of the transmitter with heavy leads of copper tape. This, being very important, makes it essential to instal the filter close to the tank circuit in cases where the feeder is tapped straight on. If the Windom is fed from a separate tuned circuit which is link coupled to the transmitter, the earth returns should be taken to the "earthy" end of the condenser tuning this circuit. The two coils should not be placed immediately next to each other.

Fig. 13 illustrates a filter suitable for insertion in a twisted pair feeder or any other circuit of about 80 to 100 ohm impedance. Where a link coupling is used between the final P.A. and a tuned circuit to which the feeder is connected, this type of filter will probably be quite satisfactory if connected directly in the link line.

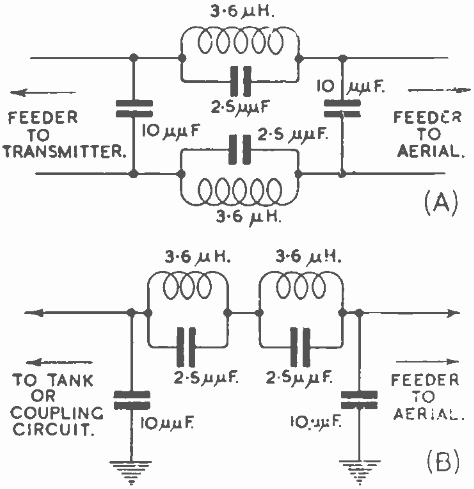


Fig. 12.

Types of filter circuit :
(A) Component values for use with 600 ohm balanced feeder.
(B) Re-arrangement of components for single wire 600 ohm feeder. For 3·6 μH coils use 18 turns spaced 18 S.W.G. wound on 1" dia. former occupying a length of 2".

The cut-off frequency of this circuit is 18 Mc, although its exact value is immaterial. In both cases an arbitrary cut-off has been chosen in order to give conveniently obtainable condenser values.

In each example quoted it is necessary to connect the condenser across the coil at its actual ends. Do not leave any length of lead on the coil. Also in the filter for the 80 ohm feeder keep the device as compact as possible, preferably soldering the condenser tags directly together without using any wire for connection. The feeder line can then be untwisted an inch or so only and connected directly across the 100 μμF condenser. For the 600 ohm circuit it will be necessary to place the coils at a distance apart corresponding to the spacing of the line. The leads to the 10 μμF condenser should be straight, short lengths of stout wire or tape.

Harmonic Reduction Using Stub Lines on Feeder

An alternative scheme to the use of a filter, which is easier to make but takes up much more room is shown in Fig. 14. It consists of two lengths of feeder (shown as an open wire feeder in the drawing), each connected across the main transmission line at the same point. One piece is made equal to λ/12 and is left open at the end. The other is twice this length, *i.e.* λ/6, and short-circuited. λ refers to the fundamental wavelength of the transmitter. In practice it will be advisable to shorten these lengths to ·08λ and ·16λ owing to the velocity of the waves in the wires being less than in free space.

The device can be applied to any form of feeder, provided that it is made in exactly the same way as the feeder to which it is connected. It will work most satisfactorily when used with a line on which there are no standing waves. In this case it is as well to connect it at a distance from the transmitter of $\frac{\lambda}{12}, \frac{3\lambda}{12}, \frac{5\lambda}{12}$ or $\frac{7\lambda}{12}$, etc., *i.e.* at some odd twelfth wavelength along the line, but this is not essential.

The operation is as follows. The open circuit length of λ/12 is actually λ/4 for the third harmonic. Now, if a quarter wave of line is left open at one end it will have a very low impedance indeed as measured at the other end. It will therefore shunt the main transmission line very heavily. Similarly the other portion, λ/6 long, will be a short-circuited half wavelength at the harmonic frequency. This also will put a very heavy shunt across the line, almost a short-circuit in fact. Consequently the third harmonic current will not reach the aerial but will flow into the stubs. An R.F. ammeter can be connected in the shorting bar in the case of high power transmitters, and the bar moved up and down until maximum current is indicated.

Since the reactance at the fundamental frequency of the short-circuited stub is positive and the other negative, the two reactances will cancel each other. Thus at the fundamental frequency the stubs will have no effect at all on the transmission line. The object of connecting the stubs at the above mentioned distances from the transmitter is to make the impedance of the load in the transmitter at the harmonic frequency become high rather than low. This reduces the harmonic current in the anode circuit and tends to keep the anode cooler.

The disadvantages of the device are that the stubs should preferably be kept at right angles to the main line which may be inconvenient, and that unless the wire spacing is small the stubs themselves may radiate the third harmonic, even although the aerial has been prevented from so doing.

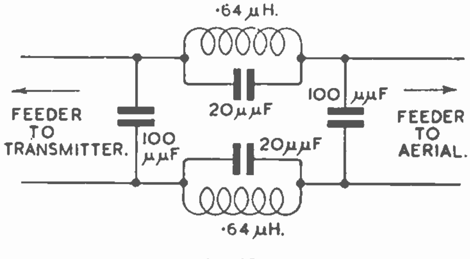


Fig. 13.

Components for use with 80 or 100 ohm feeder. For ·64 μH coils use 10 turns of 16 S.W.G. on a ½" former occupying a length of 1".

World Radio History

Modifications to P.A. Output Circuits

In some transmitters it may be possible to prevent the third harmonic from reaching the feeder at all. One way of doing this is to use a tank circuit in which the anode is tapped down the coil by a certain critical amount. In this way the third harmonic in the tank circuit can be reduced almost to zero.

Fig. 15 shows the circuits of a single-ended, and push-pull P.A. stage arranged for this method of suppression.

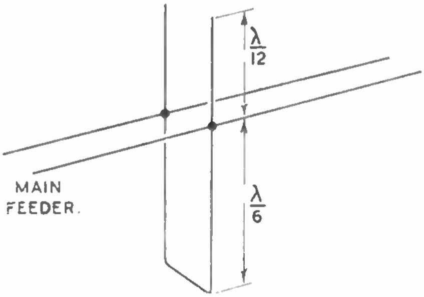


Fig. 14.

Stub for harmonic suppression. In practice cut the open and shorted lengths to 0·08 λ 2 and 0·16 λ 2 respectively.

It should be noted that the more usual form of neutralisation has to be dispensed with, as the tapping down on the anode coil will change the neutralising of the circuit. The slight rearrangement shown, where the neutralising condenser is connected between the anode and end of the grid coil remote from the grid, has exactly the same effect as the tapped anode circuit type.

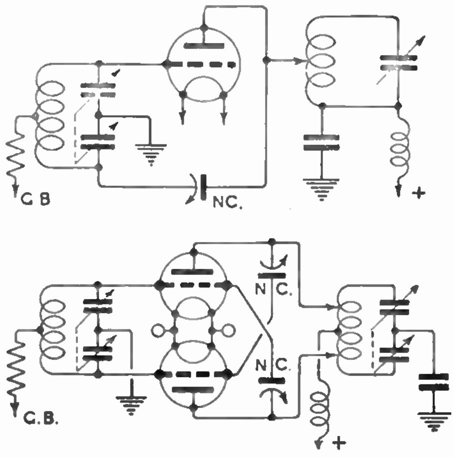


Fig. 15.

Arrangements designed to prevent third harmonic reaching the feeder.

Above: A single ended circuit. Below: A push pull circuit.

The method of adjusting the taps is described in text

To adjust the tap accurately, some means of observing the third harmonic must be available. This can be done by means of a field strength meter, or a single-valve receiver. The harmonic should be tuned in and the anode or anodes tapped down the coil carefully, until the indicator shows a minimum. From one to three turns may be expected.

The use of very loose or link coupled aerial circuits will materially assist in keeping any remaining harmonic from being radiated.

In cases where a matching network (Collins coupler) is used, the circuit can be modified to form an arrangement similar to the filters already described. This is done by connecting a small variable condenser across the series coils to tune them to the harmonic frequency. (Fig. 16 illustrates the arrangement.) This will entail the resetting of the other two condensers slightly.

Where the optimum load on a transmitter and the feeder impedance are known, the circuit values can be calculated, but where an existing coupler is already working it should not be difficult to find the correct adjustments by trial and error.

It is advisable to use coils with no short-circuited turns. Such coils should be somewhat smaller in value than are normally required for 14 Mc, or difficulty may be met in tuning them up to 42 Mc, in fact the self-capacity alone may be sufficient, in which case resonance can be obtained at the correct frequency by varying the turns.

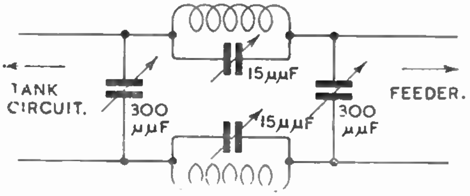


Fig. 16.

Suitable components for a matching network. Each inductance to be made of 5 turns of 2" dia. about 1" long

Using the usual type of coil with about five turns on a 2" former, a condenser with a maximum value of 15 μμF should be suitable.

Unless measuring gear is available, the only satisfactory way of adjusting the circuit is to listen on a receiver tuned to the third harmonic, preferably at a distance of several hundred yards from the transmitter, and to adjust the small condensers until minimum harmonic is heard. Both condensers should be kept at about the same setting until the tuning position is obtained, when individual fine adjustment can be made. The main condensers will now require readjustment to load the transmitter correctly, but this should not be great if the circuit is functioning correctly.

If an unbalanced network is used, the adjustment will be simpler, as there is only one small condenser to adjust. A 10 μμF maximum would probably be sufficient in this case as the coil will be about double the size used in the balanced variety.

World Radio History

The Broadcast Listener

When a transmitting amateur receives a complaint from a local broadcast listener, the transmitter should first of all be checked, to ensure that the interference is not due to an accidental misadjustment. The complainant should then be visited and the form of interference studied, and assistance given where possible, to cure the trouble.

Occasionally, the amateur is not received by the complainant in the friendly way in which the call is made. In this case the Post Office authorities should be informed immediately, and full details forwarded.

It is always advisable for the amateur to verify that he is not causing local interference, without waiting for a complaint to be made. This applies especially to those who live in populous areas.

The importance of co-operation with the complainant cannot be over emphasised, and should always be attempted, the type and severity of the interference being the first point to be studied.

If an anonymous complaint is received it is advisable to ignore it. It is natural to expect that if the interference is severe and frequent, the broadcast listener will take steps to inform either the amateur or the authorities.

If a complaint is received from the Post Office, giving insufficient information for the amateur to attempt co-operation, details should be pressed for, in order that a cure may be effected.

Considering the large number of receivers in use, a very small number suffer interference from local transmitters and it is nearly always possible to effect a cure, however bad the interference may be.

World Radio History

Chapter Eleven

ARTIFICIAL AERIALS

Coupling Methods—Practical Designs Incorporating Diode Voltmeter and Metal Rectifier—Photometric Method of Calibration

IN essentials an artificial aerial comprises a tuned circuit representing the inductance and capacity of an actual aerial, and containing resistance in which the radio-frequency energy from the transmitter can be dissipated. Thus the circuit of an absorption frequency meter illustrated in Chapter 14 (Fig. 1), would also form a simple artificial aerial. The lamp, designated B, would then serve as a resistance in which the output from the transmitter could be dissipated as heat instead of being radiated into space.

An artificial aerial could also be constructed on lines similar to the Phone Monitor and Overmodulation Meter illustrated in Chapter 7 (Fig. 24).

If the artificial aerial is to be used in connection with low power experiments a receiving type of condenser could be employed, but as large R.F. currents or voltages occur when an artificial aerial is employed in conjunction with a high power transmitter it is desirable then to use a more robust type of condenser.

The use of a lamp to dissipate the R.F. energy is often convenient but, since its effective resistance to R.F. varies with frequency and filament temperature, it is not readily susceptible to calibration. As these factors may introduce errors into the results obtained, it is preferable to use a resistance in place of the lamp. This should have a value of about 500 ohms which can be built up from several inches of thin resistance wire removed from a high resistance potentiometer. Alternatively carbon type resistors could be used.

In the selection of a resistance it should be remembered that it must be capable of dissipating the full output expected from the transmitter, which may be in the order of 70 per cent. of the input power. For this reason excessively fine wire should not be used otherwise fusing may occur. If carbon resistors are employed care should be taken in their selection to see that they are of sufficient wattage to carry the power involved otherwise their value will change, due to excessive heat, and as a result errors in measurement may be caused.

In its simplest application an artificial aerial is used as a load to replace a radiating aerial during the adjustment or design of a transmitter. In particular the experimenter will find it helpful to have some knowledge of how the power in this load rises or falls as adjustments are made. Relative indications of transmitter output may be observed by watching the varying brilliance of the load lamp. If a resistance is used in place of a lamp it may be desirable to insert a hot wire ammeter in series with it. The value of the resistance could then be reduced to permit operation at a reasonable working current.

Coupling Methods

It is necessary, for whatever purpose the aerial is used, to feed it with power from the transmitter. The simplest method of so doing is by means of direct inductive coupling between the coil L and the anode circuit of the final stage, or of any other stage, the power output of which it is required to determine. Direct coupling may not, however, be convenient in practice, in which case link coupling will undoubtedly be found the most satisfactory, and is to be recommended on all grounds. Two link coils having from 5 to 20 per cent. of the turns of L and of the tank coil respectively are coupled to each of these coils and connected together by a short length of feeder. The latter may be one of the proprietary types now available, although flat twin cab-tyre cable or lighting flex are suitable. Spaced feeders could be used to eliminate a slight source of loss,

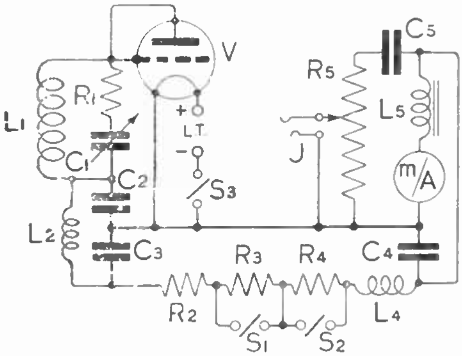


Fig. 1.

Artificial Aerial employing Diode Voltmeter.

C_1	.00016 μF, Eddystone.	L_2, L_4	R.F. chokes.
C_2, C_3	.002 μF, 620 Dubilier.	L_5	20 H. 300 ohms.
C_4	.002 μF, M. T.C.C.	R_1	350 ohms.
C_5	2 μF, Dubilier.	R_2	2,000 ohms.
L_1	14 Mc. 4 turns.	R_3	3,000 ohms.
	7 Mc. 8 turns.	R_4	5,000 ohms.
	1.7 Mc. 30 turns.	R_5	10,000 ohms.

World Radio History

but they are less convenient. A third form of coupling is by means of a small variable condenser of about 35 μμF maximum capacity connected between one end of L and the live end (or a tapping) on the tank coil. Capacitive coupling in this manner is simple but on the whole unsatisfactory because it tends to alter the tuning of both circuits and the neutralising of the final amplifier.

In order to enhance the utility of an artificial aerial it is usual to include some form of measuring circuit in addition to the load circuit. This should be so designed as to give full information about the R.F. output from the transmitter, and to do this successfully it must measure the following factors: (*a*) power output in watts, or relative output, (*b*) quality of telephony and degree of key clicks, hum, etc., (*c*) percentage modulation in the case of telephony, (*d*) frequency ripple or chirp, and general stability. All of these factors with the exception of (*b*) can be measured by a rectifier suitably arranged to act as an R.F. voltmeter thereby measuring the potential set up across R. To cater effectively for factor (*b*) calls for the use of cathode ray equipment, and further information on this matter will be found in Chapter 7.

Practical Designs

Where a high degree of accuracy is sought, an artificial aerial incorporating a diode valve voltmeter is strongly recommended. Through the use of such a device calibration is unlikely to vary very much from band to band, consequently it is possible to compare the efficiency of a transmitter at high and low frequencies. The circuit of a suitable design is given in Fig. 1. In this, the resistance R_1 should be made from thin straight resistance wire, whilst the choke L_5 should be of a type which will carry 10 mA. Suitable turn sizes for coupling the artificial aerial to the load would be one turn for 14 Mc., two turns for 7 Mc. and four turns for 1.7 Mc.

Where experiments are to be confined to one, or at the most two bands of frequency, a less complex arrangement can be employed. This simplification can be affected by the substitution of carbon resistors for R_1 and by replacing the valve voltmeter by a metal rectifier. The latter alteration overcomes the need for an outside filament battery, which besides being inconvenient, is liable to introduce errors of calibration through the coupling effect of the leads or their capacity to earth. Although the sensitivity of a metal rectifier will fall off a little at the higher frequencies, it should be appreciated that it is difficult to obtain a *true* calibration of any such device in terms of actual power output in watts. An indication of *relative* output within the limits of any one frequency band will meet most amateur requirements.

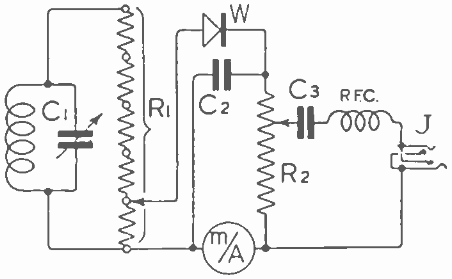


Fig. 2.

Artificial Aerial employing Westector.

C_1	.00016 μF, Eddystone.	R_1	500 ohms.
C_2	.002 μF, M. T.C.C.	R_2	10,000 ohms.
C_3	2 μF (paper), Dubilier.	W	Type W6 Westector.
L_1	As for Fig. 1.	R.F.C.	R.F. Choke.

The circuit of a simplified artificial aerial is given in Fig. 2. In this arrangement the load R_1 is made up of a number of metallised or carbon composition type resistances, connected in series. Wire wound resistances must *not* be used, as they are appreciably inductive. The total wattage of the resistances should be about double the maximum output expected from the transmitter in order that they shall not become overheated. For the 10 watt case, five 100 ohm two-watt resistances can be used in series; or ten 200 ohm one-watt type could be joined in parallel in pairs, the five pairs then being joined in series to make up a total of 500 ohms. The junction points between the five resistances provide a convenient point to which the Westector can be joined by means of a spring clip and flexible lead. This tapping is adjusted to suit the power input, since the rectifier should not receive more than 30 volts of R.F., and the current through it as shown by an 0–1 milliammeter should not greatly exceed 0·5 mA without risk of damage. The clip should, as shown in the diagram, be attached to the lowest junction point, before applying power; and if the reading obtained is not sufficient it may then be moved with caution to a higher tapping.

As illustrated, the artificial aerial is capable of reading power from considerably under one watt up to 10 watts or more at the lower frequencies, or nearly 20 watts at the higher frequencies. For powers in excess of 25 watts R_1 should be so chosen that the Westector can be tapped across less than 100 ohms, such as by including two 50 ohm resistances in series, in place of the last 100 ohm resistance.

As the resistance of a Westector is not known at radio frequencies the aerial must be calibrated experimentally by some method such as the "grease spot photometer" which is described later.

Applications

To compare output or amplitude an artificial aerial should be coupled to the tank circuit by one of the methods previously described, and the coupling adjusted to give a maximum reading on the meter with the circuit L_1, C_1, tuned to resonance. Providing this coupling is left untouched changes in output or efficiency can be read off. On plugging a pair of telephones into the jack the aerial becomes a simple modulation monitor not unlike that described in Chapter 7, and a good appreciation of quality and percentage modulation can then be obtained. The presence of hum, key clicks, and other similar transmitter faults, can also be checked by this method.

Frequency stability can best be checked by listening to the transmission on a very stable frequency meter or local receiver. If, however, a stable oscillation from a frequency meter is coupled

World Radio History

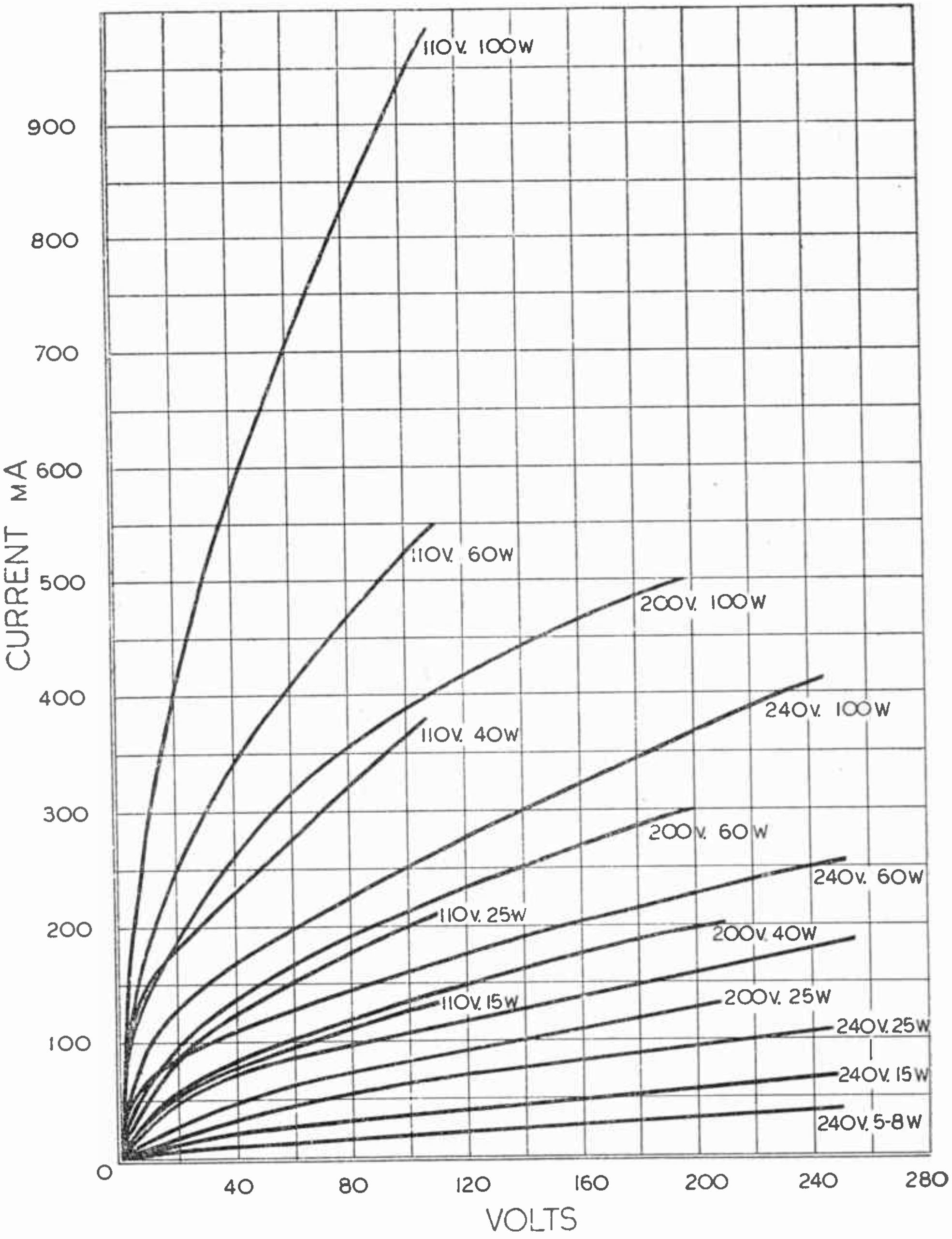


Fig. 3.

E.L.M.A. Lamp Characteristics.

The graph shows a series of curves plotting current against voltage for most standard sizes of lamps made by members of the Electric Lamp Manufacturers Association. The curves of lamps of 25 watts or over are of the gas filled type and those below of the vacuum type. From these curves the resistance and watts dissipated for any known voltage or current can be determined. It is not generally appreciated that a suitable lamp can often be substituted for a resistance with considerable saving in cost.

World Radio History

into the coil L_1, it will beat with that from the transmitter. The beat will be rectified and heard in the telephones, its steadiness under keying and heating-up conditions being an indication of the frequency stability of the transmitter.

A useful method of checking modulation (which will also give a rough indication of power output) is to couple a single turn of heavy wire (with a flash lamp bulb in series) to the coil L_1, or directly to the transmitter tank coil. The coupling should then be adjusted so that the bulb lights moderately when the carrier (without modulation) is applied. When the microphone is spoken into, the bulb should flash slightly brighter on the peaks of modulation a condition which represents about 80 per cent. modulation. Should the bulb decrease in brightness on peaks, it is a definite sign of incorrect modulation due to such defects as insufficient drive or instability of the modulated stage. If there is no change in the glow of the bulb it indicates either under modulation or an incorrect adjustment of the transmitter. If the increase in brightness exceeds about 20 per cent., over modulation or other forms of misadjustment must be suspected. Such defects may easily cause serious interference both to other stations and to broadcast listeners.

Photometric Method

One of the most satisfactory approaches to the somewhat difficult problem of accurately measuring transmitter output is to make use of the output to light electric lamps suitably arranged. Their illumination is then measured photometrically in comparison with the same lamps supplied with measured direct current. This work should of course be carried out in darkness.

A lamp of suitable size is used as the resistance R_1 or alternatively is tapped either directly on to the tank coil of the transmitter, or on to the feeder coupling coil, in such a way as to obtain a suitable impedance match, the rating of the lamp being chosen so that its resistance and wattage are of a suitable order. As a guide for the choosing of lamp ratings a set of curves is given in Fig. 3.

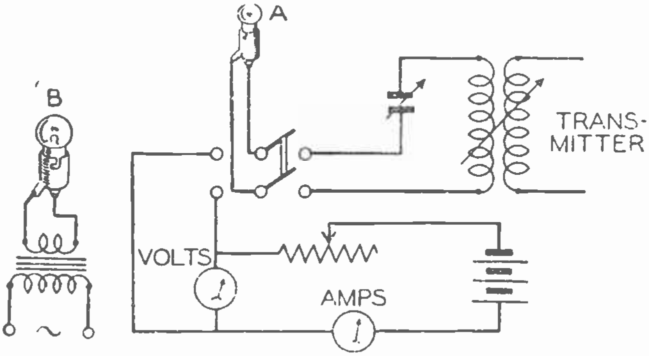


Fig. 4.

Photometric method of measuring power output.

The procedure is as follows :—Switch on the transmitter thus lighting the load lamp A. Switch on lamp B. Interpose spot card between A and B and adjust its position until spot is indistinguishable. Switch off. Change over lamp A to battery or D.C. supply, adjust rheostat until spot is again indistinguishable.

Watts applied to lamp A = Power output from transmitter.

The "grease spot photometer" (as the device described is called) comprises two similar lamps and a sheet of thin paper having a grease spot in the centre set up exactly midway between the lamps. One lamp is lit from the transmitter output and the other from battery or mains supply. The input to the latter lamp must be capable of adjustment and measurement by means of a suitable rheostat and meters. If the voltage across the second lamp is adjusted, a value will be found where the grease spot becomes invisible, *i.e.*, the transmitted and reflected light on the spot are equal. When this condition is reached, the wattage dissipated in each lamp is equal. The arrangement is shown in Fig. 4.

A photo-electric exposure meter as employed for photography can be used instead of the "grease spot" method.

World Radio History

Chapter Twelve

AERIALS

Fundamental Theory—Transmission Lines or Feeders—Simple Aerials—Transmitter Coupling—Impedance Matching—Directive Properties—Directive Systems—Aerials for 56 Mc and Reception

FOREWORD

ALTHOUGH the bulk of the information contained in this Chapter is based upon the results of amateur research into aerial problems, it will be appreciated that the principles discussed and data provided apply equally to Service and commercial requirements.

The experience gained by radio amateurs during peace-time has already been put to a severe test under war conditions, many of whom have been called upon to design, erect and operate special types of aerial systems.

Aerial problems have always interested the amateur fraternity, probably for the reason that most experimenters have the urge to obtain the maximum degree of efficiency under difficult conditions.

Due to the war amateur research has been suspended in Great Britain except in the direction of improving aerials for reception purposes. In the U.S.A., however, development continues, especially in regard to improvements of aerial systems used for ultra-high frequency reception and transmission purposes.

Details of all important developments will be published in *The R.S.G.B. Bulletin*, official journal of the Incorporated Radio Society of Great Britain, to which publication the reader is referred.

Introduction

The design of the aerial system is of the utmost importance in a transmitting station, for if it has not the ability to radiate usefully, the power supplied by the transmitter is wasted. The difference between a good and a bad aerial system can be as great as a hundredfold difference in transmitter power. The efficiency of a transmitter or receiver can be observed quite easily, but the radiation from an aerial cannot be seen, and its efficiency can only be determined by patient trial over a long period, through contact with other stations. A proper understanding of the principles of aerial design will therefore save much time and trouble.

Briefly, the problem is to transfer all the R.F. power output of the transmitter into the aerial system, whence it must all be radiated in certain desirable directions, without local absorption of the radiated energy. Sometimes uniform radiation in all directions is desired, often it is required to be directive; it may be required to work for small or for very great distances, or both; the same aerial may have to work on several amateur bands. An experimenter's ambition in these directions is often seriously hindered by the space available.

FUNDAMENTAL THEORY

Aerial systems have tuning properties, even as the tuning circuits of the transmitter and receiver, and are, in effect, open oscillating circuits, the only fundamental difference being one of scale. In order to radiate well, the aerial must be of appreciable dimensions compared with the wavelength of operation. The tuned circuits of the transmitter, however, are small and confined, and therefore do not radiate appreciably.

Simple aerials fall into two classes, the *Marconi* and the *Hertz*. The difference between them is a simple one, but it is of fundamental importance in understanding the design and operation of transmitting aerials.

In the Marconi a wire of indefinite length is used in conjunction with either counterpoise wires or an earth connection, and the system is brought into tune with the transmitting frequency by means of a coil in series. This coil is the source of coupling to the transmitter, and is either series or parallel tuned, depending on the wavelength and the physical dimensions of the system.

The operation of the Hertz aerial is based on the fact that the wavelength to which any wire will tune depends directly upon its length. The radiator is thus self-tuned and no earth or counterpoise is necessary, consequently it can be placed where it is less disturbed by the effects of the earth, buildings, etc., and so is more efficient.

Short-wave aerials are usually of the Hertz type, because of its greater efficiency, whilst the lengths of wire involved are convenient. On the longer wavebands, however, some type of Marconi is more common, in spite of its lower efficiency, because the lengths of wire required are less than for a Hertz.

Standing Waves

It is imperative that a clear appreciation shall be obtained of what happens when an aerial is energised from a R.F. source—as is the case when an aerial system is coupled to a transmitter. Perhaps the best way to visualise the phenomena under discussion is to perform experiments which will illustrate them.

Take a thick sash-cord, about 20′ long (the longer the better) and fix it to something solid with an elastic joint. Pull it fairly tight from the far end, and wave it gently. The illustration will be easier if the rope is hung vertically downwards. A frequency of waving at which the cord assumes a steady and violent oscillation (the centre waving back and forth) will soon be found. This can be

World Radio History

maintained with quite gentle pulls provided they are at the right speed and correctly timed. This oscillation is an exact analogy to an electrical oscillation in a resonant wire. If the cord is waved too slowly it will be found impossible to transmit much power to it because the source of power (the arm) is now out of tune with the resonant frequency of the cord.

Now a study of the motion will reveal that the cord has maximum velocity, and consequently maximum *energy of motion* at the centre when it is passing through the "straight" position. It will be observed that the hardest pull occurs when it is at each extremity of a swing. At this point the cord is coming to rest and reversing, and at the instant of reversal it has no energy of motion; all the energy of the system is now in the form of a *force* at the ends.

By exact analogy, the energy of motion corresponds to the current in an aerial wire, whilst the force being applied represents the electrical force or voltage at the ends. Notice also that alternate pulls are being applied in opposite directions sideways, corresponding to the opposite directions of motion of the centre, but a quarter of a period of oscillation out of step with the maximum velocity at the centre. In an exactly similar way, the sequence in an aerial carrying electric oscillations is + voltage (+ force), + current (+ motion), — voltage (— force), and — current (— motion), and so forth, and the energy alternates between the ends and centre twice per complete period.

The energy could equally well be supplied to maintain the oscillation by moving the centre or some intermediate point, fixing both ends elastically, but it would then be found that energy of motion was being supplied at the centre, and some proportion of each at intermediate points. In a similar way a resonant aerial can be supplied at any point; if at the end, it is supplied chiefly with force or voltage, and is then said to be *voltage fed*; if at the centre, it is supplied chiefly with current and is then said to be *current fed*. The ratio of the voltage at any point to the current at the same point is called the *impedance*, and it will obviously vary from a high value at the free end to a low one at the centre.

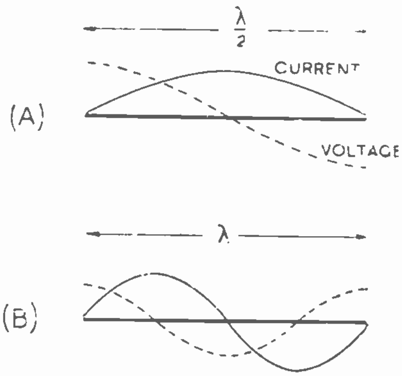


Fig. 1.

Standing waves in resonant aerials, showing voltage (broken line) and current (full line) variation along the wire. (A) Half-wave or fundamental frequency. (B) Full wave, or 2nd harmonic. The symbol λ is generally used to denote a wavelength.

Fig. 1 indicates how the current and voltage are distributed along the aerial wire. The voltage is a maximum at the ends and changes sign at each half wave. The current is maximum at the centre of each half wave. In time, the voltage at any point reaches its maximum value as the current passes through zero, whilst the current reaches its maximum at the instant when the voltage is zero everywhere. This distinction between "time" variation and "space" variation should be noted, as it is important to the understanding of more complicated systems.

Returning to the cord experiment, if the cord is waved at twice the original speed, it will be found that a second mode can occur, with two loops swinging. At three times the frequency three waves may be made to appear, and so on. Notice that at any instant adjacent loops are moving in opposite directions. In electrical terms they are said to be in *opposite phase*, and oscillations of this type are also possible in an aerial, when it is said to be on its fundamental frequency, or on its second or third harmonic, according as there are one, two or three *current loops* or maxima.

In the condition shown in Fig. 1(A) the wire accommodates one complete current loop, and the wire is then said to be in half wave resonance, or operating on its fundamental frequency. In (B) of the same Figure two current loops are shown and the wire is then on its second harmonic—or full wave resonance. In same manner the wire may carry any number of complete half-waves.

Oscillations of this type are called *standing waves* and they occur in any efficient radiating system, be it a rope, a piano string, or an organ pipe executing air vibrations. In order to understand how they are formed, a further experiment may be made with the cord. Pull it tight and give it one sharp flick. A little wave will be seen to run down the cord to the far end, and then come back. The energy of the wave will be felt when it returns, due to reflection from the far end. A further reflection will also occur when the wave returns to the source of power. When the impulses supplied by the hand are timed so as to allow one transit of the cord, then large standing waves which were observed previously are built up.

Resonant Length

Another fact which may emerge from experiments with the cord is that the shorter the rope the higher the frequency, and *vice versa*. The frequency of resonance of an aerial wire is related to its length in exactly the same way, but it is often found more convenient to talk in terms of wavelength when dealing with aerials, since the direct wavelength proportion is easier to use than the inverse frequency relationship. The actual proportion is that the wire is almost exactly half a wavelength long for its fundamental resonance.

Bearing in mind that the wavelength is equal to the velocity divided by the frequency it will be realised that in a half wavelength of wire a wave starting from one end will just arrive back at the home end in one complete period, and will thus

World Radio History

be in step with the feeding source. The remarkably convenient tuning property of an aerial wire is thus explained.

The velocity of a wireless wave in space is 300 million metres (186,000 miles) per second. The number of complete oscillations in this time or distance is the frequency of the wave; thus the distance divided by the frequency gives the wavelength. (For example a 14 Mc wave has a length of 21·4 metres.) When travelling on a wire, however, the velocity is slightly reduced if there is any radiation taking place, and so a fundamental radiator for 14 Mc is not quite half of 21·4 metres, but a small percentage less than this figure. The actual correction is difficult to find theoretically but in practice is usually about 5 per cent. In a multi-resonant wire it is only applied to the end quarter waves, so (including a factor for conversion of metres to feet) the formula becomes :—

$$\text{Length} = \frac{492\,(n - \cdot 05)}{f}\ \text{feet.}$$

where n is the number of complete half waves on the radiator, and f is the frequency in megacycles.

In Fig. 1 the wires are shown in resonance with the applied oscillations. If they were not cut to correct lengths the standing waves would not develop fully and radiation would be reduced; it would then be necessary to alter the length to correct this condition. If it were not possible to do this directly, then it would be necessary to *load* the aerial with inductance or capacity; examples of this will be seen later.

Radiation and Radiation Resistance

It is not possible here to give a complete account of how the energy leaves the aerial, but it may be noted that a fundamental requirement for efficient radiation is the presence of a standing wave system on the wire. As the energy moves about on the wire, alternating between the voltage and the current forms, electric and magnetic strains in the surrounding medium do not interchange in quite the same way. Because of the finite velocity of propagation of these strains they do not follow the oscillations in the wire exactly, but are left behind, so to speak. Each interchange of current and voltage in the wire therefore causes a quantity of energy, in the form of a system of electric and magnetic forces, to be lost in space. These are pushed forward by the forces due to the next oscillation and thus travel outward into space.

The electro-magnetic waves leaving the aerial represent a flow of power, in the same way as does a current in an electric circuit, and this flow may be expressed in watts. In terms of the current I and the resistance R of the circuit, the watts may be defined as :—

$$W = I^2R$$

the product of the resistance and the square of the current. This follows from Ohm's law. In a closed circuit it is easy to measure the resistance. In an aerial, however, there is current flowing and power being radiated; therefore it is possible to introduce a fictitious resistance, known as the *radiation resistance,* to help define the radiating properties of the aerial. The power radiated (in watts) is equal to the radiation resistance multiplied by the square of the current flowing. The radiation resistance may be determined at any part of the aerial, but it is usual to refer to a point of maximum current. At the centre of a half-wave this has a value around 75 ohms, so that a current of one ampere in the centre of such an aerial would represent about 75 watts of radiated power. In the case of a full wave aerial the radiation resistance at one loop ($\frac{1}{4}$-wave from end) due to the whole aerial is usually nearer 100 ohms. At the ends the apparent radiation resistance is of the order of several thousand ohms, and intermediate values are given by intermediate points. Table 2, towards the end of this Chapter, gives some examples.

The radiation resistance does not include the resistance of the wires of which the aerial is composed. In the Hertz or harmonic aerial it is high, compared with the wire resistance, and the efficiency is also high; in the short Marconi it is very low, and appreciable power is lost in heating the wire.

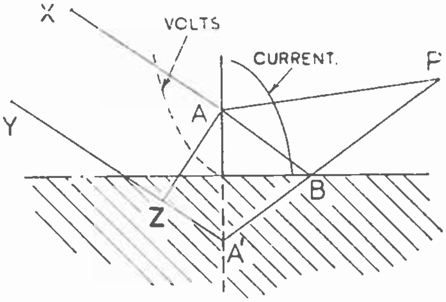


Fig. 2.

A Vertical Quarter Wave Aerial, showing "image" effects. At a point such as P one receives the direct wave AP and the reflected wave ABP, the ground acting like a mirror.

The Marconi Aerial

On the 1·7 Mc (160 metre) and 3·5 Mc (80 metre) bands it is seldom possible to erect a Hertz aerial, consequently some form of Marconi aerial is used. In Fig. 2, where a vertical quarter-wave of wire is represented, the current and voltage distributions are shown, and the wire is assumed to be earthed at the bottom. Now an observer at the point P would be able to receive two waves from any point A on the wire, one directly along the line AP, and the other by reflection from the ground at B. By extending the line PB, it will be seen that so far as P is concerned, the reflected wave appears to have originated at A^1, and not A, exactly as if the ground level were a mirror. As this holds for any position of A, it follows that the half-wave of wire is virtually completed by an image of the real quarter-wave, as shown.

This is the fundamental type of Marconi; an aerial in which the ground virtually completes the resonant length. The shortest length which will permit maximum current at the base and maximum voltage at the top, with of course the greatest efficiency, is the quarter-wave. This is shown in Fig. 3A. If this quarter-wave aerial is fed at the earth end, the conditions require a large current and a low voltage, *i.e.*, a very low resistance. The aerial might be coupled to the transmitter by a few turns and the aerial ammeter placed in the earth

World Radio History

lead. Such an aerial would be difficult to erect for anything but the very short waves, but an inverted L of the same total length will behave very much in the same manner, except that it will radiate more efficiently " off the elbow " than in other directions, whereas the vertical aerial will radiate equally well in all horizontal directions.

In cases where the available wire length is rather less than a quarter-wave, the aerial may be brought to resonance (maximum current at earth connection) by using a loading inductance, and perhaps a tuning condenser across the latter if it is much too small. This arrangement is shown in Fig. 3B.

When the aerial is a little too long, a condenser may be used in series with the coupling coil, as shown in Fig. 3C, but where the aerial is much too long it is usually better to use an harmonic aerial.

Harmonic Aerials

Instead of employing a quarter wave aerial to obtain the current maximum at the earth connection, the same purpose would be served by using an aerial of a length equal to three, or five, or any odd multiple of a quarter-wavelength. For example, an aerial 25 metres (about 82′) in length, is just a little short of three quarter-wavelengths for 40-metre operation, and a small coil and parallel condenser would tune it to this three-quarter-wave position. The voltage and current distribution in the aerial would then be as shown in Fig. 3D.

Harmonic aerials are not suitable for short-wave work, unless there are several complete half-waves in the system, because the radiation is sent off at too high an angle. The " long " one approximates to a long horizontal aerial and can be very effective, though it is advisable to avoid having the bend at a point of maximum voltage.

The Counterpoise

An earth connection is usually of high resistance, and to overcome the loss of efficiency due to this, a system of wires known as a counterpoise is employed in place of, or in conjunction with, the earth. The counterpoise should extend as far as the aerial, but need not of necessity be under it. It is best from the point of view of efficiency to arrange matters so that the portion of the system which is the electrical centre, i.e. the one carrying the maximum current, is in the centre of the coupling coil. If this cannot be arranged by adjusting the length of the counterpoise it can be done by the use of series condensers in the aerial and counterpoise leads, as well as the parallel condenser across the coupling coil. The two series condensers are adjusted so that when the third is tuned for maximum loading of the transmitter, maximum current occurs at the centre of the coil and also in the aerial lead-in.

When using the 3·5 Mc (80 metre) band, the same aerial system which was parallel tuned for 1·7 Mc (160 metres) will usually require to be series tuned as it is longer than a half-wave for this band, but frequently the same size coupling coil may be employed. To obtain an idea of the size of this coil, a rough rule is to see that it contains about half the length of wire which would be required to make the aerial system up to a complete half-wave length.

The Hertz Aerial

As the wavelength to which a wire will tune (*i.e.* its fundamental wavelength) is twice its length in metres, an aerial 21 metres long (approximately 66′) has a fundamental wavelength of, roughly 42 metres. Such a wire is therefore half-wave on 7 Mc and full-wave on 14 Mc. On 3·5 Mc (80 metres) it would be quarter-wave, but the radiation efficiency would be very low, since it would not be operating as a Hertz. On this band about 132′ of wire would be required (twice 66′).

The exact resonant frequency of any wire is, however, somewhat affected by its location, and the required length for a given frequency varies in different cases, depending on the proximity of the aerial to trees, buildings, and so on. Normally, a Hertz will radiate with practically equal effectiveness within plus or minus 1 per cent. of its resonant frequency, so that this is not of great importance under normal working conditions.

The length for half-wave resonance may be found from the formula already given, by making $n = 1$. The 5 per cent. end correction previously mentioned is suitable for most bands, although for 28 and 56 Mc work it may be advisable to increase this to about 7 or 8 per cent., because the wire and insulators become larger in proportion to the wavelength, and thereby tend to load up or effectively lengthen the aerial.

The resonance of the half-wave and full-wave types of aerials is not very sharp, consequently it is usually unnecessary to cut them closer than two or three inches in, say, a 66′ length. In the

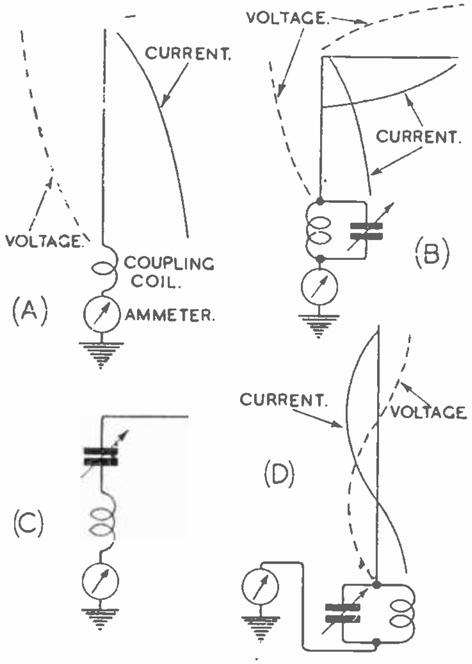


Fig. 3.

Marconi Aerials, showing feed methods. (A) Quarter wavelength. (B) Less than quarter wave. (C) More than quarter wave. (D) Odd multiple of quarter wave.

World Radio History

same way, an aerial adjusted to resonance at a frequency of 7,150 kc will operate satisfactorily over the range 7,000 to 7,300 kc, that is, over the whole 7 Mc amateur band. Thus in the case chosen, where f is 7·150 Mc, the length becomes 65·3′. A length of 66′ will be near enough for practical purposes. The length is measured to the far ends of the loops of wire round the insulators.

If the aerial comes to within a quarter-wavelength of buildings or trees, the length will often be nearer 93 per cent. of a half-wave, but it is best to use the first figure given, as a starting point, and then check up the tuning as described later.

In some varieties of the Hertz which are symmetrical about the centre, it may happen that one end comes near an earthed body, in which case it is better to effect the trimming at that end only. Thus, in the case chosen, if one end were well clear, but the other end came within a few feet of a roof, it might give a better balance in a symmetrically-fed aerial if the end near the roof were shortened by a few inches.

Long Radiators

A development of the Hertz is the long wire containing a number of complete half-waves. Such an aerial can be much more potent in some respects, as will be discussed later. The formula for the length has already been given, from which it will be noted that the length is never quite the full length of the half-waves, but approaches it as *n* increases. This is due to the fact that the wave on the wire travels slightly slower than the wave in space. From a consideration of this statement it will be seen that if a wire is cut for four half-waves on 14·2 Mc it will be slightly too long for two half-waves on 7·1 Mc and a little further out for 3·55 Mc. This is a slight handicap, when it is desired to use the aerial on several bands. In such cases it is best to cut the length to suit the highest frequency or for the one where greatest effect is required. In some methods of feeding the aerial it is important, in others it is not, as will be shown later.

One of the most interesting properties of the long wire aerial is that it tends to become *directive*, that is to say, its radiation in certain directions is increased at the expense of other directions. This becomes more pronounced as the number of half-waves increases, and can often be turned to great advantage. Details will be found under Directive Systems.

FEEDERS OR TRANSMISSION LINES

By the use of devices known as feeders or transmission lines, the energy of the transmitter may be carried a great distance without appreciable loss either in the device, or by radiation. It is then possible to place the radiating element in a position where it may be used to maximum advantage. For example, the Hertz radiator may be only 33′ long (14 Mc), yet it can be placed as high as 100′ and supplied efficiently with current. On the other hand, if it were necessary to bring part of the radiator to the transmitter, most of this valuable height would be lost, and the radiated power would be partly lost in the building. Further, it might also be sent in an unsuitable direction. The use of a feeder thus allows us to control the behaviour of the aerial more easily because it can be placed and oriented as desired.

There are three main types of feeder. The first consists of a pair of parallel wires a small fraction of a wavelength apart (a few inches). Such an arrangement is often called a *twin* or *balanced feeder*. At any point along the feeder the currents in the two wires are equal in value but opposite in sign, and as the wires are close together the radiation from them cancels out. This type of feeder may be operated in either of two ways: it may have equal and opposite standing waves along it, in which case it is called a tuned feeder, and the distribution of current and voltage is as shown in Fig. 4. This arrangement requires to be tuned at the bottom end so as to accommodate a definite number of quarter-waves. It is possible, on the other hand, to arrange matters so that current and voltage are distributed uniformly all along it, and there are no standing waves, in which case the feeder is said to be *matched*. The matching is done by making the load at the far end assume such a value that it absorbs energy just as fast as the feeder supplies it, when there can be no reflection, as in the case of the aerial which is open at the end, and thus no standing waves. It is always possible to produce a transformer effect in the aerial so

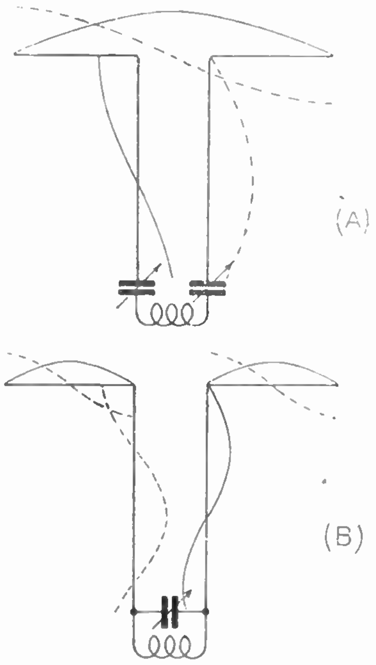


Fig. 4.

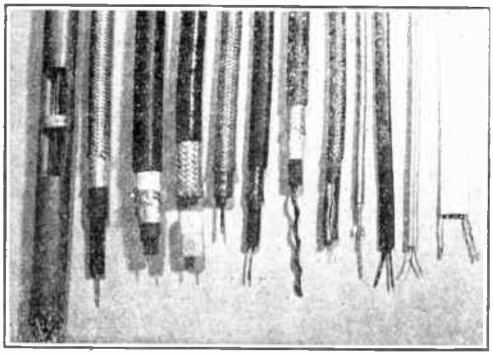
Centre-fed Aerials using tuned feeders. The standing waves are shown, voltage distribution by the broken line, and current by the full line. (A) is a current fed half-wave aerial with series tuning at the transmitter, and (B) is a voltage fed full-wave aerial with parallel tuning. The choice between series and parallel is governed by the length of the feeder. See the chart of Fig. 8.

World Radio History

that the radiation resistance is stepped up to the required value, and in some of the types illustrated this is done. On the other hand, it is often possible to make the feeder up in such a way that it matches directly into the centre of a current loop in the aerial. A matched feeder is always preferable to a tuned one from the point of view of efficiency. In commercial practice matched feeders are commonly made 1,000′ long without serious loss, but an unmatched one must not be more than about one wavelength long.

The second type of feeder also has two conductors, the second conductor forming a tube round the other. Flexible varieties of concentric feeders are available for amateur use.

In the third type, use is made of the earth for the second conductor, and so it is called a *single wire* feeder. This type can only be regarded as a feeder when it is matched, and to do this efficiently is much more difficult than in the case of the twin feeder. It is not recommended for the beginner, though examples of its use are given later.



Some examples of Concentric and Twin Flexible Feeders. Left to right :—

1. **Lead cable with trolitul spacers.**
2. **2, 3. Telconax with star section web spacer.**
4. **Trolitul thimbles.**
5. **Star section. Polyvinyl insulation.**
6. **Solid telconax core.**
7. **Spinal worm of telconax for spacing.**
8. **Hollow telconax with thread separator.**
9. **Lead outer, cotton and rubber insulation.**
10. **Belling Lee 80 ohm telconax twin.**
11. **Similar polyvinyl cable (Hamrad).**
12. **Polyvinyl 400 ohm twin.**

Characteristic Impedance

The value of the impedance which matches the feeder is known as the *characteristic* or *surge* impedance, and connection of such a load to one end gives the feeder the peculiar property that it appears to have the same impedance at the other end, whatever its length. The matched feeder may thus be regarded as bringing the load resistance to the " home " end. The characteristic impedance is usually denoted by Z_0 or R_0.

The actual value of the surge impedance of a feeder, practically independent of frequency, depends on the ratio of wire diameter to wire spacing. The graph of Fig. 5 shows how the impedance of parallel wires varies, and gives the formula for it. It will be noticed that almost any twin feeder likely to be constructed falls between about 400 and 800 ohms. In one of the aerials shown here the design is given for a 600 ohm feeder, and this is a convenient size, striking the best compromise between weight and losses. It can be built with two 16 S.W.G. wires spaced 5″ apart, about every 3′ along its length, by means of wooden or glass rods. If other gauges of wire are used with the same spacing the impedance will, of course, be different.

The surge impedance of a concentric type of feeder is given by

$$Z_0 = 138 \operatorname{Log}_{10} \frac{\text{Outer radius}}{\text{Inner radius}} \text{ ohms.}$$

If there is solid insulating material between the conductors, this expression must be divided by the square root of its dielectric constant, and the velocity of the wave in the line will also be reduced by the same amount, an important point to remember when estimating the length of a quarter or half-wave section of feeder.

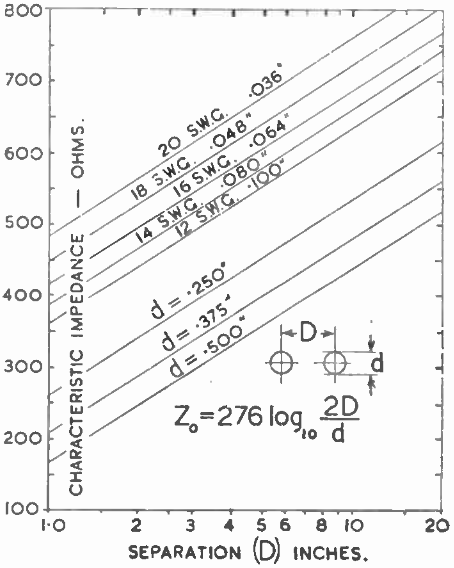


Fig. 5.

Characteristic Impedance Chart for Twin Feeders. For cases not given by the chart use the formula given, but note that proportionality may be used, e.g., ½″ dia. spaced 6″ is the same as ¼″ dia. spaced 3″. On the other hand Z_0 is not proportional to spacing alone. If transposition blocks are used, Z_0 is reduced slightly.

The impedance of a concentric feeder is usually much lower than that of a balanced pair, and such feeders can easily be made with a characteristic impedance of about 50 to 100 ohms, suitable for direct connection in the centre of a half-wave aerial.

The single wire line, however, is generally higher in impedance, and cannot be easily estimated. It is between 500 and 1,000 ohms, but usually varies along the wire as it approaches the ground.

Practical Feeders

The construction of twin feeders is not difficult, and with a little care the losses can be made very low. Enamelled wire is to be preferred as the oxidisation of bare wire in time causes its resistance to rise slightly. The separators are cut from ⅜" dowel, and a small hole (about No. 48 morse drill) is drilled near each end. The rods are then cooked in paraffin wax; 1 lb. of wax will treat enough spacers for any amateur station. The wax must not be boiled hard, but just kept near the boiling point, otherwise it will oxidise and lose its insulating value. When the rods are well impregnated they are removed with pliers and left till stone cold, after which they are given a quick dip in just molten beeswax. This will produce a thick adherent coat of wax which will make them last for years instead of months. The wax will prevent the water from soaking into the wood. Short lengths of 20 S.W.G. wire are now inserted in the holes and used for binding the feeder wires *across* the ends. Such a feeder will withstand the roughest winds, as it is very light and swings as a unit, whereas one using heavy spacers will bend at each joint and rapidly disintegrate. If the line is to be carried any distance it is quite practicable to support it on short poles using stand-off or telegraph type insulators. The latter should be screwed on to wooden dowels rather than on the usual iron brackets If hard drawn copper wire is used, runs up to 100' in length can be taken without any further support or spacers.

There is a variety of twin feeder available from *Belling Lee* which consists of a pair of wires moulded in high quality dielectric. This has a low characteristic impedance, suitable for direct connection in the centre of a half-wave aerial. It should not be used in the centre of a full wave or similar places where the impedance is high, as very little energy will be transferred at the mismatch.

Twin flex or the better types of high grade "cab-tyre" may be used, but these materials like the previous example, have low impedances and lower velocity. In wet weather they are liable to change impedance and also have greater loss; they should, therefore, not be used in damp places or in great lengths. These remarks apply particularly to lighting flex, the characteristic impedance of which is likely to be between 200 and 100 ohms.

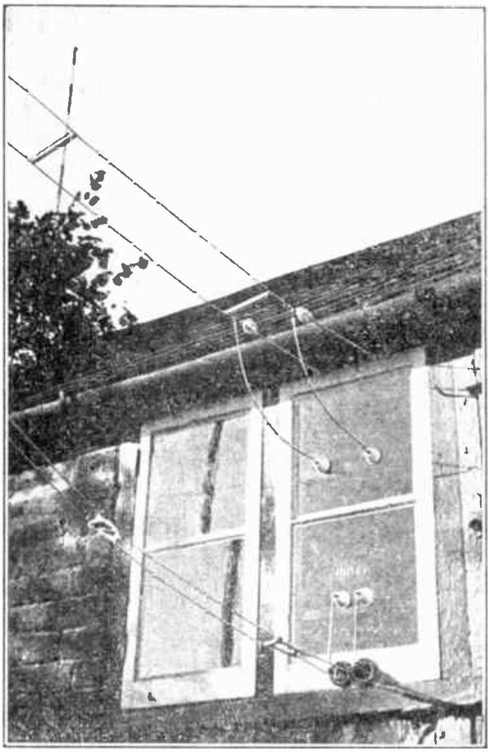
Such a feeder may be directly connected to the centre of a half-wave aerial (which has a radiation resistance about 75 ohms), without serious loss, provided not more than about a wavelength of feeder is used. On the other hand, a line of approximately 75 ohms characteristic impedance can be made from two twin flexes in parallel, *i.e.*, by using the first wire of one pair in parallel with the first wire of the other pair for one conductor, and the second wires in parallel for the other conductor.

The chief advantage to be obtained from the twisted type of feeder is in reception. Since the feeder is twisted it does not pick up any stray radiations and thus it is a great help in reducing some types of local interference which are strongest near the ground.

This type can definitely not be used when the top is full-wave, but only when it is an odd number of half-waves. For reception it is better to cut the aerial short than to run into the full wave condition.

A better system which may be used has a feeder of two wires which are transposed every few feet. Suitable insulators for this purpose may be purchased, and are known as "transposition blocks."

Concentric lines are difficult to construct but there are several varieties on the market, chiefly flexible. In particular, the "Telconax" cables specially manufactured by *The Telephone Construction & Maintenance Co., Ltd.*, may be used at all frequencies up to 56 Mc. They are moulded, some solid and some partially hollow, and various surge impedances are obtainable from 60 to 100 ohms. Another variety is marketed under the name "Pyrotenax." This consists of a copper wire with a ceramic covering fused on, and an outer copper tube drawn overall. It is not strictly flexible, though it may be bent as required without damage. The surge impedance is 50 ohms or less, and the loss very low.



Two Open Wire Feeders.

Above—600 ohms line using wooden spreaders. Below—Transposed line using transposition blocks. Note the methods of straining up the ends. The holes in the glass are drilled with a copper tube drill, using emery and turps. It is advisable to remove the window and support the glass behind, and use a wooden guide for the drill. Practise first!

Feeder Loss

Over the range of frequencies which interest the radio amateur the loss in a given length of transmission line is roughly proportional to frequency. This is convenient, as it enables us to say that a given type of line has a loss of so much per wavelength. This loss is usually rated in decibels. It can be noted here that 1dB loss represents 25 per cent. power or 12 per cent. loss of current or voltage; 3dB is half the power, or 30 per cent. of current or voltage. Any loss under 1dB therefore is not very important. It should also be noted that the received signal strength is proportional to the current in the aerial.

The 600 ohm line just described, when new and operating under correctly terminated conditions (*i.e.*, no standing waves) has a loss of less than 0·1dB per wavelength, that is to say, about 700 feet per decibel on 14 Mc. A 600 ohms line is, therefore, very good for most purposes. After some months of exposure to the weather, it may rise to about 0·5dB per wavelength, when wet, but even this is not important for average amateur purposes.

If a feeder is used as a tuned line the loss is greater, a fact which depends upon the extent of the mismatch at the far end. For example, a 600 ohm line, used for centre feeding a half or full-wave aerial would have its loss increased three to five times. This would begin to become important with age if the length were more than about half a wavelength, but apart from this case, which could be improved by using better insulators, the open wire line is obviously a very efficient way of transferring R.F. power.

The figures quoted are typical of the average open wire twin feeder, but as with most apparatus, the loss may be reduced by increasing the size of wire, that is, using a heavier gauge. Made up feeders containing much insulating material, such as the moulded twin or concentric lines, must necessarily have more loss, and the figure for these is of the order of 1dB per wavelength. If the copper cross section is very small, the cable may, of course, be worse than this figure, due to the resistance of the conductor. Used as tuned lines the loss may rise to 3dB per wavelength, and it is advisable to consider whether the cable is big enough to dissipate half the power of the transmitter without melting or cracking the insulation. This is not likely to occur with transmitter powers of below 100 watts.

SIMPLE AERIALS

The "End Fed" Aerial

Probably the simplest way to energise an aerial is that shown in Fig. 6A where one end of the wire (which may be any number of half-waves) is connected to a tuned circuit directly coupled to the transmitter. The wire could, of course, be connected directly to the anode circuit of the P.A. stage, but this is very bad practice as it allows the radiation of harmonics and other frequencies which may be in the transmitter, such as key clicks. The latter can cause interference in local broadcast receivers, whilst harmonics can produce serious trouble elsewhere. The transmitter is also likely to behave much more satisfactorily when a separate circuit is used.

To adjust the circuit, the anode condenser is tuned for minimum feed in the usual way, and the aerial coil, very loosely coupled, is adjusted until it "draws" current in the P.A. The aerial is then tapped in and the coupling increased until the load is up to the optimum which has already been found with an artificial aerial (see Chapters 6 and 11). It may be necessary to try a few taps before satisfaction is obtained. The aerial coil should be big enough to tune with not more than about 50μμF. If the system refuses to operate, a different type of earth connection may be tried, or the length of the aerial changed slightly.

This type of aerial is very suitable when the transmitter is located at the top of a building, the earth being the largest metal object available, such as the water cistern or the mains sheathing, or a lead roof. A direct earth may be long enough to become resonant, but can be series tuned. It is important to remember that one end of the coupling coil must be "earthy," even though the actual earth connection is not obvious.

A link coupling may be used in cases where it is not possible to bring the end of the aerial to the transmitter (Fig. 6B).

The above method can be made to feed the same wire on several bands, as the difference in length for the various bands can be tuned out, or inserted easily. If the wire is too long it will call for more capacity in the circuit to which it is coupled; if too short it will require less. The difference is such that a wire which is half-wave on 7 Mc will be up to 2′ short for the second harmonic on 14 Mc.

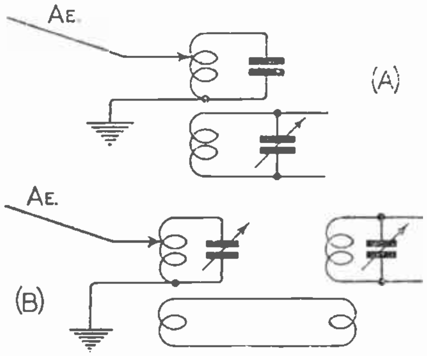


Fig. 6.
Coupling an End-Fed Aerial. (A) Loose coupling, and (B) link coupling. See text for adjustments, and notes on aerial coupling in Chapter 6.

The Zeppelin Aerial

This very popular arrangement is illustrated in Fig. 7. The radiating portion, which can be any desired number of half-wavelengths long, should be erected in as high and clear a position as possible. A pair of feeder wires is connected as shown, one wire to the aerial and the other left free but well insulated.

These feeder wires may be spaced 6″ to 12″ apart, with wooden or glass spreaders at intervals of about 3′. Close spaced lines, such as twin flex or low impedance feeders are quite unsuitable for this particular aerial, as the feeder is of the tuned type with standing waves, and high voltages occur in places.

The tuning at the transmitter end may be either series (A) or parallel (B). The choice is determined by the length L of the feeder. If there is a current maximum at the transmitter (*i.e.*, when the feeder is an *odd* number of quarter-waves long) then series tuning is needed, and the current in the R.F. ammeters may be as high as one ampere for a 25 watt input. With a voltage maximum (even number of quarter-waves) the current is very low and parallel tuning is necessary. The latter condition should be avoided, as it is very difficult to adjust, and the feeder length should be increased a few feet to avoid it. The chart in Fig. 8 shows how to locate the standing waves for various frequencies and lengths of feeder, and indicates the type of coupling circuit required.

The best adjustment does not give equal currents in the two feed wires, but is made as follows. First disconnect the radiator, and hoist the feeder into position. Connect the coupling circuit and couple it very loosely to the transmitter. Now tune to resonance. If series tuning is used, work the two condensers together for equal currents at resonance. The P.A. should then draw maximum anode current and the resonance should be sharp. Note the condenser readings, as these are to be retained.

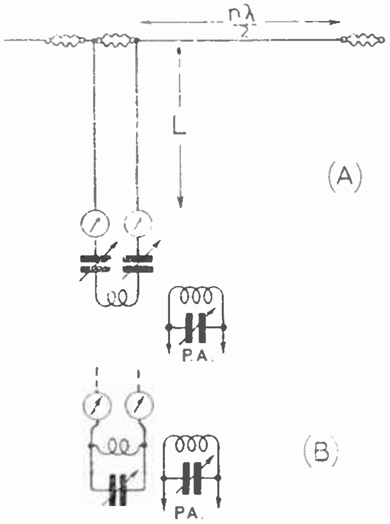


Fig. 7.

The Zeppelin Aerial. (A) Series tuned feeder, and (B) alternative parallel tuning. Use A or B according to the chart Fig. 8.

The radiator should be cut a little longer than the correct length for the required harmonic. Connect it in position and try the tuning of the coupling circuit, increasing coupling as necessary. If the tuning does not agree with the previous figure, shorten the top an inch or two at a time, until the original condenser readings are obtained. Then, without altering the tuning, increase coupling until the meters read a maximum current in the feeder, or until a neon lamp indicates maximum voltage across the coupling coil. The feeders will probably not have equal currents.

The top may be any number of half-waves long but the above optimum adjustment may only be made for one band. If other bands are to be used the only possible adjustment for these is for equal currents (*see* " Resonant Length ").

The most satisfactory length of feeder, where this is possible, is one quarter-wavelength with series tuning, but this would become a half-wavelength on the harmonic and might be troublesome. In multi-band operation it may be necessary to change from series to parallel tuning with change of band.

For operation on lower frequency bands where the top is less than one half-wave long, the Zeppelin type is not possible, but the free feeder may be disconnected and the remainder used in any other way desired, such as a Marconi or an end-on aerial.

Single Wire Feed Systems: The " Windom "

When an aerial is in resonance the impedance at any point is a pure resistance, varying from a low value near the current maximum to a high value at a voltage maximum. There is thus some point at which it will match the impedance of a single wire feeder so that standing waves and radiation do not occur in the feeder, but only in the top. When the top is a half-wave long (Fig. 9) the aerial is sometimes called a " Windom " but the principle may be applied to any resonant harmonic top.

This type is attractive for its simplicity of construction, and when correctly adjusted is very

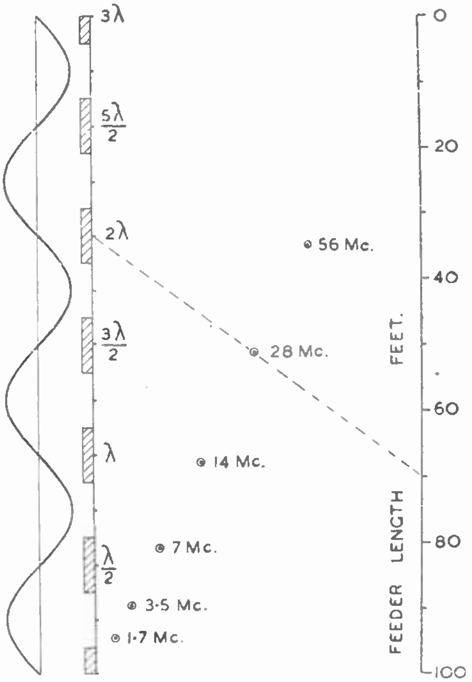


Fig. 8.

Standing Wave Chart for Tuned Feeders. The shaded scale is marked in quarter wave units. A line from the feeder length point through the frequency point cuts the scale at the required number of quarter waves, e.g., 70' feeder is 8 quarter waves on 28 Mc.

Voltage Fed—**Centre-fed top an even number of half-waves long, or Zepp any length—curve shows current distribution on feeder. Shaded regions need parallel tuning, and unshaded, series tuning (Fig. 4).**

Current Fed—**Centre-fed top an odd number of half-waves long—curve shows voltage distribution. Shaded regions need series tuning, and unshaded, parallel tuning.**

World Radio History

effective, although the adjustment is somewhat difficult, and rather more critical than when twin feeders are used. Formulæ are given below, but the exact values are affected by the presence of near objects, and it is better to regard the formulæ as a *guide*. Interested readers would be advised to go through the correct experimental procedure before finally deciding on actual values to be used. A slight adjustment to a poor aerial can often give the most astonishing improvement.

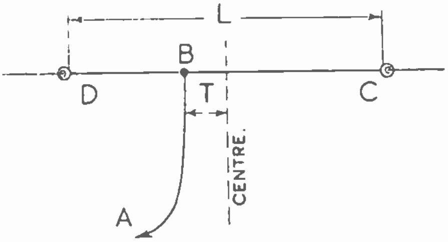


Fig. 9.
Single Wire Feed. See Table 1 and text. The clip shown in Fig. 10B is useful for tap adjustments.

The resonant length must first be correct, and then the tap position. These factors are both dependent on the height (if it is less than half a wavelength), and on the proximity of buildings, trees, etc. The feeder should hang at right angles to the top for at least one quarter-wavelength, and should possess no sharp bends.

The correct method of adjustment is to choose first an approximate position for the tap, and then insert a pair of matched meters or lamps in the top, *immediately* on either side of the tap. The length of the top can then be adjusted until they indicate equally (the top length should approximate to the formula already given). The current indicators are then inserted in the feeder, one at the tap, and the other about an eighth to a quarter of a wave below; the correct tap gives equal currents at all points of the feeder.

The position of the tap also depends on the diameter of wire used. Table 1 can be used as a guide where the same gauge is used for both radiator and feeder.

TABLE 1

Factors for Single Wire Tap Adjustments

Aerial	Wire S.W.G.	Top L	Tap T
14 Mc Half-wave	16	475	66
	14	470	61
	12	465	54
14 Mc Full-wave	16	980	180
	14	960	160

The figure under L is divided by the frequency in Megacycles to give the length of the top in feet, whilst the figure under T gives in the same way the distance of the tap from the centre of one half-wave.

The coupling to the transmitter may be much the same as is described under the "End-fed" aerial, except that the tap is nearer to an earth point as the line impedance is lower. The usual tap is about two to three turns on a 14 Mc coil, one turn on 28 Mc, and about five on 7 Mc. As with the end-fed aerial, the feeder works with earth, though the actual earth connection may not be obvious. It may be necessary to experiment with the earth connection to the transmitter or aerial coil, rather than leave it to chance and possibly send R.F. energy back down the mains. If the transmitter does not load up properly it is almost certain to have some such fault as the one just mentioned.

A fundamental difficulty occurs when it is desired to operate on two or more bands, in that the length of the top is not the same for the harmonics as for the fundamental, but is actually about two feet longer in the 14 Mc full-wave position than in the 7 Mc half-wave and so on. It is usual practice to adjust critically for 14 Mc, where correct low-angle radiation is always required, and to let the top look after itself on 7 Mc where this is not quite so important.

The "VS1AA" Tap

When there are four or more half-waves on the wire, *e.g.*, 138′ top operating on 14 and 28 Mc, the adjustment for resonance becomes less critical, and the same length is nearly correct for 7 Mc. On the other hand the tap position as given above could never be correct for more than one band, because it would come at a different part of a standing wave on each band. The following scheme, originally due to J. MacIntosh, VS1AA, was developed to improve the match and to give a multi-band single wire fed aerial.

The length of the top is made according to the formula given under "Resonant Length" and the tap is placed exactly one-third of the way along, *i.e.*, BD in Fig. 9 is one third of L. It will be found that this brings it always one-third of the way between two voltage maxima when there are 1, 2, 4, 8 etc., half-waves of radiator, making the impedance almost the same on all bands. This impedance is too high if the feeder is of the same gauge as the top, but by choosing a thinner wire it is possible to obtain a good match on at least one band, and very satisfactory operation on several others.

This aerial is still in the experimental stage, but the following figures have so far been found. If the top is made from 14 S.W.G. wire and adjusted for the 2nd or 4th harmonic on 14 Mc (68 or 138′) then a 20 S.W.G. feeder will be correct for 14 and 28 Mc and very nearly so for 7 Mc, and in the latter case 3·5 Mc. For a 33′ top of 14 S.W.G. the feeder would be made of 18 S.W.G.

Centre-Fed Aerials

Centre feeding has already been illustrated in Fig. 4. When the radiating element is one half-wave or any odd number the feed point is at a current maximum, and the current and voltage distribution are not affected by the method of feeding, which is thus just an alternative to an end-feed or Zeppelin, or single wire. But when the top is a full-wave or

World Radio History

any even number of half-waves, the centre feed is between two high voltage or high impedance points, and since the two feed wires are in opposite phase, the break in the centre of the top reverses one half. The even number cases are thus different from their unbroken counterparts, and the radiating properties are changed. This difference is illustrated at the end of the section dealing with directive properties.

For example, a 66′ radiator would be in half-wave resonance on 7 Mc, and the method of feed would not affect the properties of the aerial so long as the feeder did not radiate, but on 14 Mc it would be in 2nd harmonic resonance, or full-wave, and on 28 Mc two full-waves, and the centre-fed type would be a different aerial from the end-fed.

The feeders may be open wire tuned feeders, low impedance twin, twisted flex, or low impedance concentric; alternatively one of the matching systems described later may be used. For multi-band operation the open tuned feeder is about the only satisfactory method, as the low impedance lines mismatch badly in the harmonic cases. The length of the line should not be too great, and it is preferable to avoid a length which brings a current minimum to the transmitter. Fig. 8 shows how to judge a suitable length and how to tune the coupling circuit. In the tuned feeder case, the length of the top is not critical, for part of the top resonance can be accommodated in the feeder if desired, the only requirement being that the whole system is brought into resonance by the coupling circuit. This may be useful where space is limited, but on the other hand although any length over the half-wave may be used, if less than about 0·4λ is attempted, radiation resistance becomes very low and losses in the system become serious.

A low impedance twin feeder may have a characteristic impedance of from 60 to 100 ohms, and may thus match the impedance at the centre of a half-wave top, since the radiation resistance varies between these limits, according to the height. The top must in this case be in resonance, but an exact impedance match is not important unless the feeder has big losses; the limits given are usually near enough, as the current variation is only of the same order as the mismatch ratio. This low impedance feed is limited to one band operation, but is very popular because of ease of coupling to the transmitter. It merely requires a coil of a few turns coupled in the same way as a link coil to the transmitter. Suitable turns are as given for link couplings in Chapter 6. Care should be taken with this type of coupling to see that harmonics are not radiated. (For further information see this Chapter and Chapter 6.)

Twin flex has a somewhat higher impedance, usually about 150 ohms, and the loss is usually sufficiently high to make the mismatch important. It may be noted also that some of the "nominal" 72 ohm flexes are well over 100 ohms: this may be checked by comparing the diameter/spacing ratio of the copper. In such cases an approximate match may be obtained by increasing the length of the top slightly, say ½″ to 1″ per metre of wavelength, either at the ends, or by making a small V at the centre junction.

Concentric line could be used for centre feeding, but it may lead to difficulties because the capacities between the two halves of the top are not balanced with respect to the line. The result is a tendency for some of the current to travel on the outside of the cable, instead of inside, resulting in radiation from the feeder.

When a high impedance open line is used with one of the many types of matching transformer for one band, the system can usually be operated on other bands where the top is in resonance, with the feeders in the tuned condition.

"Y" or "Delta" Match

Fig. 10 illustrates what is known as a "Y match," or "Delta match." Its operation may be explained by regarding the top as a *transformer*, the aerial impedance between the taps being that required for matching the feeder. The aerial may only be used in this way on the band for which it is designed, but where it is possible to erect an aerial for each band it will be found excellent; alternatively it may be used for higher frequencies with the feeders tuned. It is very easy to adjust, and will operate in a matched condition almost completely over one band—being very flat in its tuning properties. The dimensions for a 7 Mc aerial are given in the diagram, whilst proportions may be taken for other bands. The feeder may be any length, as it is matched, and for this reason also the aerial is very efficient.

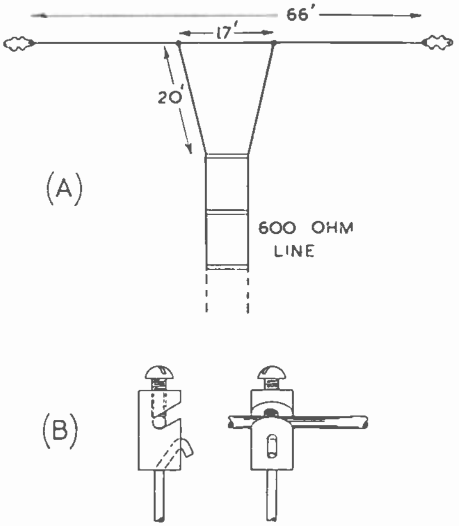


Fig. 10.
A Matched Impedance 7 Mc Aerial, using the Y-match. Proportions may be taken for the dimensions for other bands. The clip (B) is useful for tap adjustments, and it should be taped after it is finally set, to prevent loosening by the wind.

The feeder may be tapped across a few turns of a free tuned circuit, which is coupled to the transmitter output, and the two taps moved together up and down the coil. This may help to make the currents in the two wires equal. The resonant frequency of the top may be checked by listening on an ordinary receiver, provided the feeder is not too long, and does not contain an even number of half-waves (a temporary length may be added if necessary). About ten turns of wire across the

World Radio History

home end are coupled tightly into the oscillating detector circuit of the receiver, and the effect on the reaction control is noted. The resonant frequency is that at which the application of the feeders has most effect on the amount of reaction required for oscillation. This method is quite general, and may be used on a variety of aerial systems, but it is most satisfactory in the case of matched feeders.

Having tuned the top, the matching may be done by sliding the ends of the feeders about slightly until the feeder has no effect on the tuning of the coupling circuit at the base. The length of the trailers is important, but the values given will be good enough for nearly all cases; in fact, all adjustments, including the tuning, will be found very easy. If the top is set in the centre of the amateur band for which it is desired, the system may be used with success all over that band. The remarks made earlier about symmetry apply particularly to this aerial, and it may often be necessary to shift the middle by lengthening one end and shortening the other before a balance of current is obtained in the feeder wires. The importance of feeder balance is discussed later.

In dealing with this and any other system of matched feeders, it is necessary to avoid sharp bends in the feeder, and especially in this system must a bend be avoided within about quarter-wave of the bottom of the triangle.

The " W3EDP " Aerial

In the section dealing with feeders it was shown that with tuned feeders the ultimate object is to bring the whole system into multiple resonance, so that if it were opened out straight the total of aerial and feeder wire plus coupling circuit would make a definite number of half-waves. This is the general basis of all aerials using tuned feeders, or Marconi aerials with counterpoise, and the usual procedure is to make the coupling coil contain about half the length of wire necessary to complete an integral number of half-waves, the tuning condenser bringing up the remainder of the resonance.

A specific aerial shown in Fig. 11 has been worked out experimentally for multi-band operation on these principles, and is named by the call-sign of its originator, W3EDP. It does not claim to compete with a well designed directive aerial, but is an excellent solution for " awkward locations," where an aerial of orthodox type cannot be made to fit in. The aerial, which is cut to a length of about 84′, and which may be bent if necessary, is brought directly to the coupling coil, similarly to an end-on aerial. The counterpoise, which is 17′ or 6½′ long, according to frequency, is taken away at right angles to the aerial, and may also be bent to fit the space available. The counterpoise is connected to the end of the coupling coil nearest the P.A. coil, because a certain amount of capacity coupling to this part is necessary for correct working. For the same reason it is necessary to have the coupling coil proportioned correctly.

The coupling coils should be made of the plug-in type, arranged to swing against the P.A. tank. It should be possible to tune up the coupler and then swing up until the P.A. is fully loaded. If the aerial current falls off, before what is considered correct load is obtained, the balance between capacitive and inductive coupling is not quite right, and this is best adjusted by trimming the length of the aerial a few inches at a time, up to a possible total of 2′.

COUPLING TO THE TRANSMITTER

Various methods of coupling the aerial to the transmitter have been discussed under the individual aerial types, but it is better to generalise them to meet all cases. For full efficiency the power amplifier valve requires to work into a pure resistance of optimum value. This is usually a rather high value—several thousand ohms. A tuned circuit is provided to tune away stray capacities, but the resistance load must come from the aerial.

As the optimum load resistance rarely equals the aerial impedance, it is necessary to use some form of transformer to step the aerial impedance to the required value; the anode tank circuit forms the basis of this transformer. This process is often referred to as " matching," but this is not correct; all that is required is an optimum load for the valve, and not a match between the valve and aerial impedances.

There are two classes of aerial or feeder:

(*a*) Resonant or untuned, such as a resonant end-on wire, the centre of a resonant wire, or a correctly terminated or matched transmission line, single, twin or concentric.

(*b*) Non-resonant or tuned, such as a Marconi aerial or a tuned feeder system.

The former calls for two fundamental adjustments only—tuning of the anode " tank " and adjustment of the load, whilst in the latter case an additional process is needed, namely, bringing the aerial system into resonance. There are many

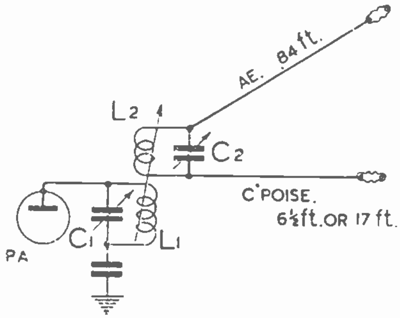


Fig. 11.

The W3EDP Multi-Band Aerial.

A suitable value for C_2 is ·00025 μF.

Band. Mc.	C'pse. Feet.	L2—2" Diam.
3·5	17	21 turns 16 S.W.G. spaced one diam.
7	17	7 turns 16 S.W.G. spaced one diam.
14	6½	5 turns 16 S.W.G. spaced one diam.
28	0	3 turns ½" spacing.

coupling circuits to choose from, which vary mostly in the method of adjusting the transformer ratio but although additional elements are sometimes needed to suit the circuit arrangement, several of this variety have been invented by simply introducing unnecessary adjustments.

Both the aerial and the transmitter may be either balanced or unbalanced (single-ended). A balanced circuit is represented by push-pull or centre tapped neutralising circuits or by a twin feeder; an unbalanced circuit by a single pentode anode tank or by end-on or Marconi aerials, single or concentric feeders. When the aerial and P.A. are of the same type the two or three adjustable elements mentioned above are sufficient, but when changing from balanced to unbalanced, or *vice versa,* an extra feature is needed.

The basic circuits for untuned, or matched feeders and end-on resonant aerials are shown in Fig. 12. The transformer ratio is adjusted by variation of the tap in (A) and by moving the coupling coil in (B). Figs. 12 (C) and (D) show two types of *reactance transformer.* In the first two the anode is tuned for minimum feed and the tap or coupling is increased until a point is reached where the current in the aerial or feeder ceases to rise. It is important not to over-ride this point because by doing so both the transmitter and the aerial are upset. It is preferable to work slightly below this point for best results. In theory, if the aerial is in tune or the line properly matched, no retuning of the anode tank should be necessary, but in practice a very slight retuning may be needed to allow for changing stray capacities. (The anode current should then drop and the aerial current rise slightly.)

The direct tap of Fig. 12 (A) assumes that an effective earth is connected to the transmitter, which may give trouble if omitted. Direct taps may also give trouble through radiation of harmonics. (See remarks under End-fed Aerials.) In case (B) it is desirable to arrange the coils with their "earthy" ends adjacent or, in the balanced circuit, to avoid unbalance by stray capacity. This can be done by opening the centre of one coil and inserting the other in the gap. In (C) and (D) the transformer ratio depends on the ratio of C_1 to C_2. The coil should be chosen according to the considerations discussed in Chapter 6, or should at least be capable of resonance with C_2 shorted. The theoretical reactance value of C_2 is the square root of the product of aerial or feeder impedance times valve load resistance. (In the balanced case the impedances from one side to earth.) This makes C_2 about 1 to 1½μμF per metre wavelength for single wire lines and about half this for end-on aerials. In practice the "tap" is adjusted by varying C_2, whilst C_1 is used to restore minimum anode current. The procedure is thus to short C_2, tune to resonance, and then adjust the load on the valve by varying C_2 whilst maintaining resonance with C_1. C_2 may also be used to take up minor tuning effects if the feeder or aerial is slightly incorrect. The optimum aerial current consideration applies as in the previous paragraph.

Systems requiring an extra element are shown in Fig. 13, where it is first necessary to bring the aerial system into resonance. The choice of aerial tuning circuit is governed by the aerial. (See Marconi, End-fed, Zeppelin and Centre-fed aerials.) Here again one may have variable tap and fixed coupling, or *vice versa.* In these couplers, starting with loose coupling or *high* tap, the circuits are first set in resonance and then the couplings increased or tap lowered until optimum aerial current occurs. As before, care should be taken not to overload the valve, and stray capacities or unbalances should be avoided by setting "earthy" ends together or by splitting one balanced coil.

When one part is balanced and the other unbalanced, special arrangements are necessary to avoid unbalance or stray capacity coupling. The balanced coil may be split in the centre and the other inserted in the gap, using any of the schemes shown in Figs. 12 and 13, although link coupling is the best method in such cases. Circuits for link coupling are shown in Fig. 14, and may be used generally for any type of circuit or aerial. They are somewhat more difficult to adjust than the others, but offer greater flexibility and simplify the station layout. The aerial network may be set up at the point where the aerial or line enters the house, thereby reducing the possibility of stray radiation in the station, whilst the transmitter may be placed wherever desired. In this way also, the facility is provided for rapid changeover from one aerial to another.

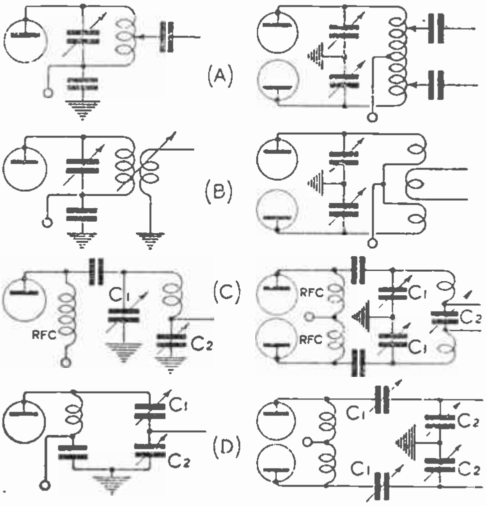


Fig. 12.

Coupling circuits for untuned lines or resonant aerials, when both aerial and transmitter are alike balanced or unbalanced. Two adjustments are fundamentally necessary—tuning and coupling. The circuits of Fig. 14 may also be used.

The link may be either twin low impedance or concentric feeder, and preferably earthed at some point. The adjustment has been dealt with at some length in Chapter 6, and reference should be made to Fig. 19 of that Chapter.

In all aerial coupling networks which use an aerial tuned circuit as well as the anode tank, the aerial coils should be chosen, or the taps and couplings adjusted to give fairly heavy damping

World Radio History

(flat tuning) of the circuit, as in this way the loss in the circuit is minimised. The size of the coil is determined by this factor. For example, for end-on working where a high-impedance is used, the coil should be a fairly large one for the frequency used, but in series-tuned cases it may be preferable to use a coil smaller than normal.

Feeder Balance

The adjustment at the transmitting end should not affect the condition of a feeder; this depends purely on the nature of the load at the far end. If it is not matched at that end, nothing can be done at the sending end to correct this effect. In a twin feeder the currents in the two wires should be equal, and under these circumstances the radiation from a balanced line is extremely low, whether it be matched or not. To secure a balance it is necessary first to balance the far end, and then take steps to see that there is no stray capacity coupling near the transmitter to disturb this balance.

Phantom Circuit

When the total length from the transmitter to one end of the aerial is near a complete number of half-waves there is a tendency for the two halves to act in parallel like a "T" aerial. This brings up a high impedance to earth at the pick-up coil, a condition which is just right for transference of considerable energy through a small stray capacity to some live part of the transmitter. The result is that besides the desired equal and opposite currents in the two wires, there are two more in-phase currents flowing in the *parallel circuit*, and these will cancel part of the balance current on one wire and augment it in the other. The parallel current radiates, and the aerial system is completely upset. This parallel circuit is equivalent to the "Phantom" circuit used in line telegraphy and telephony.

The remedies are to avoid such a length of feeder, place a symmetrical earth screen about the pick-up coil, earth the centre of the coil, use an earthed split stator condenser, or employ link coupling. In other words it is not advisable to have an unearthed pick-up coil near the transmitter. In making tests for balance it is, of course, advisable to check the aerial current meters for equality, by placing them close together in series in one wire.

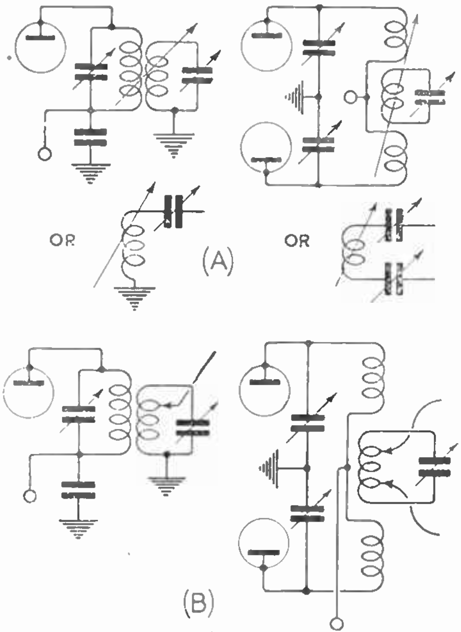


Fig. 13.

Coupling circuits for tuned lines or non-resonant aerials, where both aerial and transmitter are alike balanced or unbalanced. Three adjustments are needed—tuning the P.A.; tuning the aerial; and setting the coupling. The circuits of Fig. 14 may also be used.

Harmonic Radiation

Harmonics of the operating frequency of a transmitter should not be allowed to radiate. The second, fourth, eighth, etc., fall in or near amateur

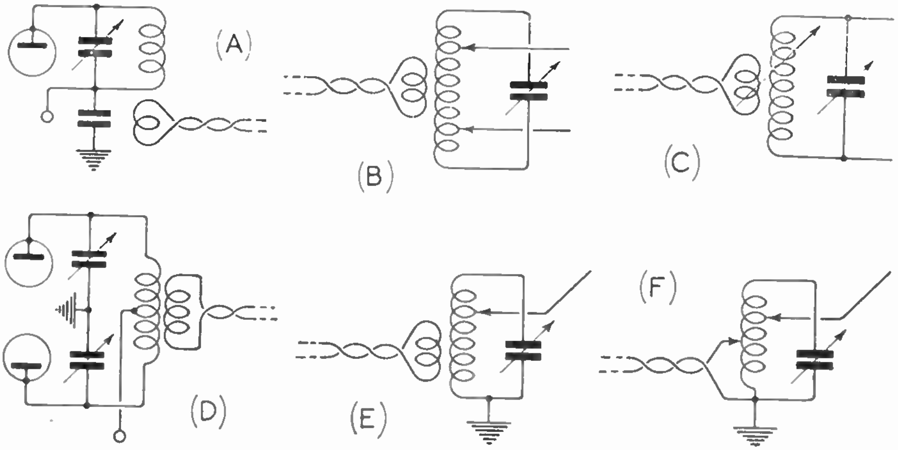


Fig. 14.

Link Coupled Aerial Networks. These are universal and will couple any type of transmitter to any aerial.

World Radio History

bands, and may cause unnecessary interference, whilst the other multiples are far removed from frequencies authorised for amateur use; consequently if any appreciable amount of power is radiated on these frequencies it may cause interference with other services.

Apart from this, the current readings in the aerial or feeders may be changed by the extra harmonic currents, and a false impression given. A transmitter operating efficiently must generate harmonics, and the procedure for minimising them has been given in Chapter 6. It is still necessary, however, to take care that the aerial system does not accept and radiate them.

The most troublesome harmonics are the second and third, but the others should not be ignored. Usually in cases of trouble one particular harmonic (which can fairly easily be removed) is responsible. Harmonics may be radiated in a number of ways, *e.g.*, they may be transferred by stray capacity coupling into the feeder or aerial system, a condition which may be prevented by using a *Faraday Screen* between the anode and aerial coupling circuits, or alternatively a link coupling circuit. A *Faraday Screen* consists of a number of wires spaced about half an inch apart on a wood or card frame, and joined together *at one end* only. The screen should be a little larger than the coil it protects. Having found its way into the aerial system, radiation of the harmonic may easily occur. Some aerials are more susceptible than others; centre-fed types for example respond perfectly to odd harmonics, whilst end-on types will radiate any harmonic. Matched impedance systems and systems using a number of resonant elements are much better, and do not tend to accept harmonics.

The above methods and others are dealt with in greater detail in Chapter 10.

Current Measurements

It has been seen that the current, impedance and voltage vary from point to point in an aerial system, and so it is necessary to be cautious in interpreting the power in the system in terms of current. Some suggestions as to what to expect will therefore be helpful. An efficient 10-watt output stage will not put more than 0·1 ampere into a matched 600-ohm feeder, and a higher current is a definite sign of mismatch and standing waves: the current in the top would, at the same time, be about 0·3 amp. For a 100-watt transmitter the corresponding currents would be about 0·3 and 1 amp. respectively. In a tuned feeder, such as that of the Zepp., the current depends on position, and may be anything from zero to 0·5 amp. for 10 watts input, whilst the current at the centre of each half-wave in the top is as before.

The simplest form of current indicator is a low wattage lamp, but this is only suitable for *relative* indications. However, indications of the current in the radiator can be obtained without actually cutting it for insertion, by shunting a small 2 volt lamp along a few inches of the aerial. This will by-pass enough current to give a glow which may be used for tuning purposes.

The hot wire ammeter is a better indicator, but may have considerable error at very high frequencies, due to by-pass capacities and the skin effect of the wire. In this type of meter a wire, which is normally under tension, sags due to expansion from the heating effect of the current passing through it. The sag is used to rotate the pointer. Meters with a range of 0—·25 or 0—·5 amp. are most suitable for amateur work. Such meters are available at reasonable prices.

The thermo-ammeter uses the heat of a thin wire to excite a thermo-junction, and the resulting e.m.f. operates a sensitive moving coil meter. These meters are somewhat expensive, but are much more accurate than hot wire meters. They have a tendency to read high on ultra-short waves, due to the rising resistance of the heater. The error is about 10 per cent. to 20 per cent. on 28 Mc in a 1 amp. meter, and greater with higher current ratings.

Methods of measuring R.F. currents without the use of expensive apparatus are given in Chapter 15, but unless actual power or efficiency are to be measured, the more simple indicators will be sufficient for tuning-up and keeping a day-to-day check on the operation of the transmitter and aerials.

IMPEDANCE MATCHING

When a transmission line is terminated with a resistance equal to its characteristic impedance, power is absorbed by the resistance as fast as it is supplied. There are no standing waves along the line, but the current is uniform along its length. The loss in the line is then a minimum and the impedance at the sending end is the same as at the load end, irrespective of the line length.

If the load is not of the correct value, the line is said to be *mismatched*. This means that the power sent down the line does not all go into the load, but some part of it is reflected at the point of mismatch and returns down the line. This causes standing waves to build up on the line, in the same way that they build up along the aerial. The line is called a tuned line because the impedance at the sending end is no longer a pure resistance, but a compound of resistance and reactance which must be tuned to resonance before it can be supplied with power. The extent of the standing wave, *i.e.*, the ratio between maximum and minimum currents, is proportional to the mismatch ratio. When the wavelength is changed the tuning and the current at the sending end change very rapidly, because the standing waves alter their length, and so it is necessary to reset the coupling circuit for slight changes of frequency, a disadvantage which is much reduced if the line is matched.

It is thus apparent that current measurements on a tuned feeder do not easily give any indication of the power flowing, because the current varies according to the length and frequency. The loss in the line is greater than when it is matched, but this is not important in a good open wire line.

Impedance Matching Devices

It is usually only possible to match the feeder to the aerial on one band at a time, although the same aerial may be used with the line operating as a tuned feeder on other bands.

There are several methods of matching, and the simplest is, of course, to use a low impedance line

World Radio History

connected directly in the centre of a current loop of the aerial. But these low impedance lines are not often suitable for long distances, and an open wire line of higher impedance is necessary to reduce loss. It then becomes necessary to provide some kind of transformer to step from the 75 ohms or so at the centre of the aerial, to the higher impedance of the line.

This could be done with a transformer of the usual type using coils, but such would not be very convenient because it would need to be suspended in the centre of the aerial, and enclosed in a weatherproof case. It is easier to use transformers made from straight wires.

One method of doing this has already been shown in the single wire feeder and the Y-match. In these systems, use is made of the fact that the voltage/current ratio, or impedance, varies from point to point along the wire of the aerial. Thus the aerial is made to be its own transformer, the ratio varying as the taps are moved.

Quarter-wave Transformers

If the half-wave resonant aerial were folded in half, as in Fig. 15, the voltage distribution (broken line) and current distribution (full line) would still be of the same form, though the radiation would be cancelled out. It would then represent a quarter wavelength of twin feeder with one end shorted. In such a line the resonance is maintained, and the high voltage open end behaves like a high resistance, whilst if the closed end is opened and measured it appears as a low resistance. These values correspond with the *dynamic* and *series* resistances of a tuned circuit (Chapter 1), and their product is equal to Z_0^2—the square of the characteristic impedance.

This makes possible two ways of securing a transformer effect. In the first a pair of tapping points is found as in the Y-match where the e/i ratio matches the line impedance. This is called the *quarter-wave transformer*. It provides a good match when the *ratio* of transformation is greater than about five, *e.g.*, when matching a 75 ohm aerial to a 600 ohm line, but for closer ratios *stubs* are better.

The two varieties of quarter-wave transformer are shown in Fig. 16. When the radiator is a whole number of wavelengths long (Fig. 16B) the feed point impedance is high and a *closed* section is used, whilst if the radiator is an odd number of half waves (Fig. 16C) an *open* section is needed. It is easy to remember which to use; if the feed point is a voltage maximum the closed transformer is required; for a current maximum the open type is required. The continuous length of wire is always an odd number of half wavelengths.

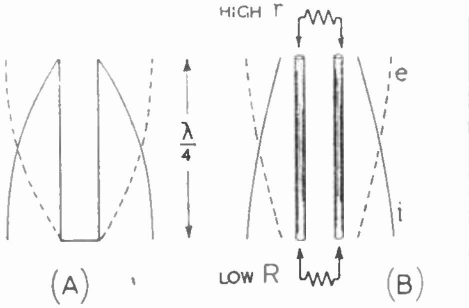


Fig. 15.

The Principle of Matching Stubs and Q Bars. The standing waves of voltage (e) and current (i) are used to produce a transformer effect. In the λ/4 transformer (A) a tapping point is found where the e/i ratio matches the line impedance. With Q Bars (B) the characteristic impedance of the λ/4 Q section is made equal to √Rr.

These transformers are most suitable for use with short aerials or small beams, where the aerial is more than about one wavelength from the transmitter. For extensive systems, such as the Vee or Rhombic types, the transformer ratio is lower, and one of the types to be mentioned later is better. It may be noted, however, that the length of the radiator is not important as long as the whole system is resonant, for example part of the top length may be accommodated in the transformer or *vice versa*.

Again, if it is inconvenient to use a quarter wavelength for the transformer, it may be made

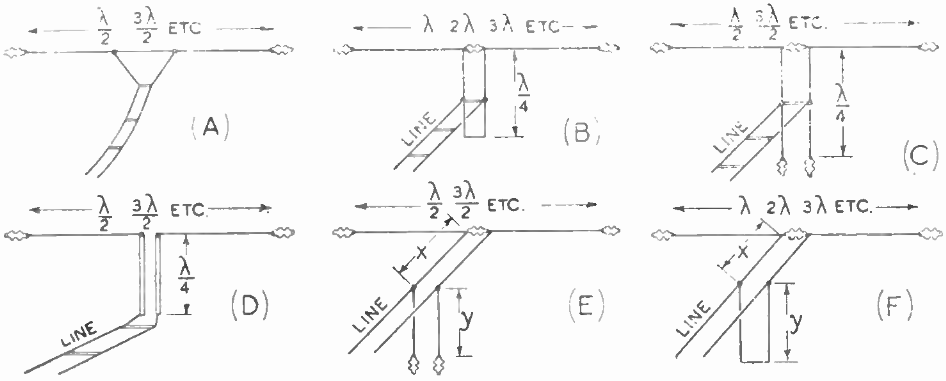


Fig. 16.

Matching Transformers. (A) Y-match (Fig. 10). (B, C) Quarter wave transformers. (D) Q-bars; see Fig. 15. (E, F) Matching stubs: see text and Fig. 18. These transformers may be used for matching any aerial or beam to a twin feeder, but only for one frequency.

World Radio History

half-wave or any resonant length so as to bring a new tapping point lower down, *e.g.* the open $\lambda/4$ transformer of Fig. 16(c) could be replaced by a $\lambda/2$ closed line, with the tapping point in the lower quarter.

"Q" Bars

The alternative type of quarter-wave transformer makes use of the property shown in Fig. 15 (B), namely $Z_0 = \sqrt{Rr}$. In this case, a special $\lambda/4$ section of transmission line is made up so that its characteristic impedance is the square root of the product of the aerial and the main line impedances. For example, if the aerial radiation resistance were 67 ohms and the main line impedance were 600 ohms, then the transformer section would be made up to a characteristic impedance of $\sqrt{600 \times 67}$, *i.e.*, 200 ohms, and the standing wave on the transformer would then perform the impedance matching.

An inspection of the impedance chart, Fig. 5, shows that such a transformer could be made from two ½" diameter conductors spaced about 1⅜" apart. The conductors need only be very thin walled tubing because the R.F. current hardly penetrates the metal. These tubes are sold under the name of *Q Bars*, and can be obtained ready cut to length for the frequency required, and complete with spacing and rigging insulators. The tubes are made of thin aluminium, and the whole outfit is light enough to hang in the centre of an aerial without undue strain, although, if it is inconvenient to suspend it, a half-wave resonant line may be used between it and the aerial proper.

It is not practicable to use this system to match a 600 ohm line into a voltage point, and these transformers are therefore most suitable for half-wave aerials or beams which are fed at a current maximum.

Adjusting $\lambda/4$ and Q Transformers

The quarter-wave transformer can be constructed in the same manner as the line, wooden spreaders being used except where the voltage is highest. The connector shown in Fig. 10 may be used for the sliding connections of the feeder and the shorting link.

The first point is to bring the aerial plus transformer into resonance with the transmitter, and for this the wire is cut a foot or so longer than the theoretical figure and the feeder tapped about 10 per cent. up or down the transformer, working from the current loop. A ½-amp meter is then connected in the shorting link, if used, or otherwise at the aerial junction. With the transmitter lightly loaded, power is supplied to the aerial, and the resonant condition obtained by adjusting the shorting link or cutting the aerial wires to length.

Having made the aerial system resonant the tap position must now be adjusted until there are no standing waves on the line. A meter in the aerial will not be much help, so it may be removed, and used for checking the current along the line. Alternatively the voltage on the line may be examined with a neon lamp, or the current *tapped* with the device shown in Fig. 17.

The position of the tap depends of course on the aerial, but for average small aerials a suitable place to test for a start is about one thirtieth of a wavelength from a current maximum, *i.e.*, about 2′ for a 14 Mc system.

The clip shown in Fig. 10 is useful for sliding adjustments, and when set it is advisable to tape the joint to hold it against wind vibration.

To adjust "Q" bars, if the aerial impedance is not accurately known, first connect the line to be matched directly to the aerial, and measure the standing wave current ratio at convenient points. The characteristic impedance of the "Q" section is then equal to

$$R_0 \sqrt{I_{MIN.}/I_{MAX.}}$$

where R_0 is that of the main feeder. The spacing for a pair of bars of convenient diameter can then be found from the chart Fig. 5.

The "J" Aerial

The quarter-wave matching transformer may be applied to aerials of the Zeppelin type, thereby eliminating the length of tuned feeder often associated with them. A shorted $\lambda/4$ section is used, and it is interesting to note that the bottom end of this may be earthed with impunity. The adjustments are made as already given. but it may be necessary to tap one feeder wire an inch or two higher on the aerial side before a balance on the feeder is obtained.

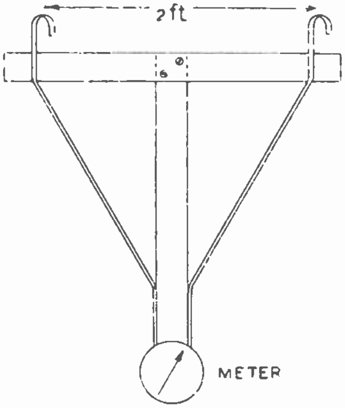


Fig. 17.
Standing Wave Detector. The frame is of light wood and the wires from the meter hook over the line. Alternatively the loop may be closed by a wire along the top, parallel to, but not touching the line The indicator may be a 0/·25 amp. hotwire or thermo-ammeter, or even a lamp.

The radiating element may be horizontal and any resonant length, or the transformer and radiator may both be vertical, the latter being a half-wave in this case. This is called a "J" aerial, and can be a very effective low-angle radiator if it is installed in clear surroundings.

Stub Transformers

The quarter-wave transformer does not give a perfect match, because the standing wave develops somewhat differently on opposite sides of the tapping point, one half being damped and the other free. This leaves a little reactance in parallel with the desired matching resistance at the tap, which may be corrected by shifting slightly the shorting link from the resonant position first found. This effect is not important when the required transformer ratio is fairly high (tap near the current loop), but a different procedure is necessary with large aerials which have high radiation resistances, *i.e.*, those approaching one quarter or more of the line impedance.

Consider it another way. Suppose the line is connected to the aerial, and that the impedance is measured looking towards the aerial. If the measuring point is moved away from the aerial, a point is eventually reached which corresponds to the tap of the λ/4 transformer, where it is found that the impedance is the R_0 required to match the line, but it now has some *reactance* in parallel with it which prevents the match. If this reactance were tuned out, a perfect match would result, and this could be done with the aid of a coil or condenser connected across the line at this point. In effect this is what is done, but instead of using coils and condensers, it is more convenient to use a short length of shorted or open line as the tuning element.

These *corrective stubs* are shown in Fig. 16 (E) and (F) an open or capacitive stub being used if the current falls from the aerial towards it, and a closed or inductive one if the current rises towards it. If the ratio of aerial resistance to line impedance, or the standing wave current ratio is known, it is then possible to calculate the position and length of the stub. The chart Fig. 18 gives these values. There are always two positions to choose from in each half-wave, one open and the other closed; it is best to work as near as possible to the aerial and choose the shorter of the two alternatives.

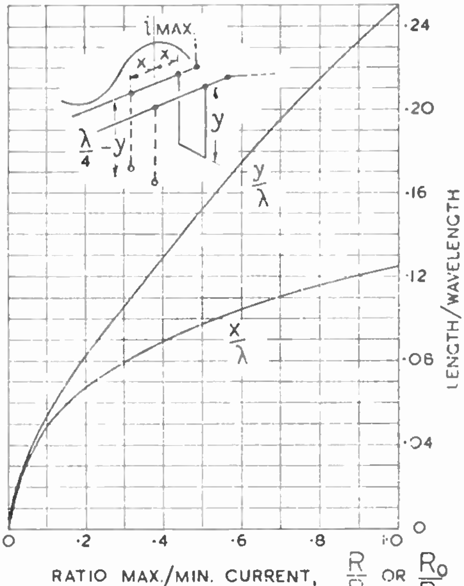


Fig. 18.
Chart for Matching Stubs of Fig. 16 E and F. Position and length of stub are given in terms of current or impedance ratio. The distance x is measured from a current maximum and both dimensions are fractions of a wavelength which is 984/f feet, where f is in megacycles

The simplest method of adjustment is to measure the current at various points along the line with the aid of a standing wave detector, and then refer to the chart Fig. 18 for dimensions. It is essential that the stub be of the same type of construction as the feeder; in the case of the closed stub the length includes the shorting link. The clips shown in Fig. 10 may be used to connect the stub to the line, or it may be soldered. The stub must be kept at right-angles to the line, and it is best to provide some form of structural support for it. Once the correct position is found, there is no reason why the feeder should not take the right-angle and the stub carry on, as in the λ/4 transformer. Incidentally it is easier to support this way.

Summary of Matching Devices

When it is desired to operate over a whole amateur band, it is best to use a direct match with a low impedance line, and the larger aerial systems will be found broader in tuning than the half-wave. The various transformers of Fig. 16 add one more resonant circuit, and are only useful at the higher frequencies where the lengths are reasonable. The "Q" bars come next, provided one is current-feeding with an aerial of not too low an impedance. The λ/4 transformers are most suitable for high ratios of transformation (*e.g.*, the Zeppelin or the 8JK aerial which follow), and are specially suitable for voltage feeding, but adjustment is critical for very high ratios, and the operation tends to become more closely limited to one frequency in the band. The stub types are most suitable for low transformer ratios (*e.g.*, large beam aerials), where the line is long enough to warrant matching.

DIRECTIVE PROPERTIES OF AERIALS

Aerials do not usually radiate uniformly in all directions, first because end-on to a straight wire there is no radiation, and second because the wave reflected from the ground produces an interfering field which may help or hinder the direct radiation, according to direction. The effect of the ground is generally disadvantageous, as it elevates the resultant radiation above horizontal, but it does help in allowing end-on or "end-fire" radiation, from a horizontal wire, though at a somewhat high angle to the ground.

Again, if there is more than one current loop in the radiator, it is found that the total radiation may be regarded as the resultant of a number of components, one from each standing wave current loop. In any given direction these various components may have to travel different distances, so that they do not arrive at the receiver in the same relative phases as they had in the wire. They can, therefore, augment or cancel each other according to the direction. For these reasons aerials are said to be *directive*, and the *directivity* is defined in terms of the power radiated in the desired direction as compared with the overall power radiated.

The calculation of the directivity of a given aerial is very difficult, but it is an easy practical matter to combine a number of radiator elements so that the radiation components add intensively in a desired direction but cancel in unwanted directions. Practical examples of such *beam* aerials will follow.

Before studying the directive properties of aerials, however, it is desirable to know what is wanted at an amateur station. Usually it is required to transmit equally well in all directions of the compass; but at what angle to the horizon should signals travel for best results? It has been shown in Chapter 1 how short-wave signals travel in a number of "hops," and stated that it is desirable to reach the receiver with the minimum number in order to avoid attenuation. This means that for long distances, shallow radiation at a low angle is best, and experience indicates that this should be between 5° and 15°. For shorter spans, say from the "skip" distance up to about 1,000 miles, a higher angle is required, maybe between 20° and 40°, in which case not so much power is required as for long spans. The aerial of greatest utility is, therefore, one which sends most of its energy off at a low angle in all directions, and also some energy at somewhat higher angles. The vertical half-wave aerial does this, but results are often disappointing, because it needs careful adjustment, and its radiation is easily modified by buildings, trees, etc., in the vicinity.

In advanced amateur work, applied directivity is now common, and this subject offers a very interesting field of experiment, especially if it is coupled with a study of wave propagation over long distances.

Polar Diagrams

For convenience, directivity may be divided into that taking place in the vertical plane and that in the horizontal plane. To send a good signal in a given direction of the compass, horizontal directivity is of first importance, whilst to cover the correct distance in this direction the angle of elevation of the wave, or the vertical directivity must be correct. Diagrams representing the relative strength in various directions are called *polar diagrams* and each aerial has its own vertical and horizontal polar diagrams. A number of these diagrams are given in Figs. 20 and 26. In these diagrams, radii are marked off at various angles to the aerial wire or to the ground, and along each radius a point is marked at a distance proportional to the signal strength in that particular direction. The points are then joined up to give a curve which represents the performance of the aerial in the particular plane for which it is drawn.

Formation of Polar Diagrams

The reason for the variation of the signal strength with direction is illustrated in Fig. 19. The two small circles A and B represent a *plan* view of two vertical aerials, and it is assumed that they carry equal currents in phase with each other, that is to say the oscillations are at a maximum at the same instant. Now suppose that there is a receiver at a great distance in the direction R_a at right angles, or as is commonly said, *broadside* to the line of the aerials. If R_a is very remote the two waves travel by nearly parallel paths and these paths are equal. Since the waves start in step they also arrive at R_a in step, so the receiver picks up twice as much energy as it would if only one aerial were used.

In the line of the wires in the direction R_b the wave from A must travel further than that from B, thus it arrives later. If the distance AB is half a wavelength, then wave A arrives half a cycle later than wave B, that is, the crest of B arrives with the trough of A and the two therefore cancel. There will therefore be no signal at the receiver. In intermediate directions such as R_c the path difference is not so great and the waves partially add. The polar diagram therefore has a maximum in direction R_a which gradually reduces with changing direction until it is zero in direction R_b. This is represented by the broken line of Fig. 26 (A).

If the two aerial currents had been in opposite phase then zero radiation would have occurred in direction R_a and maximum along R_b, Fig. 26 (B), whilst if the spacing between A and B had been other than half a wavelength the path differences would have been different and the maxima and minima would occur in other directions. It is by adding up the component waves, with due allowance for the phase of the aerial currents and the path difference, that polar diagrams can be constructed for any system. For instance, if the simple half-wave aerial is considered as a number of very short elementary aerials in series, and the elements of radiation are added in various directions, it is found to have a well defined polar diagram in the plane of the wire, whilst if the aerial is a full-wave, the diagram is quite different (Fig. 21).

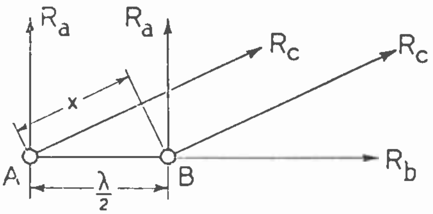


Fig. 19.

Development of Polar Diagrams. A and B are two aerials carrying equal currents. The path difference from the two aerials will depend on the direction. This causes addition of energy in some directions and cancellation in others.

Vertical Polar Diagrams

Fig. 20 shows the vertical polar diagrams for a number of different basic types of aerials and combinations. (A) is the vertical quarter-wave Marconi and it will be seen that it transmits most of its energy in the range of elevations already mentioned as being desirable, so that it is useful for both long and short distance communication. It has already been explained in connection with Fig. 2 how this arises; it is in effect half the polar diagram of a half-wave wire, the reflected image in the ground completing the radiator.

In Fig. 2 the lines AX and A^1Y have been added to illustrate the formation of the vertical polar diagram, X and Y corresponding to R_c of Fig. 19. In this case the two paths both start from the same aerial A but one of them goes by reflection from the ground and the other direct. The construction of the paths is exactly the same as for the optical effect in a mirror, so it is convenient to refer to the reflected wave as if it originated in an image A^1. The path difference is A^1Z and so the polar diagram is developed according to the angle of elevation, length and height of the aerial.

If the vertical aerial is half a wave long and above the ground the theoretical vertical polar diagram is the solid line of Fig. 20 (B). The path difference between the direct and reflected waves is greater for a given angle than in (A) because the radiator and its image are further apart, thus a secondary *lobe* appears in the diagram at a high angle, but if the bottom of the aerial is near the ground this lobe is small, and the energy is mainly concentrated at very low angles to the horizon. This would make an excellent aerial for long distance working, because the radiation is at such low angles and is uniform in all directions of the compass, but unfortunately the diagram is not accurately realised in practice because of the inefficiency of the ground as a reflector at glancing angles of reflection.

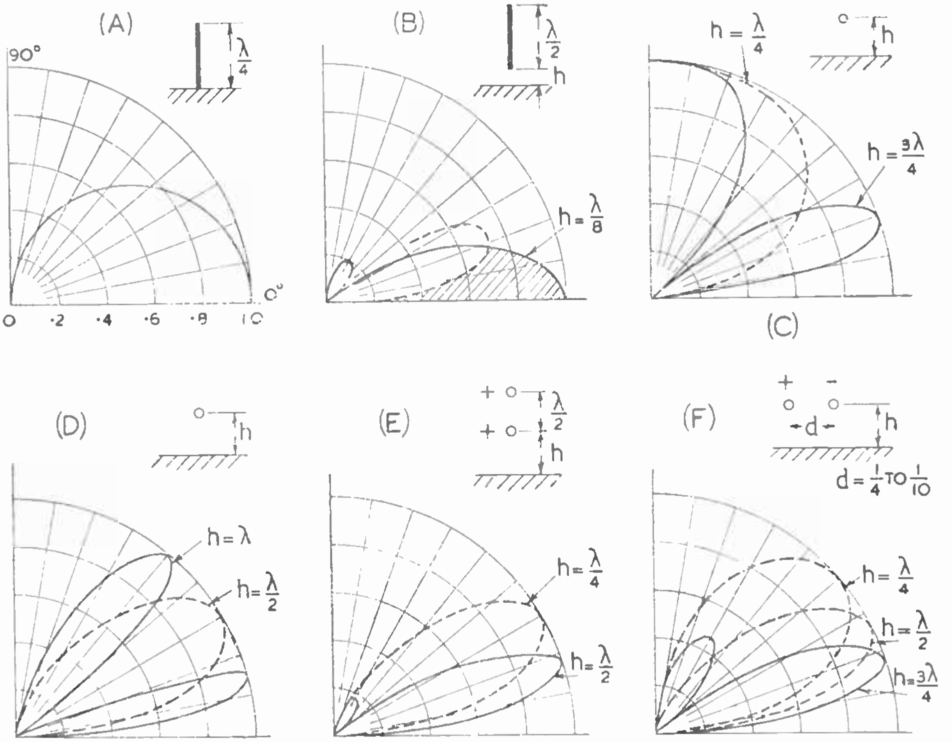


Fig. 20.

Vertical Polar Diagrams. (A) Vertical λ/4 earthed. (B) Vertical λ/2. (C, D) Horizontal wire systems. (E) Horizontal Sterba Fig. 23. (F) 8JK, Fig. 23. Diagrams (A) and (B) are the same for all directions of the compass, the remainder are for broadside direction only.

Effect of Soil ; Polarisation

The direction of electric force in the radiated wave is in the plane in which the wire lies, and in radio work it is usual to say that the wave is *polarised* in this plane. Thus the radiation from a vertical aerial is said to be *vertically polarised* whilst the broadside radiation of a horizontal half-wave aerial must obviously be *horizontally polarised*. These distinctions are introduced because they are important when considering reflections from the ground, but it should be pointed out, to avoid confusion, that this convention is different from that used in optics.

In Fig. 2 the reflected wave really originates at A and the image A^1 is an artifice to help to understand what happens, and therefore one would conclude, since both direct and reflected waves originate from A, that they are in step with each other, apart from any effect due to path difference. This is so for vertically polarised waves at high angles of elevation, but unfortunately the ground is in effect only a poor kind of mirror, badly polished and rather dirty. For this reason the ground only partly reflects the wave and moreover takes time to do it. Perfectly conducting soil would reflect perfectly, but soil is often practically non-conducting. The effect of this is that at glancing reflections the vertically polarised wave is reversed in phase and instead of helping the low angle radiation, it tends to cancel it. Thus the theoretical diagram of Fig. 20 (B) is modified in practice. The general effect is to cut away the lower angle radiation (the shaded part) some of it being absorbed and the remainder sent off at a higher angle, in the manner shown by the broken line.

Horizontally polarised waves always receive a phase reversal on reflection from the ground, be it a good or bad conductor, and the diagrams (C) to (F) allow for this condition. The general effect of the soil is therefore to deflect or to dissipate the low angle radiation, that is, effectively to raise the lobes of radiation above the theoretical angles. This effect is more noticeable with vertically polarised waves. Since the nature of the soil varies considerably with locality and with the time of year the performance of vertical aerials may vary widely.

The ground is thus a hindrance rather than a help in long distance communication; for this reason, and of course others, the locations for commercial stations are chosen with considerable care. The amateur is not usually free to choose his location, and must therefore make the best of his local soil. Seawater is probably the best " ground " available and seaside locations are usually good ; wet chalk or clay is about the best subsoil for land stations, whilst rocky places or sandy deserts are notoriously bad. These facts may help to dispel the popular myth about good and bad " locations."

The way to overcome the upward trend of the radiated wave and keep it to the desired low angles is either to use a high aerial which has sharp low angle directivity, or else to use some system which tends to force radiation towards the horizon, such as the horizontal Sterba or the " W8JK " (Kraus) aerials to be described later. The upward " push " from the earth, for single wire aerials commonly used in amateur work, is usually at least 10° ; this has not been allowed in the polar diagrams of Fig. 20, and so should be remembered when using them.

Vertical Aerials

Vertical aerials are not made longer than half-wave unless the various half-waves are all brought into phase with each other, because a long single wire sends its radiation at very high angles without even the help of the ground. The vertical half-wave may be used where the site is fairly open, and if the soil is a good reflector, as for example in damp country, it will be found very good for long distance work, but it has frequently been found disappointing. The height of the bottom should be kept under a quarter-wave. It may, of course, be fed in any of the ways already described, and has been built successfully as the " J " aerial previously described with the bottom earthed, the mast being three-quarter-wave high and used as the radiator. Some of the directive aerials described later may be used as verticals with good effect.

Horizontal Polar Diagrams

The polar diagrams for various lengths of wire are shown in Fig. 21, whilst Table 2 gives further information.

These diagrams are formed in much the same way as for the vertical case. Starting with a number of current loops in the wire in alternate phases, there are certain directions in which the distances involved allow all the component signals to add, and others in which they cancel. There is of course always zero radiation along the direction of the wire. It will also be seen that when there is an even number of half-waves the components cancel at right angles to the wire. The largest lobe is always nearest the direction of the wire, and as the length becomes greater (*i.e.*, more half-waves) the number of minor lobes increases. In the absence of the ground these lobes are really cones about the wire as axis, and their number is equal to the number of half-waves on the wire.

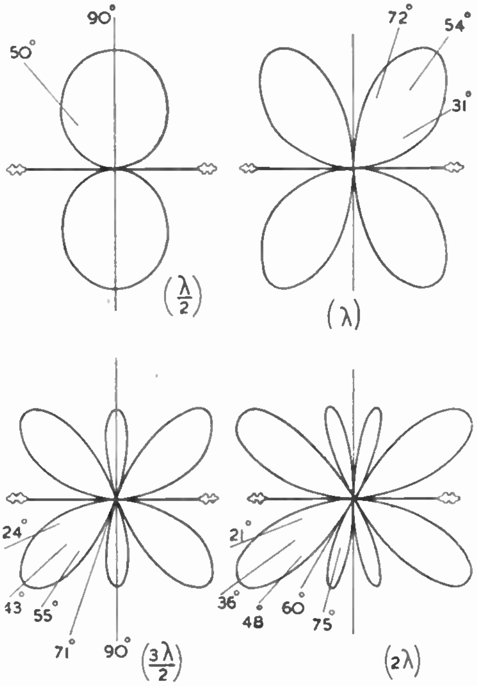


Fig. 21.

Polar Diagrams of Long Wires from λ/2 to 2 λ in length. The angles of the main lobes and crevasses are shown, and also the angles for a 3 dB loss in the main lobes. These diagrams are for free space : if the wire is horizontal the end crevasses tend to fill in giving end-fire radiation, mostly at high angles. See Table 2.

When the wires are horizontal these polar diagrams represent effectively the horizontal directivity, though the lobes are most effective at some angle above the horizon in the vertical plane, according to the height. The diagrams of Fig. 20 may be used as a guide as to what may be expected. The diagrams of Figs. 24 and 26 are for directive systems which will be described later. In these diagrams directions are marked where the radiation falls 3 dB below the maximum, a loss which is just audibly appreciable.

Horizontal Aerials

The horizontal half-wave aerial radiates best in broadside directions, and the waves are horizontally polarised. The vertical polar diagrams for this direction and for various heights above the ground are those of Fig. 20 (C and D), from which it will be seen that low angle radiation improves as the aerial is raised. Note also, that since it is the height in wavelengths which matters, better results will be obtained on the shorter, rather than on the longer, wavelengths for a given height of masts.

In the direction in which the wire points there is no direct horizontal radiation, but vertically polarised waves are radiated by reflection from the ground, though the angle of elevation is greater than in the broadside direction. In intermediate directions radiation is a mixture of vertically and horizontally polarised waves, and there is a gradual change from the end-on type of radiation to the broadside type. The general effect in practice is therefore that the free space diagram of Fig. 20 tends to fill up at the ends, but the radiation off the end is more suitable for short distances than for long. Like broadside radiation, end radiation improves as the height is increased.

The best height is a wavelength, but this requires a pair of 70 foot masts on 14 Mc. At this height the aerial is good for long distance work in practically all directions. The next best is half a wavelength or a little more, say 40 feet for 14 Mc. The ¾ λ should be avoided as it sends much energy vertically (see Fig. 20 C). At this height the radiation falls off noticeably as the direction comes within about 20° of the wire.

The effect of sloping the aerial is to increase the end-fire radiation, and if one of the masts is high the radiation off the low end may be as good as the side radiation. If the masts are respectively a wavelength and a half-wavelength high, then the aerial radiates well all round except in the direction of the high end.

Fig. 21 shows very clearly the effect to be expected from a full-wave (λ) aerial in practice, radiation in the favoured directions being good, together with short distance high angle radiation off the ends. If the height is ¾ λ the end radiation begins to become effective. The sloping method can again be used to help in one direction.

The 2 λ (4 half-wave) aerial is very effective. It is so inherently directive that the ground has much less disturbing effect than on the shorter aerials. Where space is available this makes a very good long or short distance aerial, being practically omni-directional. The end radiation is now fairly low, and the only blank directions (60° and 90°) are critically defined within a few degrees. Such an aerial is possible for 14 Mc when the length is about 138′, whilst on 7 Mc it would become a full-wave. Aerials with more half-waves are even better but are not usually attainable.

Table 2 gives the more important features of aerials up to 5 λ in length. The radiation resistance figures are for wires in free space, and will be somewhat modified according to the height. For example the half-wave aerial starts from a very low value and rises rapidly to nearly 100 ohms at h = 0·3 λ, dropping to 60 ohms at h = 0·6 λ thereafter settling down around the 70 ohms value. The longer aerials behave in much the same way. It will thus be clear why it is not possible to give accurate formulæ for adjusting single wire feed points. Notice also that the radiation resistance increases steadily as the "size" of the radiating system increases; this is a general rule for all aerial systems. Apart from this, however, the radiation resistance is inversely proportional to the directivity, so that for a given size the more directive the aerial the lower its radiation resistance, and the sharper and more critical become the tuning and feeder adjustments. Thus the centre-fed λ, 2 λ, 3 λ, etc., being more directive than their continuous counterparts have somewhat lower resistances than the figures given.

The directivity is much more noticeable than might be expected from the gain figures given in Table 2; this is because the directive effect also helps to overcome the earth's "upward push."

TABLE 2

Properties of Long Wire Radiators

No. of Half-waves	Length Feet (f in Mc)	Angle of Main Lobe to Wire	Radiation Resistance (Ohms)	Main Lobe Gain Over Half-wave (Decibels)
1	468/f	90°	73	0
2	960/f	54° (90°)	94	0·6
3	1,450/f	43°	102	1·1
4	1,940/f	36° (58°)	109	1·6
5	2,440/f	33°	116	2·0
6	2,930/f	30° (46°)	122	2·6
7	3,430/f	28°	127	3·0
8	3,910/f	26° (39°)	130	3·5
9	4,400/f	24°	134	3·9
10	4,900/f	22·5°	138	4·3

The number of complete conical lobes is equal to the number of half-waves, the main lobe being nearest the wire direction and the others progressively smaller (Fig. 21). If the aerial is centre-fed the polar diagram is like that of one half only but the main lobe is sharper and further off the wire, and the gain is slightly greater than that of the full length unbroken wire, e.g., 6/2 centre-fed has three lobes, the main one at 46° and a gain of nearly 3 dB. Angles for centre-fed aerials are given in brackets.

Effect of Feeders

Generally speaking, the radiating properties of an aerial are not affected by the method of feeding, except in the case of a centre-fed aerial working on its even harmonics, as already noted (*see* Centre-fed aerials, Harmonic Radiation). The single wire-feed is most likely to go wrong; the Zepp. is an exception in which the two wires may not be balanced. The twin-balanced feeder is the safest, for as has been seen, the loss is usually very low, and if it is correctly matched as well as accurately balanced, the energy fed into it must be radiated by the aerial, having nowhere else to go!

Feeders may be connected in any current maximum without affecting the polar diagram, but at a voltage maximum the phase of one half is reversed (compare Figs. 4A and 4B). Thus if a full wave aerial is broken and fed in the centre, the two halves come into phase, and therefore add in broadside, whereas the end-fed full-wave, exhibits the lobes shown in Fig. 21. Thus any centre-fed aerial which starts off with one or three half-waves must exhibit this effect when it is used on its even harmonics; the bracketed figures of Table 2 then apply.

DIRECTIVE AERIAL SYSTEMS

Beam Aerials

Directive systems can be constructed in two ways, first by combining a number of half-wave radiators, and second by taking advantage of the known directive properties of long wires and

World Radio History

building up combinations of these. In either case the component parts are fed in such a way that the signals add in the favoured direction and tend to cancel in other directions. The signal strength in the favoured direction, and the sharpness of the *beam*, increase with the size and complexity of the system. In commercial point-to-point work, by the use of an array occupying up to thirty or more " square wavelengths " of area, a beam only a few degrees wide is obtained.

Beam aerials fall into two main classes. In the first a number of half-wave resonant elements are combined in such a way that the components of radiation from the elements add in the favoured direction and interfere in other directions ; these are called *beam arrays*. For example, a number of half-wave radiators strung in a line and all in phase would be a directive array (broadside) ; some of the beams described later will easily be recognised as falling into this class.

The second type utilise the end-fire properties of long resonant wires, and may be classified as *progressive wave aerials*. Examples are found in the Vee and Rhombic designs (Fig. 28). Under certain conditions these aerials can be made to work in the forward direction but not backwards. Although the two classes are not entirely distinct, their properties are quite different. The arrays are resonant systems and tend to be limited to single-frequency operation. Their polar diagrams can be made very free from spurious lobes in unwanted directions, and most important, by varying the number of elements in the vertical and horizontal planes, the sharpness of the beam can be controlled independently in the vertical and horizontal planes. Arrays are, however, liable to be rather complicated mechanically.

The progressive wave class are usually much easier to erect, but require more space for a given degree of directivity, because the horizontal polar diagram is always broader for an end-fire system than for a broadside system of the same size. On the other hand, the vertical and horizontal polar diagrams are inter-connected, so that whilst the aerial may be easier to erect and feed, it is more difficult to design it to give a beam of the required width, and at the same time have the maximum radiation at the required angle above the horizon. The radiation also tends to spread in unwanted directions, although the main lobe may be quite sharp and strong ; this is very important when such aerials are used for reception. Arrays will give a well defined main lobe and little else, whilst the wave aerials tend to give rather broad general reception in addition to the strong major lobe. The two classes are not entirely distinct ; it would for example be possible to have an array of two rhombic aerials.

In amateur work only the smaller structures with their limited directivity can generally be used, but some of these give very helpful results, especially if they are applied to obtaining low angle radiation rather than great horizontal directivity.

Array Elements

Fig. 22 shows a pair of half-wave elements both supplied from a common feeder at the right. Energy arriving at the first joint separates, half being radiated from the right-hand wire and the rest travelling down the connecting feeder to be radiated from the left-hand wire. If the distance D is made equal to one half-wavelength (492/f feet) then the two radiators are in opposite phase, because the wave takes half a cycle to travel down the connecting feeder. (*See* Formation of Polar Diagrams.) This results in the bottom left polar diagram of Fig. 22, or the λ/2 out-of-phase diagram of Fig. 26 (B). If the coupling line between the two radiators is crossed over, the radiators come into phase and the broadside diagram is obtained. This principle is used in building up the Sterba arrays of Fig. 23 (B), using cross-over connections (made like Zepp. feeders) at the ends of the half-wave radiating elements. If the two radiators of Fig. 22 are horizontal and one above the other, then when they are in phase the radiation is concentrated towards the horizontal. There is nothing to reflect directly upwards, and the general radiation is thus at a lower angle than that of a single wire.

If the two wires are at the same height and both horizontal then the end-fire out-of-phase connection gives the low angle radiation, whilst if they are both vertical radiators then either broadside or end-fire radiation may be had at will by arranging a reversing switch in the inter-connecting feeder : alternatively each radiator could be fed separately with a low impedance line and the changeover effected indoors when required.

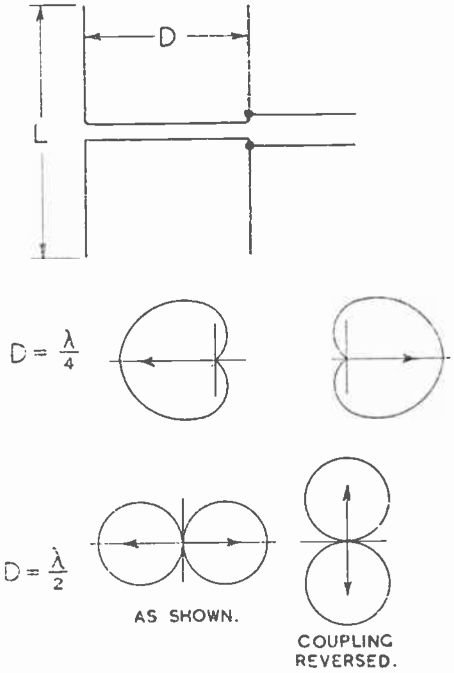


Fig. 22.

Two half-wave aerials in four combinations which are used for building up beam arrays. The quarter wave spacing gives reflector action and the half-wave spacing end-fire or broadside radiation.

Reflectors

Suppose the spacing D in Fig. 22 is made one quarter-wave. Then towards the right-hand direction the radiations from the two elements will cancel. The radiation from the left wire has to make an extra double quarter-wave journey, arriving half-a-wave or half-a-cycle late, and making it oppose the radiation from the right-hand wire.

In the other direction, towards the left, there is no difference in journey between the two radiated components, consequently all the energy is radiated this way. In this case the right-hand element is called a reflector, and because both elements are supplied directly from the feeder, it is said to be a *driven reflector*.

If the connecting link is crossed so that the current in the right-hand element is reversed, then it will be seen that the radiations towards the left will cancel, whilst towards the right there is, in addition to the half-cycle *space delay*, another half-cycle delay due to the reversal, bringing the radiations in this direction one whole cycle different, *i.e.*, back into step and additive. Reversing the link thus reverses the direction of radiation. (The two polar diagrams of the system are shown in the diagram.)

In this way a simple reversible beam aerial can be built which will give a great improvement over a single wire at great distances, not because of the extra power in the favoured direction, but chiefly on account of the lowering of the angle of radiation towards the horizon. The radiators may be either horizontal or vertical with equal effectiveness. In reception, it is of great help to be able to reduce interfering signals from the back, or unwanted direction. In fact, due to the broadness in the forward direction, the aerial is usually pointed to steer the minimum signal where desired, rather than to face it accurately towards the wanted direction. A simple switch can be arranged for reversing the link, or if the aerial is mounted vertically it can be made rotatable.

An important point is that the characteristic impedance of the connecting link must be about 80 ohms to match the aerials, otherwise the standing wave developed on it will oppose the flow of energy from one wire to the other. Alternatively some matching device must be used. The length of the elements L is about 470/f as for a single half-wave, and the spacing D is 246/f feet, where f is the frequency in Mc. Owing to the size they would otherwise attain, such arrays are only convenient for 14 Mc and higher frequencies.

Parasitic Radiators

The adjustments of a driven reflector are very difficult in practice, but it is not essential that both wires be driven directly; one of them may quite well be free to pick up and *re-radiate* some of the energy from the driven element. The free wire is called a *parasitic* radiator, and can either reflect the wave away from it or draw it over towards it, according to its length. In these cases the minimum is not so good as when both wires are driven, but the polar diagram is very similar in other respects. One frequently sees both driven and free wires cut to the same length as a single half-wave radiator, but this is not correct because of interaction between the two. With a spacing $\lambda/4$ and driven element as before, the free wire is 480/f feet long for reflection and 430/f feet long if it is to be a *director*. In the practical arrangement the direction can be reversed by connecting a clip across an insulator placed at one end of the free wire so as to lengthen it by the correct amount; approximately 4' on 14 Mc. With the two wires both equal and separately resonant the forward gain is about 4 dB, and the *back to front ratio* is about 5 dB. With the free element cut 98 per cent. half-wave, *i.e.*, 480/f and the driven element in resonance (470/f), the forward gain is 3 dB; but the front to back ratio of sensitivity is increased to 9 dB, which is much better for reception.

Close Spaced Aerials

To secure best reflector or director action with parasitic wires it is, however, better to depart from the quarter-wave spacing and bring the wires much closer so as to increase the coupling and increase the current in the free wire. Using the procedure in which the reflector length is always adjusted for maximum current *in position*, the forward gain increases slightly as the spacing is reduced from quarter-wave, until it reaches a maximum of nearly 5 dB at a spacing of about $0 \cdot 2\ \lambda$, the back to front ratio being then also 5 dB, but the radiation resistance drops to about 40 ohms.

Closer spacing with the parasitic wire in resonance will make it change to a director. At about $0 \cdot 1\ \lambda$ spacing the gain is just over 5 dB and the backward loss nil, whilst at 0·05 wavelength spacing the forward gain drops to about 3 dB but the back/front ratio is as great as 19 dB, or nearly 10 : 1 in signal strength. The radiation resistance of the aerial drops steadily from about 70 or 80 ohms at the quarter-wave spacing until it is only 10 to 15 ohms at the 0·05 wave spacing. These low resistances mean that the aerial is sharply resonant and that the adjustment and feeding become very difficult.

An alternative is to use a spacing of about 0·1 wave and shorten the director below the resonant condition, when another optimum occurs with a forward gain of nearly 5 dB and a good back/front ratio of about 17 dB. The radiation resistance is then between 20 and 30 ohms.

Summarising, it may be said that the gains to be obtained are never very great, but that with close spacings very good front to back ratios can be obtained at the expense of difficulty in tuning and feeding. This ratio is of great use in reception.

The best way to deal with the rather critical adjustment of the length of the parasitic wire is to draw in a foot or so of it into a little stub in the centre and use an adjustable shorting bar with a meter tapped into it for the length trimming. No exact formulæ for lengths are given here as individual circumstances affect them too much. It is best to set up a receiver with a signal strength meter at some distance away (using a short vertical aerial) and make adjustments for the best back/front ratio. With close spacings, currents and voltages are very high, and good end insulators are required. Further the whole array must be sufficiently rigid to ensure that the wires do not wave about, otherwise the polar diagram may vary considerably and the transmitter feed current will not be constant.

World Radio History

The impedance matching is difficult, and tuned feeders may have heavy losses. It is advisable to use the lowest impedance line available, or two such lines in parallel. One method is to make a "Q" section of two low impedance lines in parallel (cut to quarter-wave resonance with the aid of an oscillator) and to join these between the aerial and a 70–80 ohm line. This will be best for about 0·1 wave spaced directors.

Close spaced aerials are not recommended to beginners, because experience is needed in adjusting and coupling up aerials before success can be obtained. It would be better for a start to use the 0·2 to 0·25 wave spacing with the somewhat inferior performance.

Three-element Close Spaced Beams

A natural development of the above close-spaced aerials is one using both director and reflector together. In this way it may be expected that the gain and front/back ratios can be improved. Now it will have been seen that even with one parasitic element many different arrangements are possible. With two parasitic elements an infinite variety is possible. An early example, in which the quarter-wave spacing was used, has already demonstrated their possibilities. In this model both parasitic wires were first cut to suitable length to give director action. Then with the aid of clips across the insulators extension pieces could be brought into action to make them reflect. With one clip on and the other open, effective beam action with good front/back ratio was obtained, and the beam could be reversed by simply changing the clips. This aerial was vertical and required two masts, and did not come into the modern close-spaced class.

One effective close-spaced model has been described by E. H. Conklin. In this, spacings of one-tenth wavelength were used, and the director and reflector were each adjusted individually for best front/back ratio, with the other absent. There is, of course, considerable interaction between the three wires, and it was necessary to do final tuning

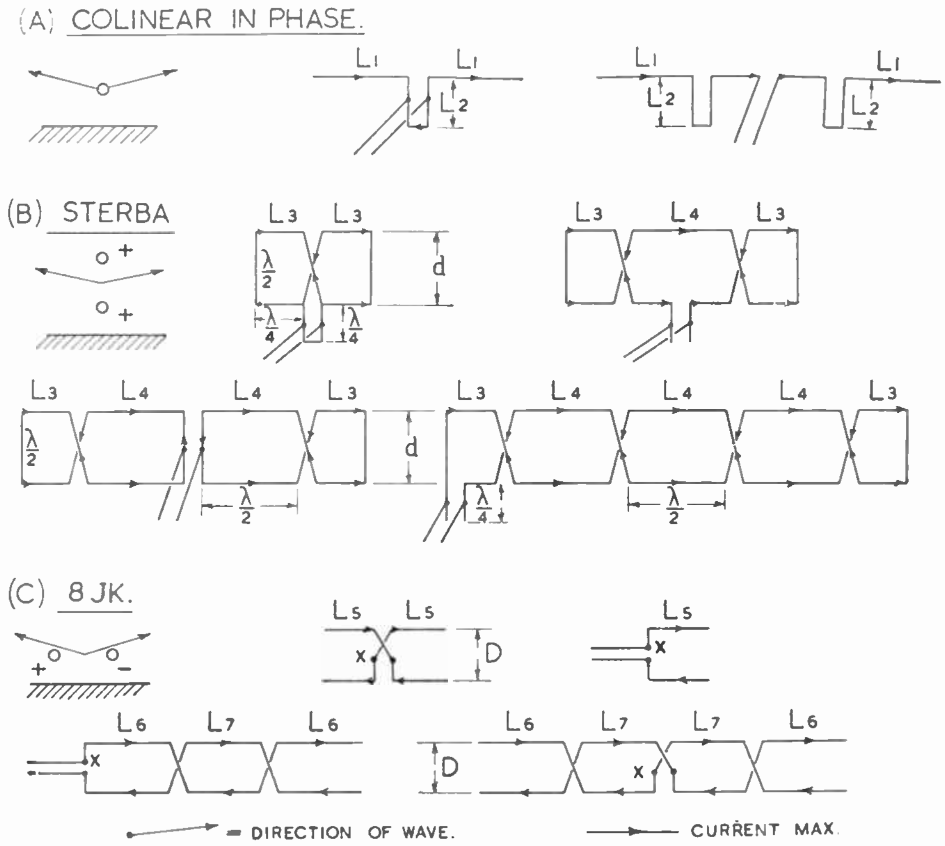


Fig. 23.

Horizontal Wire Beam Arrays.

Small arrows mark current maxima and phases.

(A) Colinear with phasing stubs. L_1 may be $\frac{1}{2}$ to $\frac{5}{8}$ wavelength but $L_1 + L_2 = 725/f$.

(B) Horizontal Sterba. $L_3 = 235/f$, $L_4 = 470/f$ and $d = 490/f$

(C) 8JK. Feed points marked x. See text for dimensions.

World Radio History

adjustments on the radiator after the parasitic elements were set. The following figures were given :—

Element	Length for 30 Mc	Formula for Length
Director	15′ 3⅛″	458/f
Reflector	16′ 4½″	492/f
Radiator	15′ 11″	478/f
Spacing	3′ 4″	98/f

When used as a vertical aerial the front/back and front/side ratios were 30 dB, and the forward gain was 10 dB, whilst the beam was only 20° wide. These results show the possibilities of the system. When used as a horizontal aerial, suspended between wooden spreaders, very effective low angle radiation was obtained.

Centre-fed H Elements

Another alternative with the "H" element of Fig. 22 is to feed in at the exact centre of the line which connects the two radiators. This leads to phase relations which are just the opposite to those obtained if the feed is applied at one side as illustrated. It will be seen that the current from the feed point branches outwards, and takes the same time to reach either aerial; if the interconnection is not crossed over the two radiators are always in phase *whatever the spacing* D. If they are crossed over then the radiators are always in opposite phase. This last type of connection is used in the 8JK type of beam.

Horizontal Wire Arrays

The simplest kind of directional array consists of a number of half-wave aerials end to end, and all in phase with one another. In amateur circles these are usually referred to as so many "half-waves in phase" and a horizontal line of aerials is implied. These aerials are represented in Fig. 23 (A). If the half-wave wires were connected end to end we should of course have the long wire aerials with alternate sections in opposite phase; to secure the correct phasing it is usual to join up the sections with quarter-wave stubs as shown. The left-hand drawing (A) shows two half-waves, from which it will be noticed that if the wire is pulled out straight it is three half-waves long, but when folded the opposing half-wave radiation is annulled.

Any number of half-waves and a variety of feeding methods may be used to suit individual requirements. One of the folded sections may be employed as a matching transformer, or tuned feeders may be used at any current maximum or in place of any particular quarter-wave stub, or else Zepp. feed at one end may be used. Thus the aerial can be fed at the most convenient point for reaching the transmitter. There is little difference between various feed points except that a central point helps to minimise phase errors if the lengths are not correct. It also allows a slightly wider range of frequencies to be used. This option in the matter of position and type of feed is fairly general in arrays, as will be noted in those which follow.

The horizontal polar diagrams for aerials using up to five half-waves may be taken from Fig. 24. They have all been reduced to the same amplitude, and only the main lobe of radiation is shown. There are other lobes but they are usually small. Unless a reflector system is used a similar lobe operates to the rear as well as forward. Fig. 24 is calculated for non-reflector systems but the effect of using a reflector is to give extra 3 dB gain forward, sharpening the diagram slightly in the case $n = 1$ but not appreciably for $n = 2$ or more. The gains and widths of the main lobes are given in Table 3. The vertical polar diagram in the forward direction may be taken from Fig. 20 (B and C), and the addition of a reflector would lower the angle of main radiation slightly, but the value of n makes no difference.

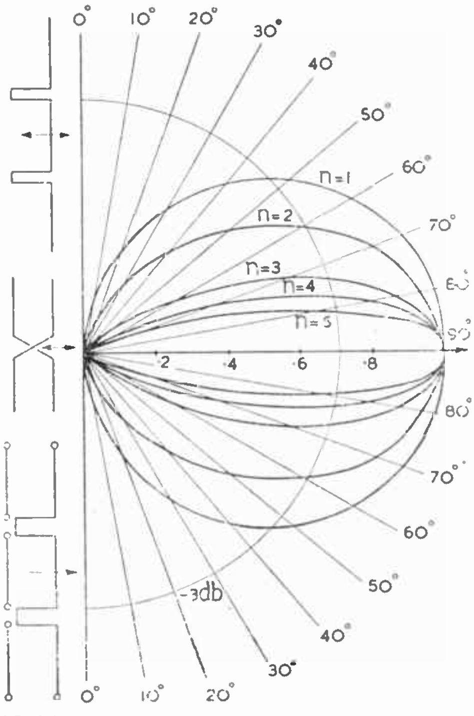


Fig. 24.

Horizontal Polar Diagrams for the aerials of Fig. 23. *n* is the total length of the system in half-waves. Only the forward major lobe is shown, and unless a reflector is used the lobe repeats to the rear. The other lobes are small. All are reduced to a common amplitude, although of course the gain increases with *n*. This can be found from Table 3.

Practical Phased Arrays

The length of the radiating elements is usually assumed to be $\lambda/2$ but they can actually be any length between $\lambda/2$ and $\frac{5}{8}\lambda$ provided the phasing stubs are adjusted accordingly so that the overall length is resonant. The gain and directivity increase progressively as the overall length ; thus a centre-fed 1·25 λ aerial is intermediate between $n = 2$ and $n = 3$.

In setting up a phased array of this type it is first necessary to determine the true direction required using a great circle map (*see* Chapter 18) and then examine the space available to find out what can be built up. A compass is advisable, preferably of a prismatic type, and the readings of this will be about 11° greater than the true north bearing from London (*see Whitaker's Almanack*). The radiating elements need not be cut accurately, but the total length $L_1 + L_2$ (Fig. 23) must be a correct $\frac{3}{4}$-wave. There is an end correction on each radiator owing to coupling between elements, and the formula to use is $L_1 + L_2 = 725/f$ feet where f is the working frequency in megacycles. The phasing stubs may be built up like a 600 ohm transmission line, with a good insulator at the top, and it is advisable to leave the stubs a little long and to adjust each shorting bar for a current maximum in it, starting with the stubs furthest from the feed point.

These aerials are easy to feed from the transmitter because the radiation resistance is high and rises rapidly with n. Tuned feeders may therefore be used for two or more sections without much difficulty or loss.

Reflectors may be added to recover the back radiation and to give an extra 3 dB gain (4 dB for dipole, $n = 1$) together with a slightly lower radiation angle, but where low angle radiation is the chief requirement the horizontal Sterba or the 8JK beams will be easier to erect.

Horizontal Sterba Arrays

A development of the previous type consists in replacing each elementary radiator by a pair so phased that radiation is encouraged towards the horizontal and cancelled towards the vertical. When the pairs are in the vertical plane, one above the other, the vertical polar diagrams are those of Fig. 20 (E). The Sterba type of connection produces the correct phasing of the elements. In this, Fig. 23 (B), the two rows of half-wave elements are half-wave apart and interconnected with crossover feeders, whilst the end half-waves are bent at the middles and joined. They could be left straight and open-ended, but the phasing is held better against stray influences. The current maxima and directions are marked with arrows.

The radiation is broadside, as with colinear-phased half-waves, and the horizontal polar diagrams may be taken from Fig. 24 and Table 3. The radiation resistance rises rapidly towards a limit of about 600 ohms, and so the feeding becomes easy if there is more than one section in use. As a rough rule the radiation resistance may be estimated by multiplying the full number of half-wave elements by the 73 ohms value of one element.

Four different sizes of this array are given in Fig. 23 (B), and a different method of feeding is shown in each, to illustrate the possibilities. Feed may be applied at any current maximum, or between any opposite voltage maxima. The best type of feeder is a 600 ohm balanced line, but it may be a tuned feeder without serious consequences, or it may be matched by one of the methods of Fig. 16.

The crossover connections may be sections of 600 ohm type line and are a full half-wave long, but as there is end-to-end coupling between radiators, these all need end correction, consequently $L_3 = 235/f$, $L_4 = 470/f$, and $d = 490/f$.

The 8JK Beams

The 8JK beams, like the Sterba, are intended to concentrate the radiation at low angles to the horizon as well as to give horizontal directivity, but in these types, the horizontal radiators of each elementary pair are one behind the other and phased in opposition. Very close spacing may be used between back and front wires, and this permits the use of horizontal spreaders which are not too cumbersome to hang on an ordinary mast. Fig. 23 (C) shows that the wiring is much the same as that of the Sterba, but in order to ensure correct phasing it is necessary to feed at a point half-way between front and back.

TABLE 3

Directivity of Horizontal Arrays

No. of Half Waves in Phase.	Beam Width for 3dB less than Max.	Approx. dB Gain over Dipole Phased.	Approx. dB Gain Phased with Reflectors, or 8JK.
1	±43°*	0	4
2	±30°	1·8	5
2½	±20°	3	6
3	±17°	3·5	6·5
4	±12°	4·5	7·5
5	± 9°	5·3	8·3

* 35° *with reflector. Others only slightly better.*

Gain and Spread of beam for horizontal phased systems, such as those of Fig. 23. The gain is referred to a single half-wave comparison aerial. Col. 3 is for colinear phased aerials, col. 4 for phased with reflectors or 8JK types. The Sterba arrays have slightly higher gain than the 8JK but their vertical directivity is not quite so good for the same total height.

The feed need not be at a resonant point, so long as the matching device is adjusted to make the whole system resonant. The only important dimension is the length of the wire from one crossover point to the next. This must be such as to bring a current maximum at the centre of each radiating element. There is a little interaction between front and back which affects the exact resonant length slightly, but small errors in this do not affect the performance. It will be realised that, since both spacing and feed point may be arbitrary, an infinite variety of designs may be produced, and therefore no attempt will be made to give complete formulæ for dimensions. Instead, rules will be given by means of which a design may be worked out to suit any given space.

Starting with the simple half section and single-section beams (Fig. 23C) the length L_5 may be anything between $\frac{1}{4}$ and $\frac{5}{8}$ wavelength. If a matching stub is used, the distance from the shorting bar

World Radio History

to a free end (measured along the wire) must be a complete odd number of quarter waves, *i.e.*, 725/f feet for three quarters.

The half and full section 8JK beams can be used as beams on two bands. On the fundamental the spacing D is made one-eighth wave and L_5 quarter-wave, then on the second harmonic the spacing is quarter-wave and the overall length becomes a full wave with correct phasing. On the fourth harmonic, however, the spacing is half-wave and the lengths L_5 each a full wave, thus the polar diagram becomes more like that of a full-wave aerial. It would then be best to feed this aerial with a tuned 600 ohm line, though it should not be too long a line, as the resonance of small 8JK beams is very sharp.

When the beam has more sections, and there are crossovers between the feed point and the ends, then care is necessary to secure correct phasing, that is, the crossover must be a voltage node. Thus in the three section beam illustrated in Fig. 23 (C) the length between crossovers must be a resonant half wave. The formula for this is $L_7 + D = 440/f$ feet. For the end sections the formula is $L_6 + D/2 = 440/f$ feet. If the aerial were end fed, as shown in the three-section beam, the length at the feed end could be reduced if necessary, and the line or matching stub would " take up " the spare part. The length from the shorting bar of a matching stub to the first crossover point would be 725/f feet.

In the four-section beam illustrated, $L_6 + D/2$ would again become 440/f, and $L_7 + D$ might also be made equal to 440/f feet, but as it is connected to a feed point it could be lengthened or shortened somewhat without much change in the performance of the array.

The directivity and gain may be taken from Fig. 24 and Table 3. The gain varies slightly with the spacing and is greatest at about $0{\cdot}15\,\lambda$. The radiation resistance is very low with close spacings; for $D = \lambda/8$ it is of the order of 10 ohms per section, or at $D = \lambda/4$ it may be 30 ohms per section. This means that currents and voltages are high in the system, and all joints must be good; further, very good insulation must be used at all crossing points and free ends. Light wooden or bamboo spreaders may be employed at the ends and crossover points, but the wires should be clear of these supports.

The low value of radiation resistance introduces some difficulty in feeding the 8JK beam, especially if it is a small one. A matching stub is probably the best method, and the tapping point for the main feeder will be very near the shorting bar, say not more than 2′ in a 14 Mc beam. In the single-section type which has a current maximum at the feed point, Q bars may be used, though the spacing will be rather small. Tuned feeders may be used provided they are not more than about half to three-quarter wave long and well insulated. Balanced feeders must be used for all these beams.

The 8JK beams will operate over the whole range of the 14 Mc band, but over not more than half of the 28 Mc band. Exact matching can only be done at one frequency, but the aerials may be used over these ranges with a slight re-tuning of the feeder.

Adjustable Directivity

The aerial of Fig. 25 consists of two half-wave elements each of which is fed by a low impedance twin line. The two lines are connected in parallel to the coupling circuit of the transmitter. One of the lines has a reversing switch, which may consist simply of an ordinary mains two-pin plug and socket. If the two lines are of equal length then the two half-wave radiators may be brought in or out of phase at will by reversing one line. This is done from indoors with the result that the polar diagram may be changed as required, from that of the two half-waves in phase (Fig. 24) to that of the full-wave single wire (Fig. 21). This is a simple and practical system which is noticeably helpful in both transmission and reception.

In this system it is essential that the two feeders be the same length so that the phasing is correct. If this is not convenient then the phasing can be adjusted by trimming the length of one of the feeders to be exactly $\lambda/2$ longer than the other, and listening for the null in the out-of-phase condition. Possibly it may not be required to have this null position exactly broadside to the aerial; for example it could be steered, by trimming one line, until it faces a local station which causes interference in the receiver.

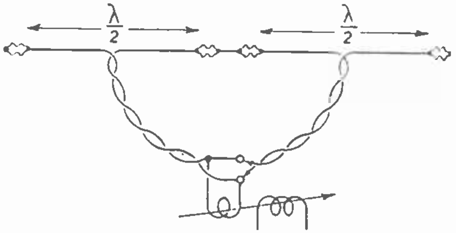


Fig. 25.
Separately Fed Aerials, in or out of phase at will, giving the two half-waves in phase or a full wave effect. The changeover switch may be an ordinary power socket and plug, and may be mounted indoors for quick operation. This principle may be applied to all classes of aerials.

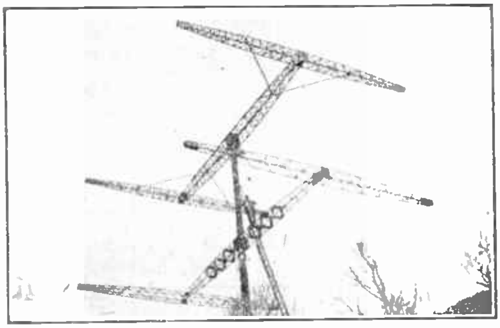
This system may also be applied to vertical H type arrays, such as those of Figs. 22 and 27, or to any pair of vertical aerials spaced any desired distance apart. The general effect of changing over the phase of one of a pair of verticals is to interchange in the polar diagram all the lobes for minima and *vice versa*.

Spaced Vertical Pair

Two spaced vertical aerials have horizontal polar diagrams in which all the lobes are the same amplitude, and so the gain is never very high, but the endfire radiation is at a low angle. The polar diagrams for half-wave and full-wave spacing are given in Fig. 26, whilst the essential figures for other spacings are given in Table 4. The aerials may be fed separately as described in the last paragraph, and if open wire tuned feeders are used the radiators may be used as half-wave on 14 Mc and full-wave on 28 Mc. The reversing switch will give a choice of polar diagrams. It will be noticed in Fig. 26 that the endfire lobes are always broader than the broadside ones, but the endfire radiation

World Radio History

is always at a lower angle because the system is extended in the line of fire this way, which improves with the separation of the radiators. The radiation resistance of each element is not very different from that of a single wire.



An example of a 28 Mc rotating beam built by a Scottish amateur.

TABLE 4

Horizontal Polar Diagrams of Spaced Verticals

Spacing in λ	Angles In phase Maxima or Out phase Zeros	Angles In phase Zeros or Out phase Maxima	Angles 3 dB below Max.
¼	90°	None (in) 0° (out)	0° 180° (in) 48° (out)
½	90°	0° 180°	60° 120°
¾	90°	48° 132°	0° 71° 180° 109°
1	0° 180° 90°	60° 120°	42° 76° 138° 104°
1¼	37° 90° 143°	67° 113°	0° 43° 79° 180° 137° 101°
1½	48° 90° 132°	0° 71° 180° 109°	34° 60° 80° 146° 120° 100°
2	0° 60° 90° 120° 180°	42° 76° 128° 104°	29° 52° 68° 84° 96° 112° 128° 151°

The centre columns give the directions according to Fig. 26, in which the maximum and zero amplitudes occur. Note that changing over the phase interchanges the maximum and zero positions, except when D = λ/4. The last column gives the angles for both cases where the amplitude is 3 dB below the maxima. All maxima are equal. The polar diagrams can be built up from this table.

Compact Rotatable Beams

It is not often that an amateur has sufficient space to erect a number of beams for various directions, unless activity is confined to the highest frequencies and so one must consider what can be done in a limited space to secure some directional gain in any desired direction. Some of the H type structures are useful here, especially the endfire types, for these help low angle radiation. Some of these may be erected with mechanical means for rotating them to any required direction, or the directivity may be switched by the method of Fig. 25. Some of the H structures are small enough for use in these ways on 14 Mc, and for higher frequencies size is no great difficulty. There are also a number of very compact folded aerials which have a certain amount of directivity.

Fig. 27 shows a few examples, and if the rules given in the previous sections are studied, others may be contrived to suit individual needs. (A) is an interesting variation in which a half-wave is bent into a circle. This is usually made from two metal tubes in parallel, mounted on a wooden frame, the object being to obtain rigidity and also to flatten the tuning against its rather low radiation resistance. Twin feeders may be used, and to preserve symmetry these are tapped on opposite rods. The distance between tapping points for a 600 ohm feeder is about 4" per metre wavelength or for a 72 ohm line about 1" per metre. The recommended separation S between the two rods is about 1" per metre and for the opening d about 0·2" per metre.

This aerial has a slight gain in the forward direction shown, but is chiefly useful because it

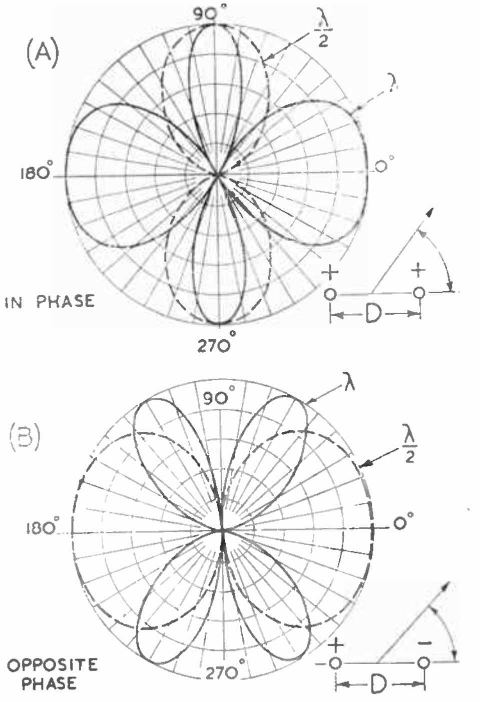


Fig. 26.

Horizontal Polar Diagrams of Spaced Vertical Aerials, for spacings of λ/2 and λ. (A) in phase, (B) antiphase. If the two aerials are separately fed after the manner of Fig. 25 either A or B may be used at will. Note that the endfire diagrams are broader than the broadside; this is because the endfire systems have lower radiation angles.

World Radio History

has a back to front ratio of about 7 dB. It is very suitable for ultra-short wave work. Fig. 27 (B) is a very similar aerial and may if desired, be built up in the same way; there is some advantage in having a square frame if the construction is attempted for 28 or 14 Mc. (C) is a folded half-wave with reflector which has a forward gain of about 4 dB.

Fig. 27 (E) and (F) are small arrays suitable for fixed operation on 14 Mc but which may be built as rotatable beams for higher frequencies. In these D is a half wavelength (492/f) but L_1 may be anything from ¼ to ⅜ wavelength. In the remainder D may be from ¼ to ½ wavelength, except in (H) where half-wave separation is needed to secure correct phasing. (*See* Centre Fed H Arrays). In these aerials L_2 may be anything from quarter to five-eighth wave, except again in (H) where it must be a half-wave (470/f feet).

It will be seen from the above that centre feeding the H array allows considerable flexibility in design, and a little study will show that most of them can be used on two amateur bands. The polar diagrams for various cases may be found from Fig. 26 and Table 4.

These aerials are all most useful on the higher frequencies of 28 and 56 Mc, though in some cases they may be used on 14 Mc. On this latter frequency, however, where space is limited, it might be preferred to use a vertical half-wave with a close spaced reflector or director. They all help to lower the radiation angle.

Long Wire Beams—The " Vee "

The four half-wave radiator of Fig. 21 has its major lobes of radiation at angles of 36° to the wire. If two such radiators are taken in the form of a V with an included angle of twice 36° or 72°, then provided they were fed correctly two pairs of major lobes would add along the bisector of the V, whilst the remainder would be in odd directions and would not necessarily add. Such an arrangement is shown in Fig. 28 (A), and is known as the RCA Vee aerial. As shown it will operate in both directions along the bisector, but if a reflector of similar type is placed behind, then it becomes unidirectional. It is equally useful in transmission or reception, and of course becomes more directive and more effective as its length (in wavelengths) increases. The angle A depends on the length L in wavelengths, as follows :—

L wave-lengths	Angle A	Approx. elevation of wave for height = λ
1	110°	31°
2	70°	27°
3	60°	23°
4	57°	20°
8	35°	14°

The adjustments are in no way critical; in fact the aerial tunes quite flatly over a wide frequency range, and can be used effectively on two or three amateur bands provided it is long enough. It is of course most efficient on the band for which it is designed. If this is done the included angle will be correct for one frequency, but this only means that the beam will be slightly broader than when the angle is correct. Narrower angles give lower elevation of the wave. As the aerial is

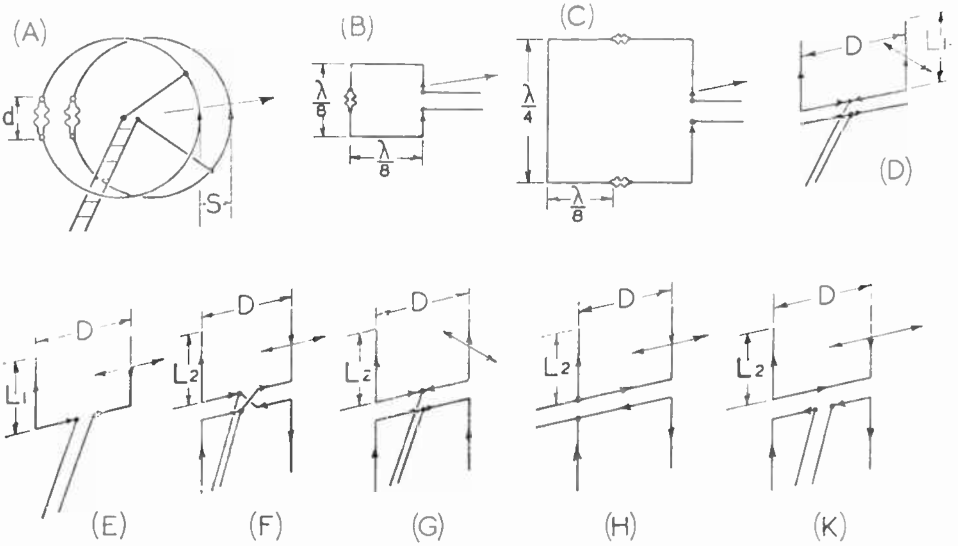


Fig. 27.

Some Compact Directional Aerials. (A, B) The Reinartz. (C) Folded λ/2 with reflector. (D to K) H-arrays. See text. The arrows on the wires indicate the current maxima and phase, and the long arrows the wave direction.

symmetrical, balanced feeders may be used, either tuned or matched by any of the methods of Fig. 16.

The gain of the Vee is of the same order as that of a long radiator using the same length of wire, and the radiation resistance is high.

The "Bruce"

This aerial, Fig. 28 (B), also known as the "Inverted Vee" is another long wire aerial working on a slightly different principle. It will not be described in great detail here, but briefly it is a single long wire in the form of an inverted V, fed between one end and earth. When it is so dimensioned that the length L is one half-wave greater than D, signals in the horizontal direction and in the plane of the V add up. A new feature is the termination of the far end of the wire to make it aperiodic, the value of the resistance R being of the order of 400 ohms. When this is done correctly it operates only in the direction of the arrow. It is most useful in reception, but unlike the horizontal Vee type, it needs a high mast.

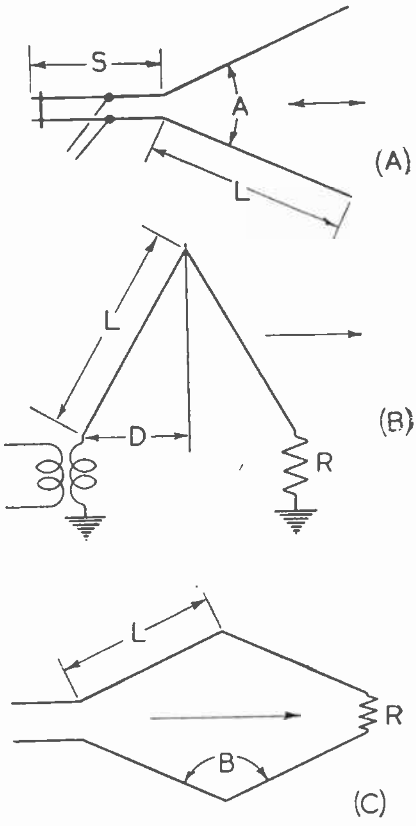


Fig. 28.

Long Wire Directive Aerials.

(A) The Vee. (B) The Bruce, or Inverted Vee. (C) The Rhombic. Radiation is in the direction indicated, and reception from the same direction.

The Rhombic, or Diamond Aerial

This highly successful development of the Vee (Fig. 28 (C)) has been called the "Rolls-Royce" amongst aerials. Briefly it consists of two horizontal V's placed end to end, but it can be designed according to a variety of methods to secure the correct combination of directivity and angle of wave elevation. As with the Bruce type, it can be terminated to make it aperiodic over a very wide range of wavelengths, and the resistance R (in this case about 800 ohms) absorbs all the energy which would be transmitted to, or received from, the "rear." In transmission the resistance may absorb half the power and must therefore be some kind of resistance-mat of sufficient dissipation. In reception, if correctly terminated, this aerial can be extremely valuable, favouring the correct direction to the almost complete exclusion of interference from the rear.

The complete theoretical design, covering all possible variations, is complicated, and would occupy a chapter to itself. To those who have no access to this information, or who cannot assimilate it, the following suggestions are offered.

Firstly the rhombic is not really effective if the four sides are each less than two wavelengths long. If space for this is not available, it would be preferable to use the Vee. Secondly, where space is available the aerial may be designed as a pair of Vees, spacing the masts so that the shape may be altered. One may then experiment with the angles of the Vees and the lengths of the sides until best results are obtained.

Multi-wire Radiators

A recent development in aerial technique, which promises to have far-reaching effects, has been made by the *R.C.A.* In place of the usual single-wire radiator element, *e.g.*, a $\lambda/2$ dipole, a narrow loop is used, or a number of wires so connected that the standing waves on the wires contribute in-phase components of radiation. In this way the radiation resistance at the feed point is enormously increased. The result is that these "multi-wire dipoles" can be matched directly into open-wire transmission lines, without the use of transforming devices, and the whole system is much broader in tuning, operates over a much wider band of frequencies than a single-wire dipole, and is much less critical in its adjustments. These aerials are suitable for television where operation is required over a wide band of frequencies, and the principle has great application in the development of amateur transmitting and receiving systems which can be used over the whole of one amateur band without the necessity for re-tuning each time the frequency is changed.

A number of examples are given in Fig. 29. (A) is a full-wave wire folded into a half-wave dipole. (B) shows two ways of introducing three wires, whilst (C) shows one way of using four wires. (D) is a radiator three-quarter-wave long, in which the principle is somewhat different but the effect just as useful. These loops must not be confused with the normal types of open loop or frame aerial, such as are illustrated in Fig. 27, for in this new type the various "parallel" wires are suspended as close together as is practicable. The wires may be held

World Radio History

apart by means of short wooden spacers at the ends and the centre, and a spacing of 6" has been found practicable on 14 Mc, but there is nothing critical in this figure. The total length of the wire may be taken from the usual formula :—

$$\text{Length} = \frac{492\,(n - 0{\cdot}05)}{f}\ \text{feet}$$

where n is the number of half-waves in the folds, (including the end connections), and f is the frequency in megacycles.

Multi-wire Radiator Theory

It has already been shown how, in a long wire radiator, the adjacent half-wave current loops are in opposite phase (Fig. 2). Now, starting with a current maximum at the feed point X of Fig. 29 (A), there comes a second current maximum in the wire (b) half a wavelength from X, that is, opposite the feed point. Thence we proceed to the current loop at the feed point Y. The current in wire (b) is in opposite phase to that in (a), but the folding back of the wire makes the directions of the currents *in space* identical. The components of radiation from the two wires therefore add, and the radiated field and polar diagram are the same as that of a single wire. But there is an important difference. One ampere of current flowing in a single wire aerial might result in the radiation of 80 watts of power (the actual figure depending on height, etc.). One would then say that the radiation resistance was 80 ohms. If the single wire is replaced by the loop of Fig. 29 (A), the same ampere makes two contributions to the radiation; the field strength at a distant point is thus doubled. The new aerial is equivalent to a single wire carrying two amperes. It is known from Ohm's law that twice the current, or twice the field strength corresponds to *four* times the power. The single ampere is thus radiating 320 watts, and the radiation resistance at the feed point must be 320 ohms. With an input of 80 watts to the feeder the single wire would carry one ampere at the feed point, and the double wire aerial only half an ampere.

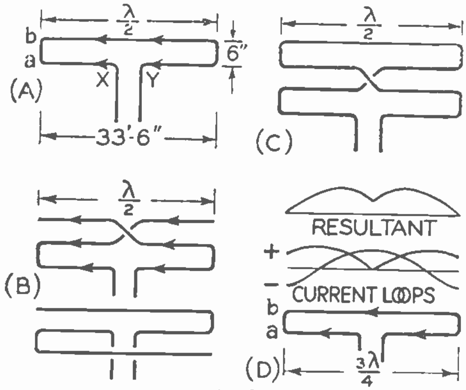


Fig. 29.

Multi-wire radiator elements using two, three or four wires. May be employed wherever single-wire radiators are used. The radiation diagrams are not affected, but the radiation resistance is greatly increased. The small arrows show positions and directions of current maxima. (D) shows how, in a particular case, the currents add to the radiation. Dimensions in (A) are for 14 Mc.

The analysis of the three- and four-wire systems proceeds in the same way, and the corresponding radiation resistances are 640 and 1,280 ohms respectively, corresponding to multipliers of 3^2 and 4^2.

Measurements made on aerials of these types show that the radiation resistance varies with height in the same way as that of a single wire, but the multiplying factors are somewhat higher than the theoretical ones, the two-wire aerial coming nearer 400, and the three-wire nearer 800 ohms. It is also found that the resonance curve of the multi-wire types is much broader than that of a single wire. A two-wire (400 ohm) aerial connected directly into a 600-ohm line shows very little change in impedance or current at the transmitter end, over the whole 14 Mc amateur band. A single-wire dipole matched by one of the transformers of Fig. 16 into the same line shows a current and impedance variation of 2 : 1 over the same range of frequencies. With the two-wire aerial it is thus possible to move the transmitter frequency over the whole 14 Mc band without any need for changing tuning and coupling at the transmitter end.

The variety shown in Fig. 29 (D) differs from those so far described, in that the current loops do not face each other, those in the wire (a) being displaced by ¼ wave from those in wire (b), since the total length of wire is 3 λ/2. The elements of radiating current are shown, together with the sum or resultant of these currents. This resultant gives a current distribution like that of a three-quarter-wave centre-fed aerial, an aerial not often encountered in practice. The radiation resistance of this aerial is about 500 ohms, and the polar diagram is approximately the same as that of a half-wave dipole. It is very suitable in practice for direct matching into open wire lines.

Multi-wire 8JK Beam

The above principle of " wire splitting " may be applied with effect to vertical earthed radiators, and to all types of resonant aerial in which it is desired to broaden the tuning and increase the radiation efficiency. As an example, Fig. 30 illustrates how it was applied to a single section 8JK beam aerial.

The radiation resistance of the 8JK type of aerial is very low, especially if close spacing is used, but its low angle radiation is about as good as that of a dipole at twice the height. As a result of low radiation resistance there are correspondingly high voltages at the free ends and in some cases at the cross-over points. The aerial is thus liable to serious loss in insulators and woodwork, especially in bad weather. A further characteristic associated with low radiation resistance is sharpness of resonance, resulting in critical adjustments and rapidly increasing feeder loss as the frequency is moved away from the resonant point. Practical difficulties of suspension between wooden spreaders encourage the use of a close spacing between the radiator wires, and the above features are accentuated as the spacing is reduced.

By using multi-wire radiating elements, the radiation resistance is increased, and insulation and resonance difficulties are considerably reduced. The aerial of Fig. 30 can easily be matched into a 600 ohm line, and will then operate over the whole 14 Mc amateur band without appreciable loss or

World Radio History

change in transmitter coupling conditions. The example shown has a spacing of about 0·2 wavelength and at a height of half a wave above the ground a single wire model would have a radiation resistance of 25 ohms in each wire or only 12 ohms at the main feed point at the centre of the cross-overs. The use of three wire elements raises this figure to about 300 ohms at the centre of each radiator. In place of the usual cross-over with centre tap feed point, a pair of quarter wave matching sections are suspended to meet at a feed point below the centre. These sections are 600 ohm open wire line, so that the 300 ohms at the top end is transformed to 1,200 ohms at the bottom of each pair (see Figs. 15 and 16 (D)). The two in parallel are thus equivalent to 600 ohms, and match directly into a 600 ohm feeder line.

If the spacing had been 10′ 6″ or 0·15 λ the radiation resistances would have been about 15 ohms for each single wire element, or 180 ohms for the three wire elements. The quarter-wave transformer could then be made from 450 ohm line (since $\sqrt{1{,}200 \times 180} = 450$) and the junction point impedance would be again 600 ohms.

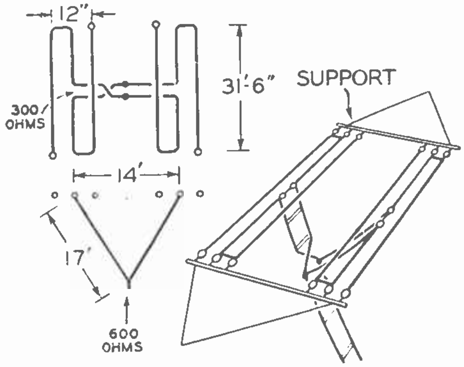


Fig. 30.

Application of three-wire radiator elements to a single-section 8JK beam, together with matching arrangements for 600 ohm feeder line.

A 14 Mc Close Spaced Array

Brief constructional details are given of a highly efficient 14 Mc rotary beam of the two element variety, consisting of a radiator and director spaced one-tenth wave with the radiator fed in the centre by means of a double " Q " matching section and an untuned line. The input " Q " consists of 72 ohms cable whilst the lower " Q " has a pair of No. 14 s.w.g. wires spaced 1½″. This method of feeding a close spaced array is not so satisfactory as some of the patent methods, but providing good quality 72 ohm cable is used and precautions taken to keep it dry, by mounting it inside rubber hose piping, the losses are not of great significance.

Any type of mast or tower is suitable so long as it is strong enough to take a weight of about one hundred-weight at the top. It is a good plan to devise some means for climbing the mast and to provide a crow's nest at the top so that adjustments can be effected safely. For long distance work the array should be mounted at least one wavelength above ground as this will ensure the radiation of low angle signals. If a mast only about half a wavelength high or less is used, the vertical angle will be slightly greater, reducing the long distance and increasing the local signal.

The mast illustrated supporting the beam in Fig. 31, is a very suitable type for this purpose and is made from two sections of 4″ × 2″ mounted vertically with joins at appropriate intervals. It is not self-supporting and should be very strongly guyed. The short pieces which space the vertical sections extend slightly either side and form ideal steps for climbing.

For a working frequency of 14,100 kc the radiator should be cut to 16′ 7″ on either side of the centre and the director slightly shorter, approximately 16′ 3″ on either side with a small tuning stub in the centre. An inch gap should be left between the elements on both the radiator and director. Welded 1″ tubing is recommended for the elements but in order to reduce the weight the end pieces can be made up with ½″ tubing to give a slight tapering effect.

Insulators of stout size, say 4″ ribbed type with brass inserts, should be used as the strain is considerable when the array is subjected to high winds.

The centre arm of the rotating framework is shown in the top diagram of Fig. 32. This is constructed from unprepared 2″ × 2″ with the sections bolted together using ⅜″ carriage bolts. The centre sketch of Fig. 32 gives details of one of the sides of the " H " framework.

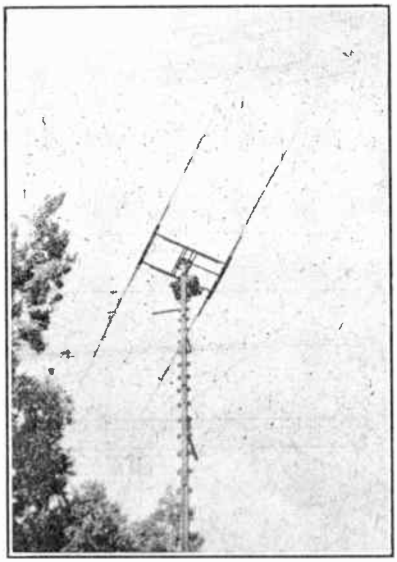


Fig. 31.

A two-element 14 Mc Rotary Beam. Tenth wave spacing is employed, and the beam is on top of a 66′ mast. Note the crow's nest for easy erection and adjustment of the beam. The elements are made from 1″ welded conduit, and feeding is by means of a double " Q " matching section and an open line.

World Radio History

The centre section is 3′ long and each side arm is 7′, thereby giving tenth-wave spacing between the elements. Across the ends of the side arms are mounted boards each measuring 4′ 6″ long × 4½″ wide and 1″ thick. These pieces are attached to the side arms by 3½″ bolts and the holes are drilled towards the outside edges to allow further construction in the centre.

The supporting framework for the elements is built up on the 4′ 6″ boards as shown in the lower diagram of Fig. 32. The total length is 8′, thus allowing a 4′ support for each element.

Numerous methods of mechanically-operating a rotary beam have been evolved but the one used by the designer of the mast illustrated consisted of a 12″ iron wheel on a shaft 1″ in diameter

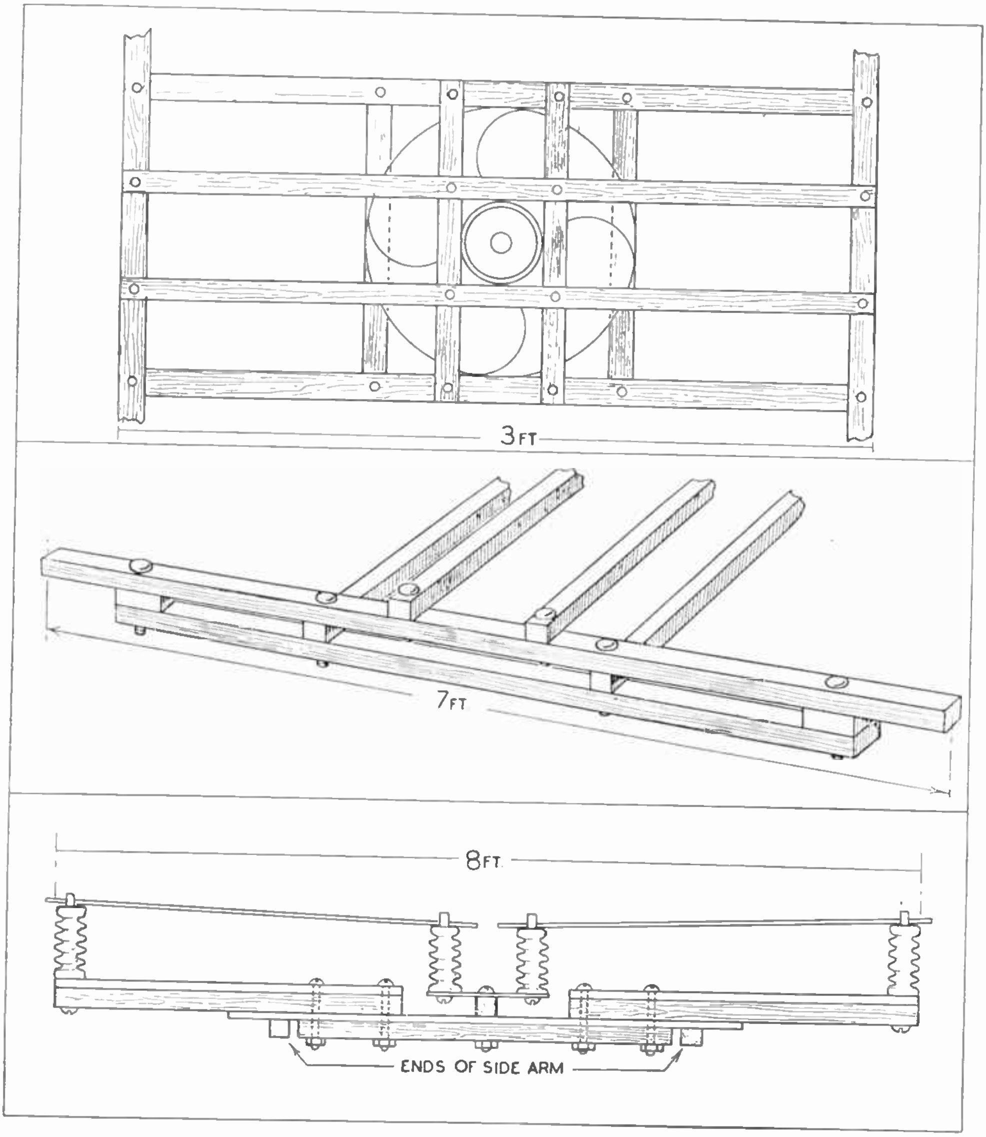


Fig. 32.

Constructional Details of different Sections forming the Rotating Head of a 14 Mc Rotary Beam.

Top : Centre section, which is built around an iron wheel 12″ in diameter.

Centre : Assembly of one of the side arms. Mounted at either end of the centre section, these form the main support for the element framework. All wood is 2 × 2 with ⅜″ carriage bolts of suitable lengths.

Bottom : Element framework which is attached across the ends of the side arms. The outside insulators are mounted 1″ above the inner ones to counteract the slight sag on the long unsupported end of the elements. Note the pivot on the centre insulators, which enable the elements to overlap during erection.

mounted up against a small collar on the shaft. The shaft was of solid steel 6′ long, and very firmly mounted between the two sections of the mast and clamped to one side so that only 2′ of its length extends above the head of the mast. The iron wheel round which the entire rotating head is built, is a 12″ pulley wheel. A car back axle would serve equally well as a rotating head.

The ideal method of rotating a beam is to mount a revisible motor at the top of the mast with the control switch on the operating table but where cost is a consideration a mechanical method of operation provides a reasonably good substitute. An arrangement of steel wires and pulleys will provide a satisfactory means for rotation. Control wires can be taken down the mast and then along to the operating room where a control wheel can be mounted in a convenient position.

A direction indicator is a very necessary addition and when control wires are used, can be devised comparatively simply.

AERIALS FOR 56 Mc

Requirements

The principles applicable to aerials for lower frequencies hold good for the ultra-high frequencies, and most of those already described may be used if scaled to suit the frequency. In fact, it is in this field that the full advantage of beam aerial systems may be enjoyed, since the physical size, reckoned in wavelengths, can be much greater in a given space.

The nature of ultra-high frequency propagation calls for two special requirements, and the first is that the aerial shall be as high as possible. On these waves, where communication is of the "optical" type, height is usually of more use than a special low angle radiator. Good results are often obtained with indoor aerials, but the reason is possibly that power transfer losses between the transmitter and aerial may be high if the aerial is some distance outside, or maybe there is some concealed radiator of large dimensions, such as the water system, which is really responsible and is accepting the energy of the aerial.

The other requirement is that the plane of the aerial must be correct for the receiver. Over open country at least, both transmitting and receiving aerials must be in the same plane, either vertical or horizontal, for maximum signal strength. Vertically polarised waves (vertical aerial) are common but recent results show that horizontally polarised waves are preferable where it is desired to cover long distances. Anomalous results are sometimes obtained in towns and crowded areas, but this may be attributed to the plane of polarisation being changed by reflections from buildings, etc. A horizontal aerial sloping at 45° will radiate waves receivable on either vertical or horizontal aerials, and will also have a slight directivity in the line of the slope.

A single half-wave aerial will be from 8′ 3″ to 7′ 9″ in length according to the frequency in use between 56 and 60 Mc. This transmitting aerial will operate satisfactorily over about half the band. The aerial wire may be solid enamelled copper of 12 to 16 s.w.g., but the feeders should be close spaced to prevent radiation, and may be of thinner wire, say 18 s.w.g. The amount of wire used to secure the aerial to the insulators should be as small as possible, since insulators may cause rather large "end effects" on these frequencies. Also the insulation should be good, and either Pyrex or a ceramic material used. Stay wires and support wires should be broken into lengths of not more than about three-eighth-wave (6′) to prevent absorption losses or undesirable reflections.

The coupling to the transmitter should be adjusted rather carefully because at these frequencies high efficiency in the P.A. stage is difficult to obtain, and there is thus a temptation to load the valve heavily and possibly to damage it. The aerial load should, therefore, be carefully adjusted to the optimum value.

Direct tap of the end of the aerial on the tank coil should not be used; if the transmitter is self-excited the signal may be too unstable to read, whilst if it is controlled, other frequencies than the fundamental may be radiated. If the aerial is to be end-fed, one of the circuits of Figs. 13 or 14 should be used.

A novel aerial for portable 56 Mc operation can be devised from a pair of steel tape rules. The spools on which the rules are wound are drilled and tapped 4 BA and then bolted to a stout supporting strip of ebonite. To the centre of the ebonite piece is fixed a supporting rod of heavy material.

In use the steel tapes are withdrawn to the requisite length—usually about 49½″ for the 56 Mc band.

The tapes are self-supporting due to the fact that they are slightly channelled.

The arrangement is shown in Fig. 33.

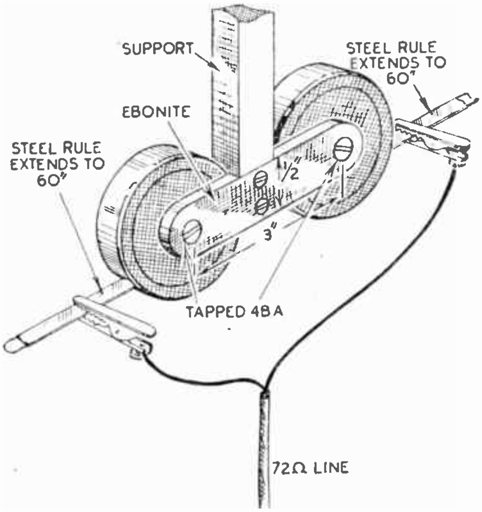


Fig. 33.
The sketch illustrates a novel type of U.H.F. aerial constructed from steel measuring tapes.

U.H.F. Feeders

As it is desirable to have the 56 Mc radiator well away from surrounding objects some kind of

World Radio History

feeder is essential. The low impedance twin feeders (72 ohm) now obtainable are most suitable when the distance to be covered is not more than about 30′ or so, but above this the loss may counteract the effect of the extra height gained, and a heavier line say 400 to 600 ohm must be used.

The low impedance line has the advantage that it matches directly into most aerials, and can easily be coupled to the transmitter. R.F. voltages and dielectric losses are low, further it is light and easy to instal, and switching arrangements from one aerial to another or from transmitter to receiver may be made with ordinary types of switches.

When the aerial is some distance away it is necessary to reduce the feeder loss, either by increasing the size of the conductors or else by raising the impedance of the line so as to reduce the current in it. The latter is probably cheaper, but dielectric must be removed as far as possible. Also, to prevent radiation the spacing must not be more than a few inches. The best type of line is therefore of about 400 ohms impedance using 14 to 16 s.w.g. wire with a minimum number of spreaders. The devices of Fig. 16 are satisfactory for matching u.h.f. aerials to open wire lines.

The Zepp. type of aerial connection is not very satisfactory for these frequencies, as it is difficult to balance, and feeder radiation may be considerable.

U.H.F. Beam Aerials

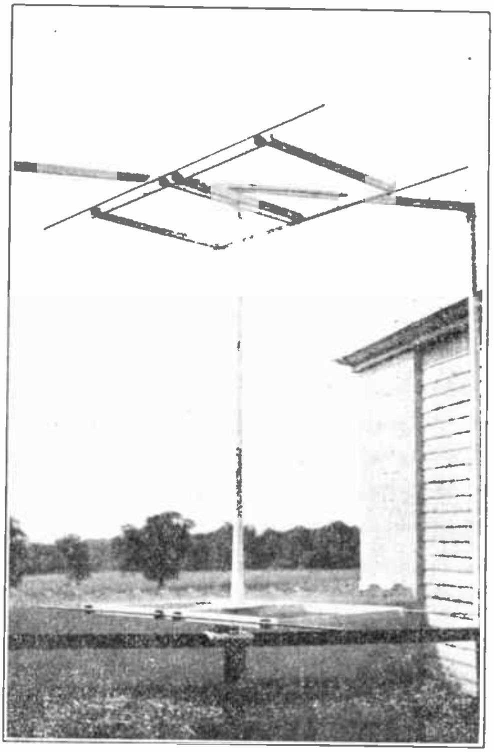
On the ultra-high frequencies beam aerial construction becomes fairly easy as the physical size need not be great, and directivity and gain can thus be obtained. It is easily possible to use long wire radiators with up to ten half-waves on them, and the directivity on the major lobe of such an aerial is appreciable (Table 2).

Alternatively a number of half-waves in phase may be arranged (Fig. 23 A) as either a vertical or horizontal system, and considerable gain easily obtained (Table 3). Reflectors may be added to either the single half-wave or to a number of half-waves in phase. The reflector is about 6″ longer than the radiator on 56 Mc, and spaced about 4′ behind; if there is a number of radiators then separate reflectors should be used. The close spaced reflector/director systems may be used, but adjustments may be found very difficult, therefore it is preferable to use the wider spacing.

Any of the compact beams of Fig. 27 may be used, (E) and (K) are recommended, as the spacing need not be the full half-wave. If L_1 or L_2 is adjusted so that the feed point is a current maximum, low impedance feeders may be connected directly.

If it is not convenient to instal a rotating beam, two vertical half-waves may be erected about half a wave apart and fed separately with low impedance lines, these feeders being arranged in the manner shown in Fig. 25.

The photograph shows a practical example of an array using two radiators and two reflectors. The two pairs are mounted one half-wave above the other and the whole is on a frame which may be rotated to face any required direction. The dimensions are as follows:—main radiator 8′ 3″ overall; distance between top and bottom 8′ 3″. The reflectors are 8′ 9″ long and 4′ behind the radiators. The two elements are each centre-fed by two low impedance feeders of equal length which are connected in parallel to the transmitter.



A 56 Mc Rotary Beam, comprising two radiators with reflectors.

Choice of Aerial System

With so much information it will probably be a difficult task to decide what is best, and matters are often complicated by the fact that local circumstances limit severely the available directions and height, so that a short summary will probably help.

It will be generally assumed that it is desired to work on several amateur bands with one aerial, including the 7 and 14 Mc bands. The primary object, of course, is to get the aerial as high and clear as possible. If the transmitter is to be located at the top of a building, then one of the end-on arrangements may be used, and converted to a Marconi with earth or counterpoise for the lower frequencies, but it is not advised if the station is at ground level.

Multi-band operation usually makes the feeder system difficult, limiting the amateur to the Zeppelin or a centre-fed type, or possibly a single wire feed of the VS1AA type. In all these cases it will pay to try to keep the feeder length down. The best length of top is the greatest possible, say 138′, or if this is impracticable, 66′.

It will pay to study a great circle map (Chapter 18) in conjunction with the polar diagrams, and where it is possible to do so, a slope down towards the

World Radio History

south will be very useful as this will tend to make the aerial cover most of the inhabited part of the globe. A 138′ radiator will, however, be found practically omni-directional on 14 and 28 Mc.

In cramped locations, the best that can be done is to get all the radiator as high as possible, even if it means folding it to get the length. Folding will upset the dimensions already given, but if the energy reaches the top it must radiate. The W3EDP type of aerial is often successful where others are impossible.

The beginner is recommended to start with something simple like a half-wave aerial with low impedance feeders, in order to obtain experience of the way in which aerials behave. Some of the small beam aerials which have been described in this chapter may offer attractions, but they all need a certain amount of skill in adjustment, lacking which, results may be disappointing. Start, therefore, with a simple aerial, and with a little patience. it will be found that even a 10-watt transmitter can make contacts with stations some thousands of miles away. Only when this has been done is it time to try to improve the signal with the aid of directive systems.

Testing of Aerials

When an aerial has been erected and adjusted to satisfaction, it often happens that it does not give immediate results, but it should *never* be condemned on this score. Short-wave transmission has a habit of " going bad " for periods now and then ; in fact, it is this variability of transmission conditions which is one of the most fascinating attractions of short-wave work. It is, therefore, necessary to give any aerial a trial lasting several weeks before one can be sure if it is working properly or not. With a 10-watt transmitter and a good aerial it is possible occasionally to send a good readable signal over long distances in at least one direction, but to give a good average signal in all directions with one aerial is usually only possible for those who are licensed to use higher power.

STRANDED COPPER CONDUCTORS

Number of Strands and S.W.G. of Conductors.	Cross Sectional Area in sq. in.	Resistance in ohms per 1000 yds. (at 60°F.).
3/24	·0011	21·5000
3/22	·0018	13·2700
3/20	·0030	8·0290
3/18	·0053	4·5160
7/24	·0026	9·1900
7/22	·0042	5·6720
7/20	·0070	3·4310
7/18	·0125	1·9300
7/16	·0220	1·0860
7/14	·0350	0·6949

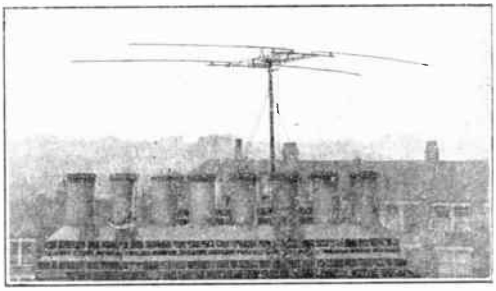
A useful Table for Aerial Construction.

Where there is space for more than one aerial, the best procedure is of course to compare one aerial against another, changing from one to the other as quickly as possible. Matched feeders help speed by eliminating tuning adjustments when a change-over is made.

It often happens that an aerial does not behave according to theory, and then it is found that some factor, such as a tree, or a resonant guy wire, for example, has been overlooked, and the design has to be modified accordingly.

RECEIVING AERIALS

The receiving problem is not quite the same as the transmitting one ; in the latter case it is always desired to give the loudest signal at the other end, but when receiving, what is required is the greatest ratio of signal to noise. Noise may originate in the receiver, or it may be interference from nearby or moderately distant electrical equipment. Also it may be atmospheric noise coming in by the same routes as the signal. To overcome the first it is obviously best to use a big aerial that can produce a loud signal, and for this there is nothing better than the transmitting aerial, connected as it would be to a transmitter. For dealing with the second form of interference, the best aerial will depend on local conditions, and a large aerial may be best in one case whereas a very short one would be best in another. The third case cannot be dealt with to any extent at the receiving station, except in certain cases by the use of directional receiving aerials.



An example of an amateur-built Rotary Beam Aerial showing what can be done even in confined spaces. The top of the mast is 20′ above the roof.

A system to be recommended is a centre-fed top with either twisted flex or transposed twin wires. Together with some kind of tuning device in addition to the receiver tuned circuit (*e.g.*, those of Figs. 13 and 14) this will make an excellent arrangement, both from the point of view of signals and local interference. By means of the coupler it will be possible to tune it for optimum performance on all bands. The length of top is not critical, but results will be roughly according to the information given for transmitting centre-fed aerials.

It is emphasised that as a general rule the use of the transmitting aerial for reception, connected as it would be to the transmitter, is excellent since the two operations of sending and receiving are governed by the same laws.

World Radio History

Chapter Thirteen

The Calculation of GREAT CIRCLE DISTANCES

Basic Principles of Great Circle Maps—Trigonometrical Considerations—Computing Distances—Practical Examples.

DURING recent years Great Circle Maps have come into prominence as a result of their interest to radio amateurs in showing the route which their signals are assumed to take. By the use of such a map centred on the transmitting station, the distance and direction of any point on the earth's surface is readily estimated. The distance between two stations is especially of interest to the operator of a low-powered station who is always eager to cover the greatest distances with the least power, and a knowledge of the direction of a desired station or country is essential if advantage is to be taken of the directional properties of most aerials. The use of a Great Circle Map is strongly advocated in Chapter 18 where the setting up of beam aerial systems is discussed. Information is given in Chapter 12, from which the effective polar diagrams of various aerial systems may be found.

A Great Circle enclosing any two points on the earth is the circle through these points which has its centre at the centre of the globe. It is thus the largest possible circle that can be drawn, but the shortest distance between two points lies along the Great Circle. All lines of longitude are Great Circles, but of the latitudes only the Equator is a Great Circle. In a Great Circle map, all Great Circles through the central point are straight lines, and the map is arranged so that these lines give the true direction and distance from the central point to any other.

This type of map, known as the Zenithal Equidistant Projection, was first employed in its simple polar form by Glareanus, about the year 1510, and was first studied in its general form by Lambert in 1772. Distances from the centre are true to scale, and the azimuths from the centre, or the angle from the N-S Great Circle route passing through the centre, are correct. The map is actually constructed by the use of these distances and azimuths as polar co-ordinates, and there is thus no question of the accuracy of these dimensions on the finished map.

Basic Principles governing Great Circle Maps

Although the construction of such a map may be beyond the patience of many people (and it involves much work), a knowledge of the methods employed may prove of value to those who have some specific objective in view and who wish to find any true Great Circle distance and direction. Amateurs in remote parts of the globe for whom these maps are not published, should find some considerable interest in a discussion on the calculation of Great Circle routes.

For a proper appreciation of the methods involved it is essential to delve a little into the elements of plane and spherical trigonometry and to investigate the fundamentals by which the required data can be obtained.

Trigonometry is the branch of mathematics dealing with the relations between the sides and angles of triangles and with the relations between certain functions of an arc (or angle) measured by the ratios of pairs of sides of a right-angled triangle. Of the considerable number of functions of angles which exist, only two are used in the calculation of Great Circle distances and directions, namely *sines and cosines*, usually written for brevity as " sin " and " cos."

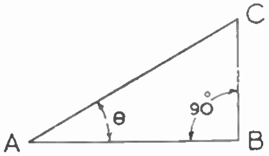


Fig. 1.
When AC is a unit length, CB is called the sine of the angle θ and BA the cosine.

Suppose we have an angle BAC which we will call θ, and make this angle part of a right-angled triangle by dropping a perpendicular line from some point C on the line AC to a point B in the base BA, Fig. 1. Then the angle ABC is a right-angle and the side AC is the hypotenuse of the triangle. Now, by fixing the angle BAC as θ and the angle CBA as a right-angle, the angle BCA is automatically fixed and the three sides will bear constant proportions to one another irrespective of their length. That is, *inter alia*, the ratios :—

(*a*) $\frac{\text{perpendicular}}{\text{hypotenuse}}$

World Radio History

and (*b*) $\dfrac{\text{base}}{\text{hypotenuse}}$

are fixed for the angle θ, and are known respectively as the sine and cosine of the angle. Hence :—

$$\sin \theta = \frac{BC}{AC}$$

$$\cos \theta = \frac{AB}{AC}$$

This is simple enough for angles less than a right-angle, but what happens when the angle θ becomes greater than 90°?

Consider Fig. 2. Assume a radius OX which rotates about the centre or " origin " O in a positive (counter-clockwise) direction. The radii OY, OX^1, and OY^1 represent the positions of this radius after traversing 90°, 180° and 270° respectively, and the angles AOX, BOX, COX and DOX represent one angle in each of the four quadrants. The perpendicular heights corresponding to these four angles are AF, BG, CH and DK and the bases, FO, GO, HO and KO respectively.

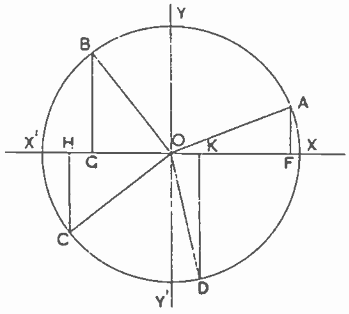


Fig. 2.
Finding the value of sines and cosines for angles between 90° and 360°.

The angle AOX is readily seen to be similar to the angle θ of Fig. 1, in that it is less than a right-angle, and the functions in which we are interested are therefore :—

$$\sin \underline{|AOX} = \frac{AF}{AO}$$

$$\cos \underline{|AOX} = \frac{FO}{AO}$$

Distances in the directions OX and OY are considered positive, and the radial hypotenuse is positive regardless of its position, so that *the sines and cosines of any angle in this first quadrant are positive.*

Suppose the radius OA moves round into the position OB, so that the angle BOX is between 90° and 180°. The triangle, to contain a right-angle, must be constructed by dropping a perpendicular from B to the point G on OX^1.

Without proceeding into a mathematical proof it can be stated that: —

$$\sin \theta = \sin (180° - \theta)$$

so that $\sin \underline{|BOX} = \sin \underline{|BOX^1}$

The same applies to the cosine, so that :—

$$\sin \underline{|BOX} = \frac{BG}{BO}$$

and $\cos \underline{|BOX} = \dfrac{GO}{BO}$

It was stated above that distances measured from the origin in the directions OX and OY are considered positive. On the other hand, distances measured from the origin in the directions OX^1 and OY^1 are considered negative, so that the distance GO is negative. Hence, $\cos \underline{|BOX}$, the ratio of a negative to a positive dimension, is negative. The sine of this angle is the ratio of two positive dimensions and is therefore positive. The rule is then that *for angles in the second quadrant the sine is positive and the cosine negative.*

Proceeding in the same way for the third quadrant containing angles between 180° and 270° we have the functions :—

$$\sin \underline{|COX} = \frac{CH}{CO}$$

and $\cos \underline{|COX} = \dfrac{HO}{CO}$

Since CH and HO are negative while CO is positive, *sines and cosines of angles in the third quadrant are each negative.*

Finally, in the fourth quadrant containing angles between 270° and 360°, we have :—

$$\sin \underline{|DOX} = \frac{DK}{DO}$$

and $\cos \underline{|DOX} = \dfrac{KO}{DO}$

DK is negative while KO and DO are positive, so that *for angles in the fourth quadrant the sine is negative and the cosine positive.*

It is most important when adding or multiplying together the functions of angles to adhere rigidly to the algebraic signs of the angles. That is, when it is necessary to subtract a negative quantity from a positive quantity, the result is the arithmetical sum of the two numbers. If subtracting a positive quantity from a negative quantity, the result is the arithmetical sum, but with a negative sign. The sum of two negative quantities is still negative. For multiplication or division, the rule is that like signs produce a positive and unlike produce a negative result.

The functions of angles less than 90° are published in the form of tables, and by applying a suitable algebraic sign the function of any angle can be obtained. The following examples illustrate the method :—

$\sin 60° = 0{\cdot}866$

$\sin 120° = \sin (180–120) = \sin 60° = 0{\cdot}866$

World Radio History

$\sin 240^\circ = -\sin(360-240) = -\sin 120^\circ = -0{\cdot}866$

$\sin 300^\circ = -\sin(360-300) = -\sin\ 60^\circ = -0{\cdot}866$

and similarly :—

$\cos\ 60^\circ = 0{\cdot}500$

$\cos 120^\circ = -\cos(180-120) = -\cos\ 60^\circ = -0{\cdot}500$

$\cos 240^\circ = \cos\ (360-240) = \cos\ 120^\circ = -0{\cdot}500$

$\cos 300^\circ = \cos\ (360-300) = \cos\ 60^\circ = 0{\cdot}500$

The reader has probably realised that the discussion so far has been of angles in two dimensions only, and that for the calculation of Great Circle distances and directions a three-dimensional system is necessary, involving spherical trigonometry.

Before proceeding further it would be as well to recall the unit of measurement of an angle which is used as an alternative to the degree. The " radian," as it is called, is the ratio of the perimeter of a segment of the circle which subtends the angle formed by two radii of the circle to the radius of the circle.

As an example, consider Fig. 3, where the angle ø at the centre of the circle is subtended by the arc of the circle, AB. The size of this angle in radians is the length of the curved distance AB divided by the radius AO or BO. It is generally known that the perimeter of a circle is :—

$$2\pi \times \text{radius}$$

and that the angle made by one complete revolution of a radius is 360°. The size in radians of this angle of 360° is therefore :—

$$\frac{2\pi \times \text{radius}}{\text{radius}}$$

$$= 2\pi \text{ radians,}$$

and half this, or 180°, is π radians. The angle of one radian is therefore :—

$$57{\cdot}2958^\circ = 57^\circ\ 17'\ 45''.$$

From this it is evident that a distance along the circumference of a circle or the surface of a sphere can be expressed as the angle subtended by that distance at the centre of the circle or sphere. The distance itself is readily obtainable by multiplying the angle (in radians) by the radius of the circle (in inches, feet or miles as the case may be).

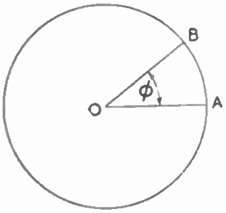


Fig. 3.

" Circular measure " of angles. When the distance AB along the circle is equal to the radius, the angle φ is called one radian ; other angles are measured in terms of this unit.

Computing Great Circle Distances

In this way the distance between two points on the surface of the earth is calculated as the angle subtended by these two points at the centre of the earth, and the distance in miles is obtained by multiplying the angle by the radius of the earth. Thus two points subtending an angle of 57° 17′ 45″, or one radian, are 3,957 miles apart, by the Great Circle route, this distance being the mean radius of the earth. If a number of these calculations are being made it is perhaps simpler to use the distance of 69·063 miles per degree instead of 3,957 miles per radian.

Imagine the earth to be represented by the circle in Fig. 4, with two points A and B upon its surface. Draw the three Great Circle routes BC, AC and AB, the two former passing through the N and S poles, and one of the two points respectively, and the third through the two points alone. By joining the three points A, B and C, to the centre of the earth a solid figure is obtained, a spherical triangle which is generally oblique. If the two points A and B both lie upon the equator, it is a right spherical triangle. It has four surfaces, three flat ones where the planes of the Great Circle routes cut through the globe, and a curved one, triangular in shape, on the surface of the earth.

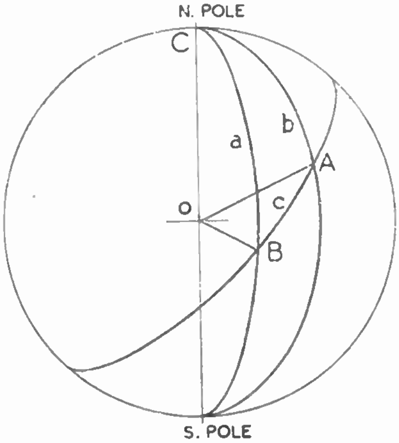


Fig. 4.

The Spherical Triangle ABC is enclosed by three Great Circles, two passing through the poles. To find the Great Circle direction and distance from B to A it is necessary to solve this triangle.

Let us represent the three angles formed by the cutting of the three Great Circle routes on the earth's surface by the letters *A*, *B* and *C*, respectively, and the distances between the two points opposite these angles by *a*, *b* and *c*, respectively. Then, according to the explanation given above, the angles subtended by these distances at the centre of the earth can also be represented by the letters *a*, *b* and *c*, respectively.

Now, suppose *B* is the home station, and *A* is the station whose distance and direction it is required to find. Then distance required is *c* and

World Radio History

the angle away from north is *B*. The equations from which these dimensions can be calculated are :—

$$\cos c = \cos a \cos b + \sin a \sin b \cos C \qquad (1)$$

$$\text{and } \sin B = \frac{\sin C \sin b}{\sin c} \qquad (2)$$

By a study of Fig. 4 it will be seen that :—

a is 90° minus the latitude of the home station (latitudes start from the equator, and the angle used is that from the N. pole).

b is 90° minus the latitude of the required station.

C is the difference in longitude between the two stations.

If either of the stations is south of the equator the angle *a* or *b* is, of course, 90° *plus* the latitude of the station. Similarly, if one station is east of Greenwich and the other is west, the difference in longitude is the *sum* of the two longitudes.

As is readily seen, it is necessary to work out equation (1) first, since the result, *c*, is used in equation (2). Cos *c* is obtained from equation (1) and by reference to tables the angle *c* is evaluated. A companion table will give the value of sin *c* as required in equation (2).

A Practical Case

Suppose it is required to find the Great Circle distance between Pointe-à-Pierre, Trinidad, and Tunbridge Wells, England. The geographical positions of these two stations are :—

Pointe-à-Pierre	10° 19′ N.;	61° 28′ W.
Tunbridge Wells	51° 8′ N.;	0° 16′ E.,

and the data to work upon are :—

$$a = 90^\circ - 10^\circ\,19' = 79^\circ\,41'$$
$$b = 90^\circ - 51^\circ\,8' = 38^\circ\,52'$$
$$C = 61^\circ\,28' + 0^\circ\,16' = 61^\circ\,44'$$

Then from equation (1) :—

$$\begin{aligned}\cos c &= \cos 79^\circ\,41' \cos 38^\circ\,52' + \sin 79^\circ\,41' \sin 38^\circ\,52' \times \cos 61^\circ\,44' \\ &= 0{\cdot}17909 \times 0{\cdot}77861 + 0{\cdot}98383 \times 0{\cdot}62751 \times 0{\cdot}47358 \\ &= 0{\cdot}43181 \\ \text{and } \quad c &= 64^\circ\,25' \\ &= 1{\cdot}1243 \text{ radians.}\end{aligned}$$

The distance between the two stations is therefore :—

$$1{\cdot}1243 \times 3957 = 4{,}447 \text{ miles.}$$

From equation (2) :—

$$\begin{aligned}\sin B &= \frac{\sin 61^\circ\,44' \sin 38^\circ\,52'}{\sin 64^\circ\,25'} \\ &= \frac{0{\cdot}88075 \times 0{\cdot}62751}{0{\cdot}90196} \\ &= 0{\cdot}61275 \\ \text{and } B &= 37^\circ\,47' \text{ E. of N.}\end{aligned}$$

Supposing on the other hand it is required to find the direction of Pointe-à-Pierre from Tunbridge Wells, the values of *a* and *b* are reversed, *i.e.* :—

$$a = 38^\circ\,52'$$
$$\text{and } b = 79^\circ\,41'$$

This gives from equation (2) :—

$$\begin{aligned}\sin B &= \frac{\sin 61^\circ\,44' \sin 79^\circ\,41'}{\sin 64^\circ\,25'} \\ &= \frac{0{\cdot}88075 \times 0{\cdot}98383}{0{\cdot}90196} \\ &= 0{\cdot}96069 \\ \text{and } B &= 73^\circ\,59'\end{aligned}$$

A glance at an atlas will show that the angle of Trinidad away from north at Tunbridge Wells can be considered as being in the second quadrant, when :—

$$\sin B = \sin(180^\circ - B)$$

and the angle required is :—

$$(180^\circ - 73^\circ\,59') = 106^\circ\,1' \text{ W. of N.}$$

For short distances three figure calculations are usually sufficiently accurate, but for places on opposite sides of the globe four figure tables should be used, or even five figure tables for stations near the antipodes.

As an example of the comparatively small error introduced by the use of the three-figure tables of functions for stations moderately far apart, let us recalculate the Great Circle distance and direction of Tunbridge Wells from Pointe-à-Pierre using three figure tables.

Starting with approximated data we have :—

$$a = 79^\circ\,40'$$
$$b = 39^\circ$$
$$C = 61^\circ\,40'$$

when by equation (1)

$$\begin{aligned}\cos c &= \cos 79^\circ\,40' \cos 39^\circ + \sin 79^\circ\,40' \sin 39^\circ \cos 61^\circ\,40' \\ &= 0{\cdot}179 \times 0{\cdot}777 + 0{\cdot}984 \times 0{\cdot}629 \times 0{\cdot}475 \\ &= 0{\cdot}433 \\ \text{and } c &= 64^\circ\,20' \\ &= 1{\cdot}123 \text{ radians.}\end{aligned}$$

The approximate distance between the two stations is therefore 4,440 miles.

For the direction of Tunbridge Wells from Pointe-à-Pierre we have by equation (2) :—

$$\begin{aligned}\sin B &= \frac{\sin 61^\circ\,40' \sin 39^\circ}{\sin 64^\circ\,20'} \\ &= \frac{0{\cdot}880 \times 0{\cdot}629}{0{\cdot}901} \\ &= 0{\cdot}614 \\ \text{and } B &= 38^\circ \text{ E. of N.}\end{aligned}$$

For the most part, the errors introduced by the use of an abbreviated table of functions are not sufficiently large to be of any consequence to radio amateurs. As pointed out before, however, this error rapidly increases with the nearness of the "wanted" station to the antipodes.

World Radio History

Practical Map Construction

For the amateur who wishes to construct a Great Circle map of the world on this system, the following outlines of a suitable method should be of use.

Instead of calculating the data for specific towns or countries, the entire graticule of the lines of latitude and longitude should first be constructed. Having selected the point on which the map is to be centred (usually, of course, the operator's own station) the geographical position of that point is carefully ascertained. A simple method of doing this is by the use of a fairly large-scale Ordnance Survey Map, when the latitude and longitude of the station can be determined with probably greater accuracy than is required. For the plotting of the graticule the co-ordinates should be calculated for the points at the cutting of the " tens " of longitude with the " tens " of latitude, *i.e.*, 10°, 20°, 30°, etc., E. or W. with 10°, 20°, 30°, etc., N. or S. A simplification could be made by the use of the lines 20° apart instead of 10°, but the choice lies with the reader and can be arranged to suit the size or style of map he requires. Using the 10° spacing, some 800 or 900 points would be calculated, and it will in addition probably be found advisable to use 5°, 2° or even 1° spacing near the antipodes, because the distance at the outer edge of the map between the 10° points will be so large as to render the drawing of a smooth curve very difficult. The calculation of these co-ordinates and the drawing of the lines will call for some 80 or 90 hours' solid work.

For the choice of a scale on which to base the map, 1,000 miles to the inch will give a map approximately two feet in diameter, which is a useful size for most purposes. Outside the edge of the map a second circle can be drawn, inside which are graduated the degrees of arc from the N-S Great Circle through the centre of the map (which line is, of course, the diameter of the map in a vertical direction). These arrangements, however, are best left to the taste of the constructor who can embellish the map as he wishes.

For the plotting of the points, the degrees of arc should be the initial step. A good stout drawing-paper should be used—preferably holland-backed if it can be obtained—and mounted on a drawing board or large piece of plywood or other similar material. A pair of beam compasses should be borrowed from a draughtsman or made up from Meccano or other material which may be handy, and the large circles drawn. The degrees can be marked off by the use of a protractor. The next step is to construct a scale about 13″ long with a drawing pin at one end on which the scale will pivot about the centre of the map. The scale should be of stout material—again preferably the holland-backed paper—and it should be graduated from 0° to 180° starting at the drawing pin and finishing at a distance from the pin equal to the radius of the map. By the use of this scale, the values of the angle *c* can be plotted direct on the map without the conversion to radians and miles. Care should be taken to ensure that the edge of the scale forms a radius of the circle. The edge will have to stop ¼″ or so short of the centre of the map to allow for the drawing pin, but it should be so constructed that the edge if produced would cut the centre of the drawing pin exactly. The outer edge of the scale can then be placed at the appropriate angular-scale reading according to the value of B and the position of the point marked from the 0°–180° scale according to the value of *c*. It is advisable to plot the whole of one meridian of longitude and to connect up the points before commencing another, as the apparently strange position of some of the points may otherwise cause some confusion.

Having constructed the graticule, the interesting part of the work is reached in the insertion of the various continents and any towns or other data required. An ordinary school atlas will supply the necessary information and the outlines of the continents can be followed from meridian to meridian or parallel to parallel as they may run. As an additional check, the positions of towns lying on the coast or elsewhere can be calculated individually, especially those in the antipodes.

Continents and countries can be marked with their international prefixes, or these can be inserted as they are heard or worked. An interesting variation would be the insertion of the signal strength reports as received, which would show at once the lines of optimum radiation. The angle along which the transmitting aerial lies can be marked together with the angles of maximum radiation for the frequencies used according to the standard radiation patterns (see Chapter 12). Other uses to which the map can be put will occur to the amateur as he progresses with the construction or use of his Great Circle Map. The reader is also referred to Fig. 3 of Chapter 18, where an example is given of a Great Circle Map centred on London.

World Radio History

Chapter Fourteen

FREQUENCY MEASUREMENT

Standard Frequency Transmissions—Types of Frequency Measuring Equipment—Absorption Meters—Sub-standards—100 kc Bars and Dual Crystals—Multi-vibrators—Buffer Amplifiers—Heterodyne Meters—Electron Coupled and Franklin Oscillators—Components and Valves—Calibration.

THE radio amateur is, perforce, interested to a very definite degree in the matter of frequency measurement, since the conditions of any transmitting licence require that the frequency of transmission be known to within 0·1 per cent. This is no small degree of accuracy, as will be realised when it is considered that such an accuracy in a 0–50 milliammeter would imply reading the dial to better than the nearest twentieth part of a milliampere.

U.S.A. Bureau of Standards Transmissions

In this field, however, the amateur is fortunate in that the Government of the United States of America place their national standard of radio frequency permanently at the disposal of all who care to tune in the Bureau of Standards transmitter. According to the Department of Commerce Letter Circular (LC–565) published on August 30th, 1939, this station is always on the air, day and night, with a power of at least 1 kW in the aerial on a frequency of 5, 10 or 20 Mc. The details of these transmissions are as follows :—

(*a*) A continuous emission on 5 Mc, with an aerial power of 1 kW, continuously modulated 100 per cent. by a standard audio pitch of 440 c.p.s. The modulation is interrupted every 5 minutes for an announcement of the station call (WWV) by telephony and telegraphy. This transmission only closes down when the high-powered 5 Mc transmissions as detailed in (*b*) are being radiated.

(*b*) Additional standard frequency transmissions take place every Tuesday, Wednesday and Friday (except American national holidays) with a power of 20 kW. The frequency of these transmissions is according to the following schedule :—

5 Mc ..	.. 15.00 to 16.30 G.M.T.
10 Mc ..	.. 17.00 to 18.30 G.M.T.
20 Mc ..	.. 19.00 to 20.30 G.M.T.

The Tuesday and Friday transmissions are unmodulated c.w. except for short pulses of 1,000 c.p.s. tone, marking one-second intervals. Each pulse consists of five cycles of the modulation frequency, and the modulation depth is 50 per cent. The time intervals are accurate to better than 0·00001 second.

The Wednesday transmissions are modulated 50 per cent. with the standard audio frequency of 1,000 c.p.s. Both carrier and audio frequencies are accurate to better than one part in 10 million.

Readers are warned, however, that due to the war these standard frequency transmissions may be modified or cancelled without notice. Details of present arrangements may be obtained by addressing an enquiry to the United States Bureau of Standards, Washington, D.C.

The Uses of Frequency Measuring Equipment

Before proceeding to describe the various types of frequency measuring devices available to the amateur, it will be desirable to examine the uses to which they may be put. Assuming the user possesses a transmitter, then, first and foremost, must come the duty of ensuring that it is actually working in the frequency band intended and not radiating power in any other part of the spectrum. This latter point is of special importance when regenerative frequency-multipliers and special oscillator-multiplier circuits are used in the transmitter. A frequency measuring device can also perform useful work in determining the frequency of any distant station so that other operators can be informed of its position in the band with some precision, thereby enabling them to establish contacts which might otherwise be missed.

Further, where any appreciable amount of experimental or constructional work is undertaken, the necessity for a reliable, rapid and fairly accurate means of frequency measurement is not long in making itself felt.

Types of Frequency-Measuring Equipment

All frequency-measuring gear consists essentially of devices designed to compare the frequency of an unknown source with one or more known frequencies. This is well illustrated if consideration is given to the principle upon which one of the most satisfactory commercial systems is operated.

Assume that an oscillator is producing a frequency of 100 kc and that an harmonic generator is producing a long series of harmonics of this frequency. If the spectrum is then tuned by means of an oscillating autodyne detector, to which the harmonic generator is coupled, a series of chirps spaced

World Radio History

100 kc apart over the whole range of the detector tuning dial will be heard. For the sake of simplicity, assume that the approximate tuning range of the detector is 90–500 kc. Then, with the 100 kc oscillator running and the harmonic generator switched off, there will be only one chirp (at 100 kc) upon tuning over the whole range. The point at which the chirp occurs can be logged on the detector tuning dial. If now the harmonic generator is switched on and the receiver tuned from the l.f. end of the scale towards its high-frequency end, the fundamental frequency of the oscillator will be found to give a chirp as the condenser passes through the previously recorded setting. Further up the scale a second chirp will be heard which is the second harmonic of the 100 kc oscillator, on 200 kc. Additional harmonics 100 kc apart will be heard as the condenser is rotated towards its minimum capacity. If now an oscillator of unknown frequency is used, providing it is within the tuning range, a chirp will be produced probably between two adjacent 100 kc points. When the 100 kc harmonics which lie on either side of the unknown have been recognised, an idea of the frequency of the unknown oscillator can be obtained at once. If a graph is prepared of the dial readings of the detector for each 100 kc point and the dial reading of the unknown oscillator is then applied to this graph, the frequency of the unknown oscillator can be found accurately within the limits of the accuracy of dial and chart. This, of course, assumes that the 100 kc oscillator is on exactly 100 kc, a point which can be checked by tuning in to one of the WWV transmissions and switching on the oscillator and harmonic generator. A little thought will show that the fiftieth harmonic of the 100 kc oscillator should fall on 5,000 kc and will, if its frequency be exact, produce zero beat with the WWV 5,000 kc transmission.

The determination of zero beat between two continuous, unmodulated carriers can be performed by ear to within about 50 cycles, and even more accurately if one of the carriers is modulated with a steady tone. When the two carriers approach within about a hundred cycles of each other, the modulation tone assumes a tremolo character, throbbing at a rate that diminishes as they approach closer, until at exact zero beat the fluctuations become so slow that they are no longer recognisable. This phenomena gives so accurate a comparison that the error is absolutely negligible when compared with the other errors. In fact, unless the most extreme precautions are taken to stabilise the 100 kc oscillator, it will be found impossible to maintain any condition approaching zero-beat for more than a few seconds. For amateur purposes it may be possible to assume that exact adjustment to 100 kc can be obtained by this means, for, even without the modulation effect, an accuracy of comparison of better than one part in a hundred thousand is attained. In any case, few amateur-built 100 kc oscillators will maintain their frequency to anything like this accuracy, so that more precise comparison is unnecessary.

The system outlined for the measurement of the unknown frequency is termed the "Interpolation Method," and is used, with certain refinements, at the National Physical Laboratory.

The autodyne detector referred to above becomes, when calibrated, the simplest form of heterodyne frequency meter. This type of meter (which will be discussed in detail later) is a very important piece of equipment, for it is capable of an accuracy of at least 0·05 per cent., besides being simple to use.

Absorption Meters

A circuit consisting of a coil and condenser connected in parallel has the property of resonance at one particular frequency, at which frequency it will draw power from any other circuit to which it is coupled in order to build up a large circulating current in its own circuit. If either the coil inductance or the condenser capacity be made variable, the resonant frequency can be varied. Resonant frequency is given by the formula

$$f = \frac{1}{6{\cdot}28\sqrt{LC}} \times 10^6$$

where f = Frequency in kc
L = Inductance in μH
C = Capacity in μμF.

If the inductance of a coil and the capacity corresponding to each reading of a variable condenser are known it is possible to calculate from the formula, the resonant frequency for each setting.

If such a circuit be calibrated, it is termed an absorption wavemeter or frequency meter, but such a device can only be used to determine the frequency of oscillating circuits, since it relies upon drawing power from an "unknown" circuit to give an indication of resonance. This indication may be obtained in various ways; for example, a current meter in the supply leads to the oscillator under test will show a sudden flicker as the absorption wavemeter passes through resonance with the oscillator to which it is coupled. Alternatively, the heavy circulating current in the absorption circuit at resonance may be used to light a small pilot bulb, or again the voltage built up across the coil and condenser by this voltage may be used to light a neon bulb. Examples of absorption circuits are given in Fig. 1.

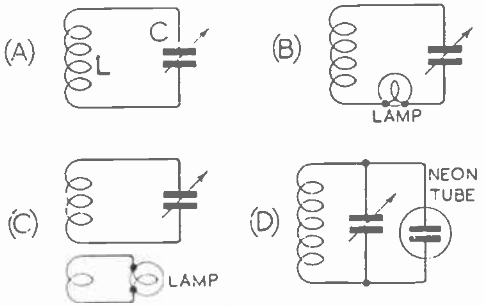


Fig. 1.

Theoretical circuits of absorption wavemeters, showing methods of indicating resonance.

(A) Basic circuit, resonance being indicated by effect upon the oscillator being measured.

(B) Pilot lamp bulb in series with tuned circuit glows brightest at resonance.

(C) An alternative connection for the bulb giving better matching and less damping of circuit.

(D) Neon tube across tuned circuit glows at resonance providing oscillator has enough power. If power is insufficient to ignite neon, circuit behaves as A.

Frequency Sub-standards

When a stable oscillator is adjusted to synchronism with a standard frequency source, as described in an earlier paragraph, and is then kept for reference when the original source is not available, it is termed a " frequency sub-standard " or " secondary standard of frequency." Such sub-standards may be of any frequency, but, as a matter of convenience, they are usually designed for 100 kc, or sometimes 50 kc. Occasionally, especially for u.h.f. work, 1,000 kc sub-standards are used.

Since quartz crystals may readily be cut for frequencies of 50, 100 and 1,000 kc, and because they are inherently more stable than inductance-capacity combinations, a large majority of frequency sub-standards consist of carefully designed and constructed crystal oscillators with or without buffer amplifier stages, the latter to prevent changes in external couplings affecting the frequency.

Many factors conspire together to reduce the stability of a quartz oscillator, and whilst some can be readily combated others tax every resource known to the expert. The more important factors are : the quality of quartz, the skill of the manufacturer, the quality of the crystal holder, changes in temperature, humidity and barometric pressure, alterations in applied voltages, tuning of associated circuits, vibration and ageing of components.

This list appears extremely formidable (and in the search for real precision is actually the case), but in so far as the amateur is concerned, he may assume that the crystal maker has taken care of the correct choice of quartz and holder design, whilst temperature, humidity and barometric pressure effects only become important when accuracies better than 0·002 per cent. are required.

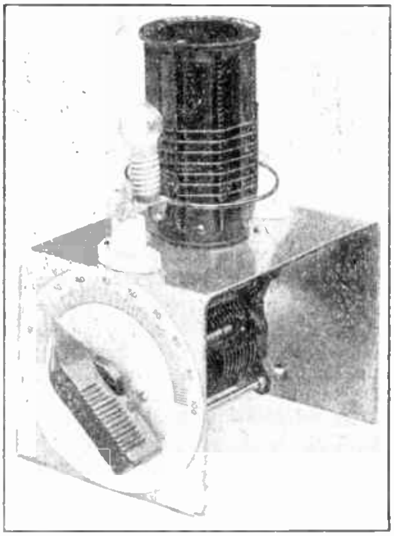


Fig. 2.

Photograph of simple absorption wavemeter. Indication of resonance is given by a loop-coupled flash-lamp bulb as in Fig. 1 (C).

An important factor, however, even at relatively low accuracies, is the matter of plate tuning in conventional oscillator circuits. Arrangements should therefore be made to clamp this adjustment at the correct value so that it will not readily slip when once set. Special circuits have been evolved to minimise the effects of tuning and changes in components other than the crystal and its holder.

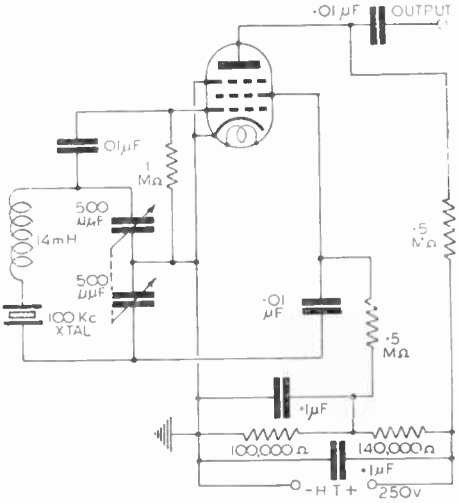


Fig. 3.

Circuit of an exceptionally stable 100 kc oscillator suitable for use as a frequency sub-standard.

Design of Sub-standard

One of the most reliable of these circuits was developed some years ago by the *General Radio Company* of America, and is shown in Fig. 3. From this it will be seen that a pentode electron-coupled Colpitts oscillator is used with the crystal connected in series with the tank coil. The advantage of this arrangement is that all the factors tending to change the frequency of oscillation from the series resonant frequency of the crystal are absorbed in the self-controlled circuit, and if this is adjusted to oscillate at 100 kc (with the crystal shorted out of circuit) all reactances, except those of the crystal, will be cancelled and will not, therefore, affect the frequency if they vary slightly. Since the crystal has to carry the whole circulating current of the tank circuit without fracturing or heating up, the power applied to an oscillator of this type must necessarily be small, and in actual practice the output is only about 2 volts R.M.S. It has, however, a very " peaky " wave form which is rich in harmonics. This circuit is so much more satisfactory than the older designs previously described that no apology is offered for omitting them from the present edition.

If the frequency of the oscillator under discussion is not exactly 100 kc, small changes, amounting to perhaps 6 or 8 cycles, may be effected by adjustment of the tank condenser, although it is preferable to effect adjustments

World Radio History

which exceed 2 cycles by varying the gap in the crystal holder. This can be done by the makers for a very small charge if the completed set is sent to them. It must be remembered that any considerable departures from the zero-reactance condition of the tank circuit will be accompanied by some loss of stability and should be avoided where possible.

Quartz Bars

The temperature co-efficient of X-cut bars commonly used for amateur sub-standards depends upon the ratio of width to length, and is usually in the region of 4–6 cycles/Mc./deg. C. This figure is not excessive and will make a difference of only about 1 kilocycle in the 14 Mc band for normal room-temperature variations, but if this variation appears to be too great for the purpose required a solution may be found in the use of a thermostatic chamber or a special zero-temperature co-efficient quartz plate.

There are two cuts available for 100 kc crystals. These are derived from AT- and BT-cut high-frequency plates, and are designated CT- and DT-cut respectively. Both types are very satisfactory, as they save much trouble in the design of thermostats, but they are naturally more expensive than simple X-cut bars.

Dual Crystals

Special dual crystals have recently become available in this country. These are cut to oscillate longitudinally at 100 kc, and transversely at 1,000 kc, and have a higher temperature co-efficient than the straightforward 100 kc crystals. Such crystals should, however, be reserved for special purposes where the undeniable convenience of a two-frequency oscillator outweighs the loss of accuracy, as, for example, where u.h.f. measurements are much used. In this case the 1,000 kc harmonics from dual crystals will be stronger and more easily identified than those of the 100 kc fundamental oscillation. A suitable circuit using these crystals is shown in Fig. 4.

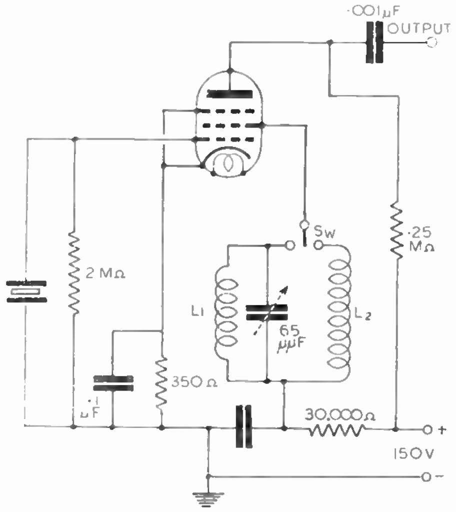


Fig. 4.

Circuit for use with dual frequency calibrating crystals. L_1 is tuned by a 65 $\mu\mu$F trimmer to approximately 1,000 kc whilst L_2 is self-resonant at a frequency which enables the crystal to oscillate at 100 kc with this coil switched into circuit. L_1 and L_2 are plug-in type coils of about 500 and 10,000 μH respectively. Any small pentode is suitable.

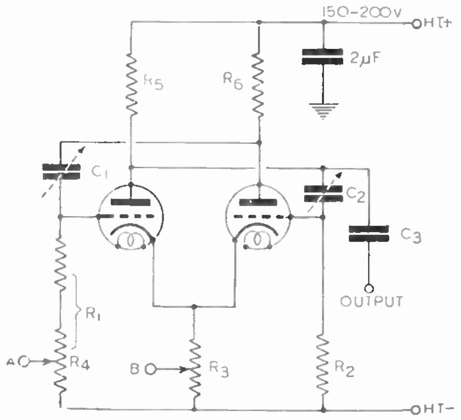


Fig. 5.

Circuit of Multi-vibrator. For 10 kc suitable values are :—R_1 10,000 ohms total, with the locking potentiometer 5,000 ohms if used. R_2 10,000 ohms. R_3 800 ohms. R_5 150,000 ohms. R_6 20,000 ohms. C_1 and C_2 each ·0006 to ·0015 μF variable compression type. With locking voltage applied to A, the vibrator will work equally well on odd or even harmonics. If R_5 and R_6 are both made 30,000 ohms and the locking voltage applied to B, the circuit shows a strong preference for even harmonics.

Buffer Amplifiers

For sub-standards intended for fairly accurate work it may be worth while to use a voltage-stabilised power-pack and a buffer amplifier to separate the crystal stage from any influences introduced *via* the coupling circuit. Such amplifiers may well be untuned, as they will then accentuate the harmonics so that, even in the 28 and 56 Mc bands, they are quite strong. If it is desired to accentuate any particular range, the output circuit of the buffer may be tuned to this range with good effect.

Frequency Sub-standard Construction

In the construction of frequency sub-standards only the best and most reliable components should be used, and these should be mounted on a chassis of thick metal or metal-covered wood. Connections should be carried out with not less than 16 s.w.g., and all wires should be kept short and rigidly supported. No components should be supported in the wiring if it is at all possible to mount them more rigidly by other means. All wires and components carrying R.F. potential should be especially well fixed and preferably kept away from earthed objects.

The whole oscillator should be well screened, and a buffer stage, if used, built into a separate compartment. All circuits should be thoroughly de-coupled where they leave the compartment.

World Radio History

When the apparatus is completed, it is desirable to place it high up on a small shelf so that nothing can be placed on top of it. Finally, it should not be unnecessarily disturbed.

The Multi-vibrator

A two-stage resistance-capacity coupled amplifier with its output circuit connected back to its input, such as is shown in Fig. 5, will oscillate with an irregularly square wave form at a frequency which is principally determined by the values of the grid condensers and resistors. The frequency is very unstable, but it can be readily stabilised by the injection of a small alternating voltage from an external source. The action of such an injected voltage upon one grid is to reverse the phase of that grid voltage slightly before it would otherwise have been reversed spontaneously. If the natural frequency of the multi-vibrator circuit is slightly lower than that of the injected voltage, it will lock in step very readily and the constants may be varied appreciably without affecting the frequency. The output is extremely rich in harmonics, which are detectable even up to the order of several hundreds. The circuit is thus an admirable harmonic generator, yet this is not its greatest virtue, for it can be controlled as well by an injected voltage two, three, four or even forty times the approximate frequency of the multi-vibrator. It can thus be used to generate sub-harmonics or to frequency-divide. Such an arrangement is widely used with crystal standards of frequency in order to obtain lower frequencies and chains of harmonics of these lower frequencies. For example, a multi-vibrator operating on 10 kc can be readily locked by a few volts of crystal-controlled A.C. of 100 kc frequency, and the harmonics of the multivibrator stage will produce carrier frequencies spaced throughout the radio-frequency spectrum at 10 kc intervals with a precision equal to that of the locking source.

If the grid condensers or resistors are varied over fairly wide limits, with no locking voltage, a very rough rasping sound will be heard in nearby receivers with peaks of intensity spaced at intervals corresponding to the fundamental frequency of the circuit. This fundamental frequency will be found to change gradually as the circuit constants are changed. If, however, a locking voltage is introduced and the process repeated, it will be found that in place of the diffuse rasping sound there is a series of pure c.w. whistles spaced evenly at either the frequency of the locking source or of a harmonic or sub-harmonic of that frequency. These whistles will remain steady and fixed over an appreciable range of adjustment of the condensers or resistors until a point is reached where they suddenly switch over and lock with equal rigidity upon another harmonic. The method of injection can be modified to give preferential treatment to either odd or even harmonics, but this is outside our present scope. The interested reader is, however, referred to the bibliography at the end of this Chapter.

If the uncontrolled multi-vibrator is set to operate at some simple sub-harmonic of the locking voltage (say the tenth) and the locking voltage gradually increased, a point is recognised at which the rasping uncontrolled note changes abruptly to the clear controlled tone.

If the locking voltage is increased very much past this point, it may be found that the frequency of the vibrator will suddenly change and lock upon a lower harmonic (say the ninth), and that further increases in locking voltage will drag the multi-vibrator frequency to harmonics nearer and nearer the fundamental of the locking frequency, until a point is reached at which the circuit is forced to oscillate actually at the fundamental frequency, even though its uncontrolled frequency may be only one-tenth of this frequency.

In practice, therefore, it is desirable to have some means of adjusting the locking voltage to slightly more than the minimum which will just hold the vibrator on its correct harmonic. Further, to prevent extraneous influences occurring to turn the balance from the right to a wrong harmonic it is desirable to incorporate input and output buffer amplifiers for each multi-vibrator stage. The reader should not be unduly concerned by this suggestion, for the cost is not great and no trouble will be encountered in getting both buffer amplifiers to behave properly.

Multi-vibrator Construction

The actual construction of multi-vibrators is not difficult, for no special precautions are necessary other than the use of good reliable condensers. Wire-wound resistors are desirable, but good metallised types serve quite well. In arranging the layout it is a good practice to copy the theoretical diagram as closely as possible and to avoid undue capacity from anode to earth which would tend to by-pass some of the higher frequencies. To the same end it is as well to employ relatively high grid capacities and low resistances. The latter should be not more than 100,000 ohms. The condensers can be of the mica-compression type, as used for series tracking in broadcast superhets with fixed mica condensers in parallel to make up the correct capacity, if required. The correct capacities can be calculated from the formula.

$$F = \frac{1000}{R_1C_1 + R_2C_2}$$

where F = Frequency in kc
C_1 and C_2 = Capacity in μF
R_1 and R_2 = Resistance in ohms.

For the locking amplifier of a multi-vibrator it is not essential to use anode chokes as well as resistors, since in this stage the fundamental frequency is more important than the harmonic frequencies. In the output amplifier, however, where harmonics are to be specially amplified, there is a definite advantage to be gained from the use of chokes.

In the adjustment of the circuit to the correct uncontrolled frequency, either the condensers or the resistors can be varied, but perhaps the chief deciding influence is the relative cost of compression condensers compared with good variable resistors. The actual adjustment resolves itself into a matter of persuading the vibrator to lock on the correct harmonic with the minimum locking voltage.

After the vibrator has been switched on, and just enough locking voltage introduced to produce a crystal note, the variable elements should be adjusted so that there are the correct number of multi-vibrator harmonics between each pair of

World Radio History

adjacent 100 kc harmonics. This accomplished, the locking voltage should be reduced to the point where the vibrator just slips out of lock. Further slight adjustments should then be made so that the spacing between the uncontrolled peaks of noise are slightly greater than the spacing between the controlled harmonics. The locking voltage is then increased again to slightly beyond the point at which it assumes control. Maximum stability is thus obtained.

Buffer Amplifiers and Harmonic Amplifiers

Little need be added to what has already been said upon this subject save to reiterate that, where their purpose is isolating rather than amplifying, they should have their input and output circuits well shielded from each other and special attention paid to decoupling the power leads.

Where harmonics are to be accentuated, abundant drive should be allowed for, with plenty of grid bias, whilst the anode resistance should not be too high. In order to increase the load impedance to the higher frequencies, R.F. chokes may be used. If very strong harmonics are required in a limited part of the spectrum, a simple tuned-anode circuit, either series or parallel fed, will give excellent results. In this case the input circuit should never be tuned.

The final output amplifier may well be a multi-element valve, designed as a super-heterodyne mixer. If such a valve is used the output of a multi-vibrator can be introduced into the control grid and the 100 kc harmonic drive applied to the oscillator grid. In this way the valve can be made to serve both as a buffer output amplifier for the multi-vibrator and also as a means of varying the relative strengths of 100 and 10 kc points in order to render identification more easy. In this case excellent results are obtained by tuning the output circuit to the band required. A suitable circuit is given in Fig. 6.

Heterodyne Frequency Meters

The essential requirements of a heterodyne frequency meter are: (1) It must consist of a variable frequency oscillator, capable of covering the whole range of frequencies to be measured, either with its fundamental or harmonic oscillations. (2) It must be consistently stable over considerable periods of time. (3) Its frequency must not be liable to sudden and unpredictable changes. (4) It must be fitted with a dial capable of being read accurately to within very fine limits.

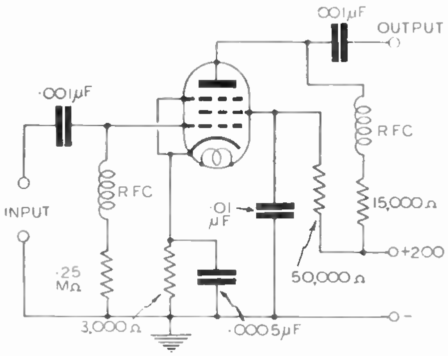


Fig. 6.

An untuned buffer amplifier and harmonic amplifier. The arrangement is used as a buffer for frequency sub-standards and as input and output amplifiers for multi-vibrators.

All that has been said previously about rigidity of components, chassis and wiring applies with even greater force to the design of a heterodyne frequency meter. *It is not an instrument to be knocked up out of odd parts lying about the shack.*

The heart of the meter will be a good coil and condenser, which latter must be fitted with a good dial, whilst a good valve amplifier must be provided to maintain oscillation without introducing variable errors to spoil the "goodness" of the tuned circuit. A self-controlled oscillator is far more susceptible to the effects of temperature, humidity, vibration etc., than is a crystal oscillator, and these effects become serious if greater accuracy is needed. Additionally, age, vibration and changing electrode potentials upon the valve exert a more deleterious effect than they do upon a crystal circuit.

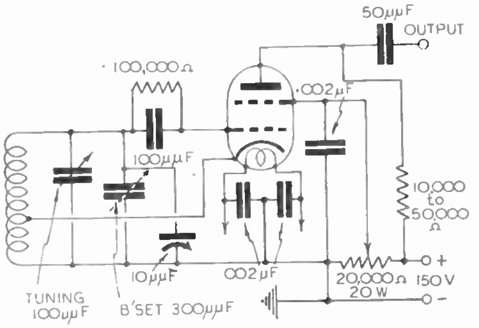


Fig. 7.

Circuit of electron-coupled oscillator (using an indirectly heated valve) suitable as a frequency meter. If a battery valve is used, the only change required is the use of a coil with the part between the cathode tap and earth wound with double wire. The extra wire is connected to the other side of the filament and its earthy end by-passed with a 0·01 μF mica condenser to earth.

The effects of vibration must be combated by mounting the instrument upon springs or sponge rubber and by the most scrupulous attention to rigidity. The circuit itself should be well shielded and the tuned circuit wired into a compartment separated from the valve and other heat-evolving components. The latter should be enclosed in a well-ventilated compartment.

Changing electrode potentials affect frequency in two ways: first, they alter the internal impedances of the valve; and second, they alter the internal heating and thus the inter-electrode capacities. The changes in potential which cause these difficulties can be minimised to a great degree by using a stabilised power supply, whilst the reactance changes caused by these effects can be swamped by using large series or small parallel impedances. Alternatively the valve circuit and its electrode potentials may be so arranged as largely to cancel out changes of frequency caused by variations of the main high-tension supply. All three methods are used, although the third is the most popular among amateurs.

The Electron Coupled Oscillator Circuit

This form of circuit, shown in Fig. 7, uses a screen-grid valve as a Hartley or Colpitts oscillator with the screen-grid acting as the anode of the oscillator. It is a property of the Hartley and Colpitts circuits that they will operate equally well with either the plate, grid or cathode earthed and with the other two electrodes supplied with suitable R.F. potentials. In the e.c.o. the screen-grid, acting as oscillator anode, is by-passed to earth by a condenser, whilst the cathode assumes an R.F. potential above earth but less than that of the control-grid. Since the screen-grid remains at earth potential, it acts as an electrostatic screen, separating the oscillator circuit from any capacitative coupling to the anode proper. When voltage is applied to this electrode, plate current is drawn, and this is controlled in amplitude by the R.F. potential on the control grid. This potential swings over a wide range of values, extending from beyond cut-off to well into the grid current region; consequently the anode current has a wave-shape similar to that of a Class C amplifier. Such a circuit is, therefore, very rich in harmonics, any one of which may be extracted by inserting in the anode a tuned resonating circuit operating at the frequency of the desired harmonic. If the anode load is untuned, the whole gamut of harmonics will be well represented, and it is in this condition that the circuit is generally used as a frequency meter.

It is another important characteristic of the screen-grid valve that alterations of screen and anode potential produce opposite changes in its internal impedances; increasing the anode voltage causes an increase in anode impedance, whilst increasing the screen voltage causes a decrease. If the screen voltage is derived from a potentiometer connected across the plate supply, it is possible to find a ratio of plate and screen voltages which will effectually cancel out any changes in valve impedance produced by a changing high-tension supply. This at a single stroke removes one of the major causes of frequency instability when a self-controlled oscillator is used, for the changing potentials can now only act by varying the heating of the valve electrodes, and hence the spacing and inter-electrode capacities. These changes, once the valve has warmed up to an average operating temperature, are very small and may usually be neglected. In using the electron coupled oscillator for this effect, however, the ratio of plate to screen voltage must be determined experimentally for each case, for unless the correct ratio is chosen the circuit is no more stable than any other. Where pentodes are used in an e.c.o. circuit it is not usual to find a ratio of plate to screen voltage that will exactly balance out the frequency change. It is preferable therefore to use the simple screen-grid tetrode in all cases where the highest stability is desired.

The technique of the adjustment of an e.c.o. circuit is simple, assuming the H.T. supply is derived from a source that can be smoothly varied about 20 per cent. above and below the average value. After the oscillator has been allowed to warm up for half an hour it should be set so that one of its harmonics produces a zero-beat with a high-frequency crystal oscillator or similar source of constant high frequency. The H.T. voltage is then varied and the deviation of the beat note from zero-beat noted. The process is repeated with various settings of the screen potentiometer until a setting is found at which the H.T. voltage has little or no effect upon the frequency of oscillation. This is the correct adjustment. The setting of the cathode tap should be such that the grid current of the oscillator remains as nearly as possible at a constant value over the whole tuning range of the frequency meter. Usually this will be found to be at a point approximately one-fifth the number of turns from the earthed end. In passing it may be mentioned that the system of stabilisation mentioned above should be employed in adjusting e.c.o.'s for transmitter drive units.

The Franklin Master Oscillator Circuit

The Franklin arrangement provides a two-valve oscillator of exceptional stability and simplicity. In this circuit (Fig. 8) a second valve, placed in cascade with the first, reverses the phase of the feed-back energy so that it is correct to feed it back through a small condenser to the grid end of the tank coil without any intervening reaction coil, etc. The two-stage amplifier also gives a very high gain, so that very little drive need be applied by the tuned circuit to the first valve and very little energy is needed from the second stage to make up the losses in the tuned circuit in order to maintain steady oscillation. The condensers C and C′ are very small and do not exceed one or two micro-micro-farads. Condensers of this capacity have a very high reactance at the frequencies for which

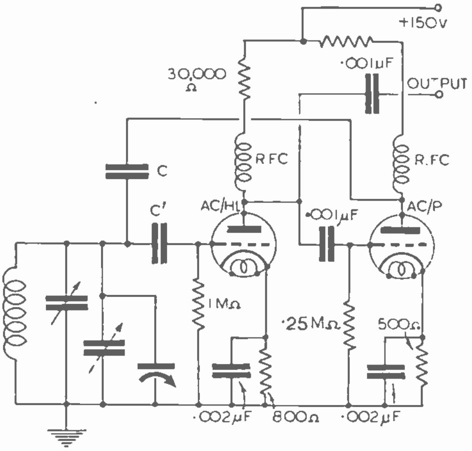


Fig. 8.
Circuit of the Franklin master oscillator as used for a frequency meter. The tuned circuit elements have the same values as suggested for the meter shown in Fig. 7. Condensers C and C′ are variable around a capacity of 1 μμF (see text). Almost any type of valve may be used, battery or mains.

World Radio History

the circuit is designed (up to about 4 Mc) and, being connected in series with the valve capacities, render these ineffective in producing frequency changes. Simply put, the amplifier is so weakly coupled to the frequency controlling circuit that it has negligible effect upon its constancy.

The method of adjusting the Franklin is easier than that employed for the correct adjustment of the e.c.o., whilst the effects of changing valves, high tension, etc., are even better cared for. The only adjustment required is to set C and C′ to the smallest values consistent with steady oscillation; thereafter, for amateur purposes, the sole factors that will affect the frequency are those acting directly upon the tuned circuit, such as temperature, humidity and structural instabilities. The output is taken from the anode of the first valve, so that it is separated by a valve from both ends of the amplifier connected to the tuned circuit. In this sense it may be considered an electron coupled oscillator although, if triode valves are used as shown in Fig. 8, there will be some slight capacitative coupling as well. The last traces of back-action from subsequent stages can be eliminated by using a screen-grid buffer stage.

The reliability of such an oscillator is superior to most others, whilst its range can at any time be altered by plugging in another untapped coil suited to the range desired.

Choice of Components and Valves

When in doubt regarding the necessary quality of any component for use in frequency-measuring gear, always use the best. Variable condensers connected with tank circuits should have thick vanes, a strong frame and two good rotor bearings assembled not too closely together. There should be no trace of side-play or slackness in the bearings. Where it is intended that a condenser, once set, should remain undisturbed, a clamp should be provided to hold the rotor shaft rigidly at any desired setting. For all variable condensers used in tank circuits, which determine frequency, the dielectric must be air. Insulating material must be used sparingly but in sufficient quantity to ensure rigidity, and its quality must be the highest possible. Ebonite is not usually satisfactory since it undergoes changes which impair its properties when it is exposed to light. Polystyrene is very good, but tends to soften and warp if exposed to heat. The better grades of ceramic are excellent and should be used where possible.

For the coils, thick wire is desirable, for not only does it provide low R.F. resistance but it also contributes to rigidity. Where thin wire is used, it should be silk or cotton covered, and after thorough drying it should be doped in place upon an unglazed but thoroughly dry ceramic former. The best dope for the purpose is a solution of polystyrene in benzene. Celluloid dope should not be used, nor should nail varnish, since both will seriously spoil the coil. Very good results are obtained with air-spaced coils of 12–16 s.w.g. enamelled wire threaded through six drilled polystyrene spacing strips held in place with polystyrene dope. The ratio of length to diameter should not be greater than 3 to 1, and screening boxes should be large enough to allow one coil-radius spacing all round the coil. As far as possible, components should be kept out of the field of a coil, otherwise they may cause stray couplings or upset calculations of coil inductance. All fixed condensers, especially up to ·005μF capacity, should wherever possible be of the mica dielectric type, whilst smaller values, when used in places where they might affect frequency, should be of the plated mica, ceramic or ceramic-mica type, designed to have a negligible temperature co-efficient.

In choosing a valve for an electron coupled oscillator, almost any screen-grid type with a straight characteristic will be satisfactory, provided the cathode-filament insulation is good. A valve with a top-anode connection is desirable for improved isolation, and the *Osram* MS4b and *Mazda* AC/S2 have been found specially good.

For multi-vibrators almost any medium impedance triode is satisfactory, and an economy may be effected by the use of a twin-triode of the B13 or 6N7 class to take the place of two separate valves.

The original valves used in the Franklin oscillator were the *Osram* HL610 and P610, and any valves of this class will be satisfactory. Indeed, this oscillator is not at all critical in the type of valves required. The original design had a screen-grid buffer amplifier for the output, using an S610 valve.

For 100 kc crystal oscillators, the *Mazda* AC/S2Pen and similar valves will be satisfactory. The American metal valves are very good because of their short leads and rigid structure, but modern British valves now leave little to be desired.

Resistances should be of very generous rating to obviate the necessity of recalibration required by replacements, or drift of value. R.F. chokes should have low distributed capacities, and if they must be supported in the wiring, it should be short and thick. Wherever a live wire passes through a screening panel it should be bushed with ceramic or polystyrene. The latter material will be found convenient since it is so easily worked. In cutting or drilling polystyrene, however, the tool and material should be kept wet with cold water to prevent softening and sticking of the tool. Polystyrene does not blunt tools as does ebonite, and the best and sharpest tools can be used without fear.

Calibrating Frequency Meters

It is possible to calibrate a frequency meter with some degree of accuracy without a frequency sub-standard, using only the known carrier frequencies of commercial or broadcast stations in the fundamental or harmonic range. It is, however, neither easy nor altogether satisfactory, and a simple sub-standard is strongly recommended.

Assuming the possession of some form of 100 kc oscillator, and the desire to calibrate a heterodyne meter covering the 1·7 Mc amateur band with a slight overlap at each end. First the sub-standard and frequency meter are switched on for half an hour to attain a steady frequency, after which time they are coupled to an ordinary amateur-band receiver. The coupling need only be sufficient to produce comfortably strong whistles, for if it is too strong it will block the receiver or cause second channel trouble with a superhet.

Some experimental work on the cut and try method will probably be needed before the tank capacity and inductance of the frequency meter are such that the range 1,700 to 2,000 kc covers nearly the whole dial. If the frequency coverage is too great, the inductance should be reduced and the band-setting condenser increased in capacity. When a 180° dial is used, the 1,700–2,000 kc range should cover from about 5° to about 175°. If the receiver has already been roughly calibrated, it will easily be possible to identify the various harmonics of the 100 kc oscillator which will appear as continuous c.w. whistles when tuned in with the b.f.o. working. With the 17th harmonic (on 1,700 kc) tuned in, switch off the b.f.o. (or retard the reaction if an autodyne receiver is used) and rotate the frequency meter dial until a whistle is heard. Set to zero beat and record the dial reading of the frequency meter to the nearest tenth of a degree (if a *Muirhead* vernier dial is used) or equivalent accuracy. Repeat the process with the 18th, 19th and 20th harmonics. After this has been done insert 3·5 Mc band coils in the receiver and repeat the process with the 34th to 40th harmonics of the oscillator and the second harmonic of the frequency meter. These points, in terms of the fundamental frequency of the frequency meter, will give calibration points every 50 kc. Similarly the 7 Mc band coils will give points every 25 kc and so on.

If a 10 kc multi-vibrator is available, the process is simplified to the extent that 10 kc points are instantly available with the 1·7 Mc coils in the receiver. If desired 5 kc and 2·5 kc points can also be obtained by the procedure described.

Graphs

A graph should then be made by plotting the dial reading of the frequency meter against the frequency. The scale should be so chosen that there is 0·1° for each graph square, and the frequency scale selected so that the graph line runs at approximately 45° to the horizontal; a method which produces the most open scale. Such a scale will, however, give a huge chart if drawn on paper with 10 squares to the inch (which is the size it should be); therefore it is as well to divide the whole range into convenient sections, with a small overlap on each. The several charts thus produced should be mounted on stiff card, varnished, and filed. Upon the accuracy of these charts depends the accuracy of the whole instrument, therefore it does not pay to "skimp" in matters of graph paper. If the sheets are mounted on cards and fixed in a ring file, they are easily available for use.

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World Radio History

Chapter Fifteen

MEASURING APPARATUS AND INSTRUMENTS

Types of Meters, Moving Coil, Moving Iron, Hot Wire, Metal Rectifier, Thermal, Electrostatic—Extension of Ranges, Voltmeters, Ammeters—Universal Shunts—Meter Applications—Wheatstone, Capacity, Bolometer Bridges—R.F. Impedance Meter

WHEN designing or operating transmitting and receiving apparatus it is necessary to take measurements of the currents and voltages in the circuits involved in order to obtain satisfactory results. The instruments required for these purposes must be reasonably accurate and robust and cheap enough to be within the reach of the amateur's pocket.

Of recent years, many firms have produced small instruments with the qualities mentioned. These instruments cover a wide range of measurements which for convenience may be divided into the following classes :—

(1) Direct current.
(2) Mains-frequency alternating current.
(3) Audio-frequency alternating currents.
(4) Radio-frequency alternating currents.

No one instrument can be made to deal with all these quantities, therefore a meter must be chosen of a type most suitable for the particular work in hand.

It may be required to measure direct currents ranging from microamperes to many amperes, and voltages ranging from microvolts to many thousands of volts, while the alternating currents and voltages of similar magnitudes which have to be dealt with may have frequencies ranging from a few cycles to many millions of cycles per second.

This Chapter is broadly divided into three sections. The first describes the various types of meter available; the second shows how their range may be changed by means of shunts or series resistances so that a particular meter can be used for a greater variety of measurements; whilst the third gives some applications of meters to simple bridge and other measuring circuits.

TYPES OF METERS

The Moving-Coil Meter

The most practical and widely used instrument for measuring direct currents and voltages is the moving-coil meter. In this instrument a coil of wire, usually rectangular in form, is mounted on pivots in the field of a permanent magnet. When the current to be measured flows through the windings of the coil, it is caused to rotate, thus moving a pointer across a scale and giving an indication of the current. The current is led into the coil through hairsprings mounted at each end of it. The springs also serve to control the movement of the coil and to restore it to its normal position when the current ceases to flow. The range can be varied when measuring voltages, by connecting resistances in series, thereby losing some of the applied voltage in them, and when measuring current, by connecting shunt resistances in parallel with the coil, thus by-passing some of the current through the shunts.

A moving-coil meter movement is shown in Fig. 1. Moving-coil instruments can be made highly sensitive, that is, a large deflection can be obtained for a very small power consumed in the meter, so that an accurate reading can be taken without appreciably altering the quantity to be measured. For instance, if the voltage of a small high tension battery, as used in radio receivers is measured with a voltmeter which takes 100 mA from the battery, the battery volts will drop and an inaccurate reading will be obtained. A moving-coil meter could, however, be made to read the volts and take say only 1 mA, which would be well within the intended discharge rate for the battery, and would not appreciably alter its voltage. Many instances such as this occur in radio work, where the quantities to be measured are small.

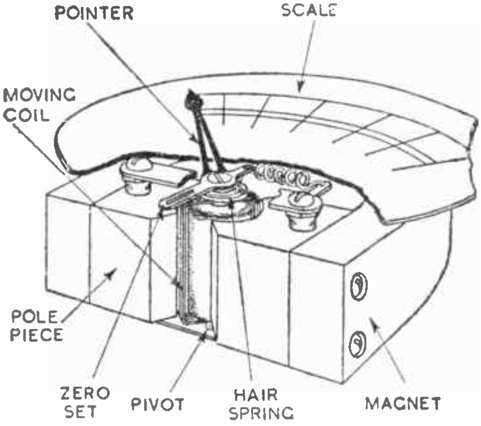


Fig. 1.
A moving-coil meter.

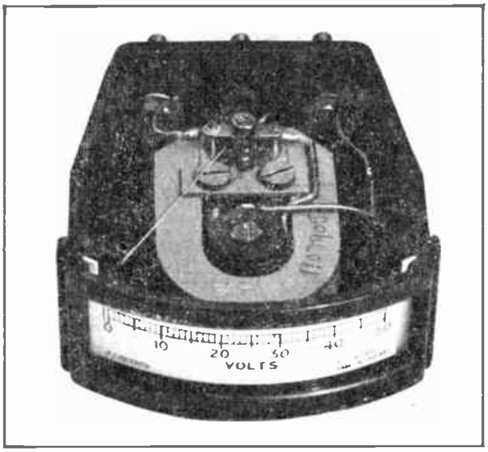
The deflection of the pointer, in the case of a moving-coil meter, is proportional to the quantity being measured (voltage or current) over the whole of the scale. This is advantageous where the same instrument is being used to take readings through a wide range, because a high degree of accuracy of reading is obtainable across the entire scale. A moving-coil meter can only be used for direct current measurements, unless it is fitted with a rectifier, a method which will be described later.

The Moving-Iron Meter

For measurements on A.C. circuits of mains frequency and where the current taken by the instrument is not of importance, moving-iron types can be used. They can also be employed for D.C. measurements if a high degree of accuracy is not required. Further they are cheap and robust in construction.

In these instruments a fixed iron and a moving iron are mounted in the magnetic field at the centre of a coil through which the current to be measured is passing. Under these conditions a mutual repulsion exists between these two parts, the moving iron being deflected, thus indicating on a scale the current measured.

The deflection obtained is approximately proportional to the square of the current or voltage being measured (*i.e.*, it is a " square law " instrument). Thus the scale divisions are close together at the low end of the scale and are opened out at the top. This means that accurate readings cannot be taken at the low end of the scale, but the open scale at the top is sometimes very useful. For example a moving iron meter with a full scale reading of say 250 volts would be excellent for reading small fluctuations of voltage on a 240 volt mains supply, whereas the same meter would be useless for measuring voltages below about 50 volts.



An edgewise pattern moving-coil meter with top cover removed to show the interior. These instruments are made in many ranges and are usually 200 ohms per volt for voltmeters, although for certain ranges they are made 1,000 ohms per volt.

The Hot Wire Ammeter

The hot wire ammeter, although not so accurate or robust as some types of meter, is simple in design and can be made cheaply.

The meter is designed to make use of the heating effect of a current through a wire. The wire is supported at both ends and kept under tension by a fibre attached to its centre and pulled by a spring. When the current to be measured passes through the wire, heating and expansion takes place, and a spindle, round which the fibre is twisted, rotates and moves a pointer across a scale. The current in the wire is thus measured or indicated.

The heating effect is independent of the direction of the current, consequently D.C. or A.C. measurements can be made with such an instrument.

The hot wire ammeter is liable to suffer from a change of zero reading due to slipping between the spindle and fibre, whilst errors may also creep in, due to expansion of the frame supporting the wire. The frame is sometimes made of a material which has the same co-efficient of expansion as the hot wire so that a change of temperature of the whole instrument does not tend to slacken or tighten the wire.

Metal Rectifier Instruments

The metal rectifier instrument is very useful for measurements at mains frequency, and for alternating currents of audio-frequencies, but it cannot be used for D.C. measurements. Recently these instruments have been made to function with fair accuracy on R.F. currents up to 15 Mc per second.

Most of the advantages of the D.C. moving-coil meter are retained in this instrument. The power consumption is low and the sensitivity is high, rendering it very suitable for measuring low alternating currents (microamps) and small A.C. voltages. For instance, the audio volts across the output or loudspeaker terminals of a radio receiver can be measured with one of these instruments.

Essentially the instrument consists of a moving-coil meter into which has been incorporated a *Westinghouse* metal rectifier, and the scale is approximately linear, as in the case of the moving-coil meter on D.C.

Thermal Meters

Thermal meters can be used very effectively for measuring alternating currents of both audio and radio-frequencies. They comprise a moving-coil type meter into which is incorporated a thermo-couple or thermo-junction. When the current to be measured is passed through the " heater," to which the couple is attached, the rise in temperature produces an E.M.F. in the " couple " which deflects the meter and enables the current to be read. The couple consists of a junction of two dissimilar metals, such as Chromel and Eureka, and is attached to the heater by means of a bead of high thermal conductivity material, which has good electrical insulation properties.

For high ranges, an open type junction is used, but for more sensitive ranges a vacuum type is used to prevent temperature changes and losses.

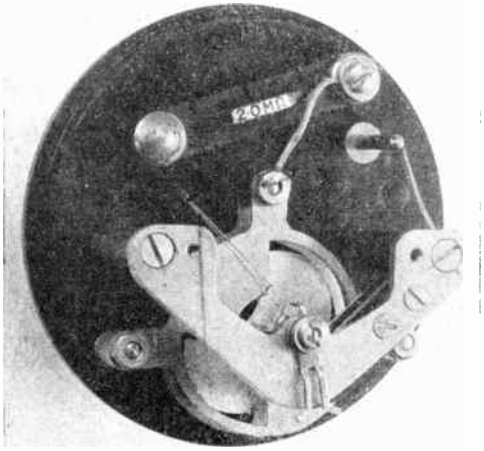
World Radio History

The thermal meter is the only type of instrument which can be used for the measurement of radio-frequency, aerial, and feeder currents with any degree of accuracy.

Electrostatic Instruments

Where even a small load, taken by the measuring instrument from the quantity to be measured, introduces a considerable error, the Electrostatic Voltmeter is used. The instrument consists of a set of fixed metal plates interleaved with, but not touching, a very delicately suspended set of moving plates. When a voltage is applied across these sets of plates there is a mutual attraction and the moving plates are deflected.

As the instrument is in effect a condenser, it must be used with care in radio-frequency circuits where its capacity might alter the conditions of the circuit.



An interior view of a Ferranti electrostatic 3,500 volt voltmeter. Note the safety resistance in series to limit the current in case the fixed and moving plates should spark over. Smaller meters of this type can be obtained with full scale readings of 150 volts and upwards.

The instrument is not very sensitive, therefore it can only be used for measuring high voltages in general, although in recent years more sensitive models have been made. A typical example of its use is the measurement of the audio volts across the modulation choke in a speech transmitter, or the measurement of actual D.C. anode volts on a valve without introducing errors due to increased D.C. resistance drop in the anode resistance.

The scale divisions of these instruments are only open at the top end of the scale. As a result it is not easy to take accurate readings at the lower end of the scale.

EXTENSION OF INSTRUMENT RANGES

Very often it is useful and convenient to be able to alter the range of an instrument so that a wider range of measurements can be made with it.

Voltmeters

In the case of a voltmeter a certain voltage-drop occurs across the instrument, which drop is fixed by the design of the instrument. Any voltage can be measured directly by means of the instrument, provided it does not exceed that voltage required to produce a full-scale deflection of the pointer. If a higher voltage is to be measured a series resistance must be provided to drop the excess volts.

Thus, suppose a full-scale deflection is produced on a certain instrument when one volt is applied to its terminals, and it is required to measure 100 volts. Then a resistance of 99 times the resistance of the meter would be required in series with it so that a voltage drop of one volt would occur across the instrument and a voltage drop of 99 volts would occur across the series resistance.

In Fig. 2(A), let R_M be the resistance of the meter in ohms, R_S the resistance of the series resistance in ohms, V_M the voltage across the meter and V_S the voltage across the series resistance; then the value of the series resistance is :—

$$R_S = \frac{R_M \times V_S}{V_M}$$

so that a voltage of $V_M + V_S$ could be measured by means of the instrument.

For example, suppose a voltmeter, which reads full-scale when 100 volts is applied to its terminals and which has a resistance of 20,000 ohms, were required to read full-scale when measuring 1,000 volts. Then the voltage across the added series resistance must be 1,000 — 100 = 900 volts. The series resistance to be added would be :

$$R_S = \frac{20{,}000 \times 900}{100} \text{ ohms} = 180{,}000 \text{ ohms},$$

and a voltage of 100 + 900 = 1,000 volts could be measured by means of the instrument.

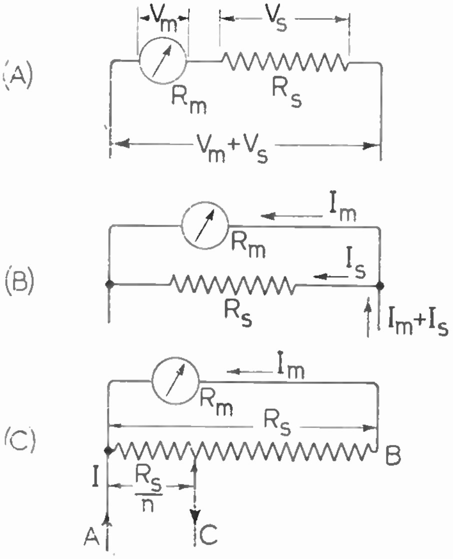


Fig. 2.

Illustrating the use of a series resistance to increase the range of a voltmeter, and the use of a plain shunt and a universal shunt to increase the range of an ammeter.

World Radio History

Ammeters or Milliammeters

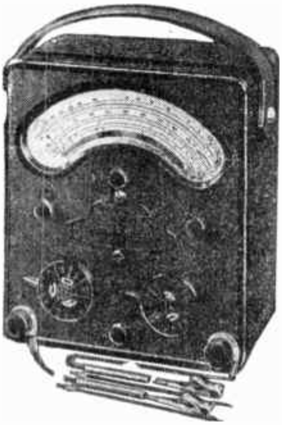
When a simple shunt is used in the case of an ammeter, the voltage across the instrument and the voltage across the shunt resistance are the same, because they are connected in parallel.

If the current in a circuit which is to be measured is higher than that required to produce a full scale deflection of the instrument, a resistance capable of carrying the excess current must be connected in parallel with it. In Fig. 2(B) let I_M be the current in the instrument, I_S the current in the shunt, R_M the meter resistance in ohms and R_S the resistance of the shunt in ohms ; then the resistance of the shunt is :—

$$R_S = \frac{I_M}{I_S} R_M$$

where the current to be measured is $I_M + I_S$.

Thus if a milliammeter of 10 ohms D.C. resistance and a full scale deflection of one milliampere was required to measure 100 mA, then a shunt must be provided which would carry the excess current, that is 100 — 1 milliamperes (= 99 milliamperes). Thus the resistance of the shunt would be :—



Model 7 Avometer.

$$R_S = \frac{1}{99} \times 10 \text{ ohms} = \frac{10}{99} = 0{\cdot}101 \text{ ohms.}$$

The Universal Shunt

A useful type of shunt which can be attached to any instrument is shown in Fig. 2(C). This consists of a high resistance, AB, connected across the instrument. The current I enters at A and if it left at B, the current in the instrument would be :—

$$I \times \frac{R_S}{R_M + R_S}$$

If, however, the current is made to leave at C, the resistance of AC being $\frac{R_S}{n}$, the current in the instrument would then be :—

$$I \times \frac{R_S}{n(R_M + R_S)}$$

Thus the current in the instrument is reduced by $\frac{1}{n}$ times its original value by making it leave at C instead of B.

If several tappings along AB are made for C, having different values for n, a range of currents can be measured. It should be noted that for a given position of the tapping point C, the shunting value will be the same for any meter irrespective of the latter's resistance.

METER APPLICATIONS

Circuit Testers

A very useful piece of apparatus now available to amateurs at a reasonable cost is the Circuit Tester.

In the Circuit Tester, a meter, usually a good moving-coil instrument, is combined with a range of shunts and series resistances. The Tester is made up in a portable form, and is capable of being used for many kinds of measurements. The shunts and series resistance are arranged so that they may be changed by means of switches or by plugging the test leads into appropriate sockets or by a combination of the two methods.

Such instruments are made by Messrs. *Weston, Ferranti*, and *Automatic Coil Winder Co.*

Many of these test sets are equipped with an internal battery so that a range of resistance measurements can be made, whilst a metal rectifier is often fitted which permits A.C. measurements to be taken. A typical circuit is shown in Fig. 3.

To use the instrument for resistance measurements P is adjusted with the switch at " + " to give a scale reading marked " +," and to zero reading by means of R with the switch in the 1,000Ω position. For both adjustments the instrument terminals are short circuited.

In the Circuit Tester shown, a range of voltages, currents and resistances as indicated on the stud-switch can be measured, the necessary series resistances, shunts and adjustment resistances being connected to the moving-coil meter by means of the switch and the coupled switches S_1, S_2 and S_3.

For the voltage measurements an ordinary series resistance tapped for various ranges is used.

It will be noted that the universal shunt described earlier in this Chapter is employed for the current ranges. A rheostat is provided for use in controlling the currents in circuits which are to be measured.

" Avo " Test Bridge.

World Radio History

The variable resistances P and R (used when setting up the instrument to measure resistances) enable variations in voltage to be allowed for, as the battery, which is self-contained, runs down.

The Wheatstone Bridge

For more accurate measurements of D.C. resistance than can be made with a Circuit Tester a simple Wheatstone or Resistance Bridge is employed. This consists of two known resistances R_1 and R_2 which are termed the "ratio arms," a variable calibrated resistance R_3, and the resistance to be measured R_4. These are connected to a battery and a galvanometer as shown in Fig. 4(A).

If R_3 is varied until the ratio of R_1 to R_3 is equal to the ratio of R_2 to R_4 the potentials at A and B will be the same, and the galvanometer will not be deflected. The bridge is then said to be "balanced" and the value of the unknown resistance can be calculated from the known values of R_1, R_2 and R_3 and is :—

$$R_4 = \frac{R_2\,R_3}{R_1}$$

The range of measurements obtained on a Wheatstone bridge can be extended by varying the values of the ratio arms. The greatest sensitivity is obtained when the resistances are similar in value.

A Simple Capacity Bridge

A simple capacity bridge is shown in Fig. 4(B). The ratio arms R_1 and R_2 must be calibrated and may be 5,000 ohms each. C_1 is a condenser of known capacity preferably similar in value to that of the condenser to be measured, C_2.

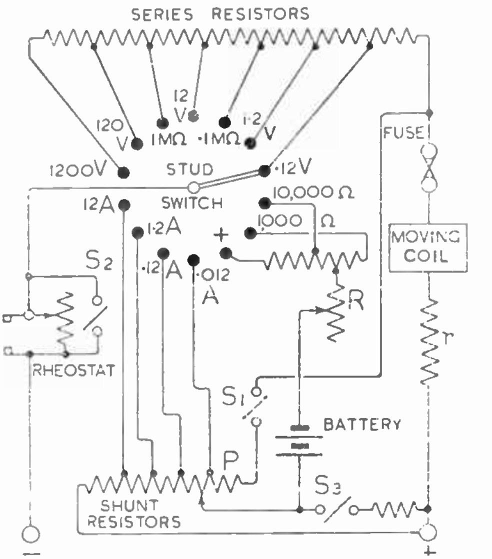


Fig. 3.

The circuit of a typical circuit tester.

S_1 is closed in "+" 1,000Ω, 100,000Ω, and amps position of stud-switch.

S_2 is closed in 1,000Ω, 10,000Ω, 100,000Ω, 1 MΩ and volts position of stud-switch.

S_3 is closed in 1,000Ω position of stud-switch.

For simplicity in drawing, the studs in the stud-switch are not necessarily connected in the correct order.

A source of tone such as that obtained from a low frequency valve oscillator or a buzzer circuit is applied to the bridge, and the ratio of R_1 and R_2 adjusted until no sound is heard in the headphones. An absolutely silent point may be impossible to obtain but a minimum position can always be found.

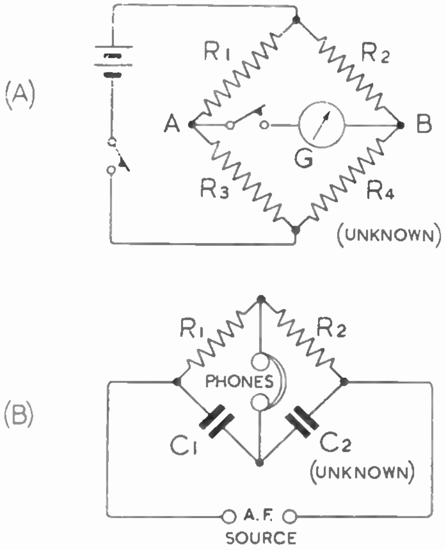


Fig. 4.

(A) Circuit of a Wheatstone or Resistance Bridge.

(B) Circuit of a simple Capacity Bridge.

The value of the capacity C_2 when the bridge is balanced is given by :—

$$C_2 = \frac{R_1\,C_1}{R_2}$$

It will be noted that this result appears to be inverted relative to that obtained on the Wheatstone bridge when measuring resistances. This is due to the fact that the impedance of a condenser is *inversely* proportional to its capacity.

With care the simple capacity bridge described can be very useful, but it must be realised that it will not be accurate for measuring very small capacities below, say, 100μμF, due to the capacity unbalance of the headphones and the ratio arms.

The Bolometer Bridge

A useful form of bridge circuit which can be used to measure radio-frequency currents in the order of milliamps is known as the Bolometer Bridge. The principle is similar to the Wheatstone bridge as will be seen from a study of Fig. 5.

The resistances X_1 and Y_1 are two 60 or 100 milliamp low wattage lamps, R_1 and R_2 are preferably resistances of similar values to those of the lamps chosen, the shunt resistance R_3 is in the form of a 400 ohms potentiometer and is used for balancing the bridge when no R.F. is flowing. The resistance R_4 which has a value of about 30 ohms is in series with the battery (3 or 4 volts)

World Radio History

and is used as a further means of balancing the bridge. The chokes L_1 and L_2 which are to prevent H.F. from getting into other parts of the circuit, should be made a few turns each to keep their ohmic resistance low, which condition is necessary in order not to upset the balance. The bridge is first balanced by means of R_3 and R_4 when no R.F. is flowing. When the current flows through the lamp X_1 the resistance of the filament changes and the bridge is unbalanced, thus deflecting the milliammeter M. If this deflection is noted the same out of balance can be produced by a D.C. supply across the input provided the current in the battery circuit, as indicated by the milliammeter A, is kept constant.

The R.F. current being measured will then be equal to the amount of D.C. which will produce the same deflection of M.

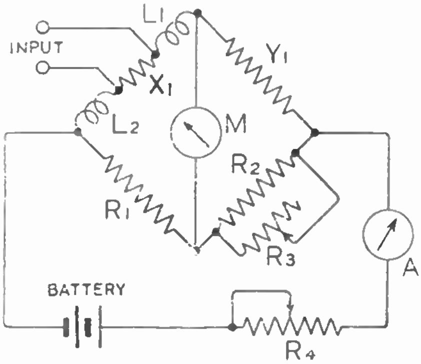


Fig. 5.
The Bolometer Bridge, suitable for measuring small R.F. currents.

The Field Strength Meter

The simple field strength meter to be described can find many applications, especially in aerial experiments, for determining whether one system is better than another. It will give more accurate results than the comparison of " S " strengths.

The instrument as seen in Fig. 6 consists of an ordinary triode V_1 utilised as a linear rectifier, a tuned circuit and a sensitive indicating device such as 0–1 mA meter. The pick-up which is shown connected *via* the condenser C_2 to the tuned circuit, can consist of a short length of copper tubing or stiff wire. The 9v. battery is used for grid bias and as a low voltage anode supply. The relative H.T. and G.B. should be adjusted to bring the valve exactly to cut-off when there is no signal.

When the signal is tuned in, rectification takes place and the anode current of V_1 rises and produces a meter reading. This reading has no absolute value and is only used for comparisons when carrying out aerial or transmitter adjustments.

The instrument should be made with all the components, including batteries, completely screened in a metal box, so that there is no pick-up except *via* the pick-up wire and condenser C_2.

The Peak Valve Voltmeter

The peak valve voltmeter is a simple device and deserves to be more generally used than at present. Its applications are many and varied because measurements can be made at both audio and radio frequencies.

The voltmeter to be described measures the maximum or peak volts, and one of its features is that it draws no power from the circuit being measured owing to the high impedance which it offers to the load circuit. The valve V_1 in Fig. 7 (which can be either a triode or a screen grid type) has a 0–1 milliammeter in its anode circuit. R_1 and R_2 are two potentiometers necessary for adjustment purposes, and these should be of the wire-wound variety. The anode supply can be taken from two 9 volt grid bias batteries, whilst the grid bias supply should be obtained from a separate 9 volt battery.

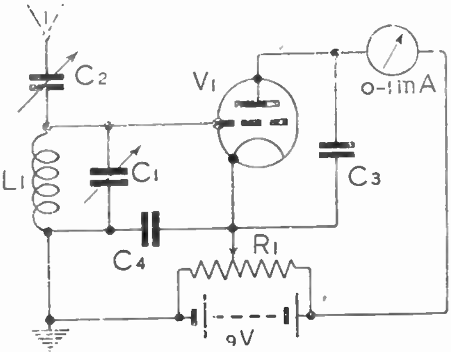


Fig. 6.
Circuit of a Field Strength meter.

L_1, C_1 = Tuned circuit.
C_2 = .00004 μF.
C_3 = .0002 μF.
C_4 = .0002 μF.
R_1 = 1,000 ohms.

The voltmeter V is of the 0–10 volts type and should be a high grade make giving 500 or more ohms per volt. This meter gives a direct measure of the applied peak volts (by what is known as the "slide back" method) and should therefore be

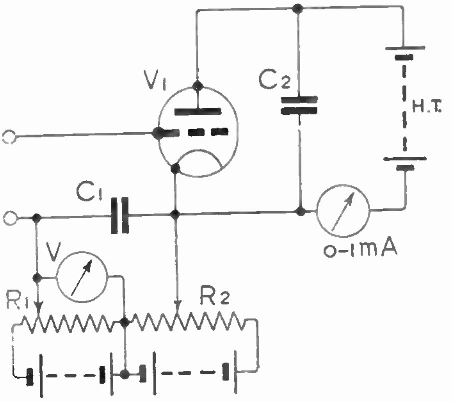


Fig. 7.
A Peak Valve Voltmeter

R_1 = 2,000 ohms.
R_2 = 1,000 ohms.
C_1 = .0005 μF
C_2 = .01 μF

accurate. C_1 and C_2 are by-pass condensers. When used for audio frequency measurements C_1 should have a value of 0·1 μF.

The operation of the meter is as follows:—the input is short-circuited or closed through the circuit to be measured and R_1 is adjusted until a zero reading is obtained on the voltmeter (*i.e.*, it should be turned right back). The valve is then biased back by means of R_2 until zero or nearly zero anode current is indicated in the milliammeter.

This arbitrary zero is noted. The voltage to be measured is then applied across the input terminals and the peak volts so applied will cause a rise in anode current. The resistance R_1 is then adjusted until the arbitrary zero position is again obtained on the milliammeter. The voltage shown on the voltmeter will then be equal to the applied peak volts. In use it is important to see that there is a direct D.C. path through the circuit under test.

Measurement of Voltage Amplification (μ) of a Valve

A simple method of measuring the voltage amplification (μ) of a valve is shown in Fig. 8. V is the valve to be measured and the H.T. and grid bias supplies are adjusted so that it is working under its normal conditions.

The operation of the bridge depends on the fact that if an alternating voltage is applied to the anode of a valve, which is μ times as great as, and in antiphase with the voltage on the grid, there will be no change in anode current. An audio-frequency source of say 500 cycles per second is applied to the potentiometer AB, and the voltages at the ends will be in antiphase. If the point C is adjusted until no sound is heard in the telephones, then the voltage across BC will be μ times the voltage across AB, and the ratio of the resistances:—

$$\frac{BC}{AC} = \mu$$

The transformer shown feeding the A.F. into the bridge is the output transformer of an A.F. oscillator. The telephone transformer should have a primary winding which will carry the valve anode current but for small valves it can usually be dispensed with, and the 'phones can be connected direct to the anode circuit.

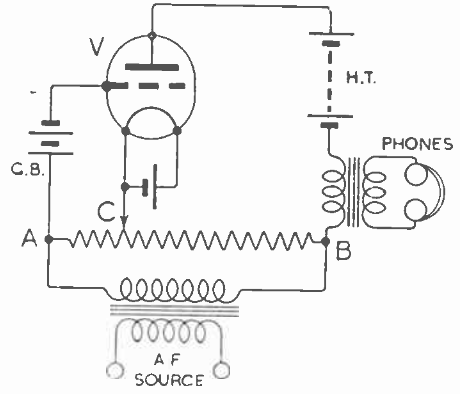


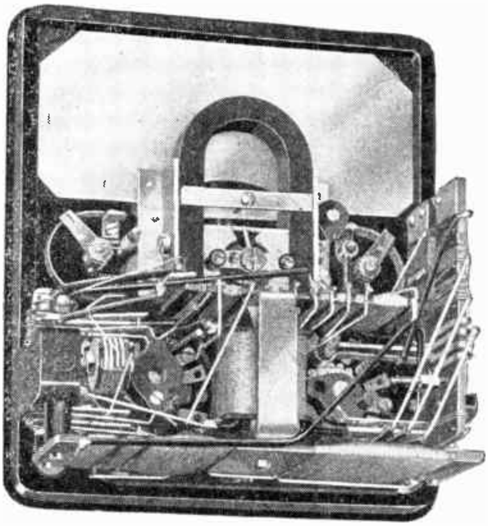
Fig. 8.

Circuit for the measurement of voltage amplification of a valve. The resistance A.B. can be a 5,000 ohm potentiometer.

Radio-Frequency Impedance Meter

Those who experiment with aerials and more especially with the construction of transmission lines and impedance matching circuits, will find the radio-frequency impedance meter very useful.

A very satisfactory arrangement for measuring H.F. impedance, known as the resonance method, consists of coupling a tuned circuit in series or parallel with the unknown impedance to a source of oscillation. The effect of the unknown impedance on the current or voltage in the tuned circuit is compared with that produced by a standard resistance connected in the same way.



Interior of Universal Avometer, showing Series and Shunt Resistances.

A circuit diagram of an R.F. impedance meter is shown in Fig. 9, where V_1 is a conventional T.P.T.G. valve oscillator with its own power supply.

A " backed off " milliammeter is used as a sensitive indicator of current changes in the anode circuit of the oscillator. The resistance R_4 is used to short out or shunt the milliammeter while setting up or switching on or off. A 0–1 milliampere meter is suitable as the indicator. L_3 and C_6 form the tuned circuit, which is loosely coupled to the anode coil L_2 of the oscillator. The unknown impedance Z or the standard resistance R can be connected in turn across the tuned circuit.

In operation the oscillator is first set to the frequency at which the measurement is to be made, and R_5 is adjusted to " back off " the anode current so that the meter reads zero. The tuned circuit is tuned to resonance and the reading is noted on the dial of C_6.

World Radio History

The unknown impedance is then connected across the tuned circuit and the new resonance reading of C_6 is noted. It may be necessary either to increase or decrease C_6. The unknown is then removed and various values of resistance are placed across the tuned circuit until the meter reading is the same as with the unknown in circuit.

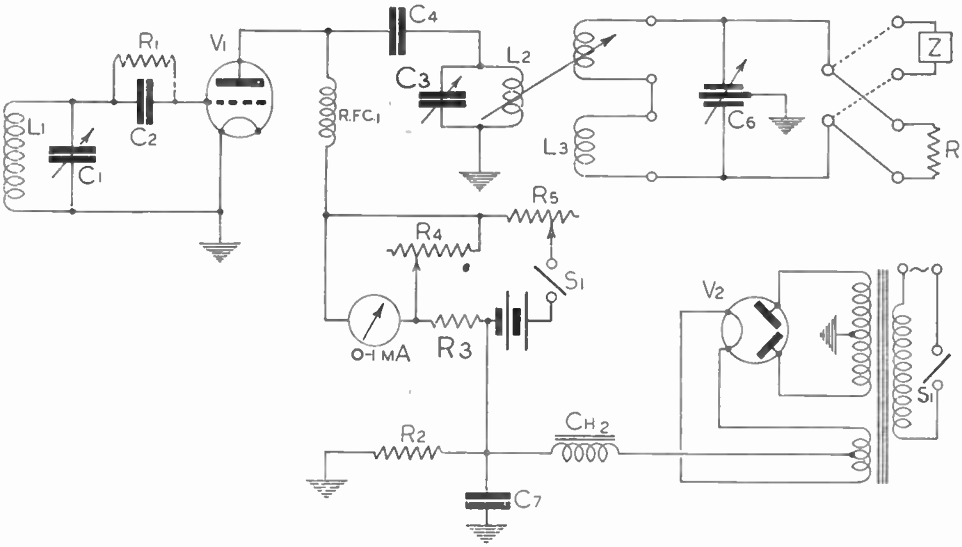


Fig. 9.

Circuit of R.F. Impedance Matching Meter.

L_1	Grid Coil.	R_1	50,000 ohms, 1 watt.
L_2	Anode Coil.	R_2	10,000 ohms, 2 watts.
L_3	Load circuit.	R_3	150 ohms, 0.5 watt.
C_1	180 $\mu\mu$F.	R_4	500 ohms, variable.
C_2	.0003 μF.	R_5	5,000 ohms, variable.
C_3	100 $\mu\mu$F.	RFC_1	R.F. Choke.
C_4	.001 μF.	CH_2	Smoothing Choke 20H.
C_6	.0005 μF (each section)	V_1	MHL4. Osram.
C_7	2 μF.	V_2	U10, Osram.

Mains transformer 200V-0-200V and 4V 1A + 4V 1A.

The unknown impedance is then equivalent to the resistance found necessary, in parallel with a capacity equal to the decrease in capacity in C_6. If the change in capacity is an increase the unknown is equivalent to a resistance in parallel with an inductance.

Obviously the resistance R must be non-inductive, and a wire-wound one would not be very suitable at R.F. A number of metallised type resistances can be used in series and parallel. In computing the values of resistances in parallel it is easier to add their conductances than to calculate the values. A suitable chart for achieving this result simply and quickly is given in Chapter 24 (No. 5).

World Radio History

Chapter Sixteen

The Ultra-High FREQUENCIES

General Characteristics—Short and Long Distance Communication—Horizon Distances—Historical Survey—Recent Amateur Developments

Introduction

THE term " ultra-high frequencies " is generally accepted as relating to those frequencies of the radio spectrum lying between 30 and 300 Mc or, expressed in wavelength, from 10 to 1 metres. Wavelengths below 1 metre are referred to as " micro-waves " or " centimetre waves," and demand special treatment which is beyond the scope of this Chapter. In the first mentioned band the frequency channels most in use are those between 40 and 47 Mc, wherein the television services operate, and in normal times 56 to 60 Mc, often referred to as the " 5 metre band," populated chiefly by amateurs. The following information relates chiefly to this particular band, but at the same time is applicable, more or less, to the television frequencies, and to the 112 to 120 Mc (2½ metres) pre-war amateur band, especially where ground wave propagation is being discussed. In addition to these services, which have been temporarily suspended on account of hostilities, numerous American broadcasting transmissions which employ experimental wide-band frequency modulation can sometimes be heard between 40 and 55 Mc, whilst American police transmissions may be found between 30 and 40 Mc. Experimental transmissions of many varieties are common in the u.h.f. region, making it of particular interest to the amateur.

General Characteristics

For many years it was assumed that communication on ultra-high frequencies was limited to what is called the " optical distance "—that is to say, unless an imaginary straight line could be drawn between two stations without cutting through the curvature of the earth, or a range of hills or mountains, it was thought that contact between them was impossible. This theory has been modified during recent years (largely through the patient work of amateurs), and it has been proved that wavelengths of less than 1 metre are capable of travelling far beyond the horizon. The reasons will be given later in this Chapter, but, at the moment, it will suffice to say that it is sometimes possible to cover considerable distances.

Many readers will already be familiar with the fact that as the frequency is increased, atmospherics become less troublesome. Around 14 Mc they are seldom strong enough to cause discomfort, and on 56 Mc they are never heard at all, except under the extreme conditions of a local thunderstorm. On the other hand severe interference is often caused by " man-made static ", motor cars with coil ignition being particular offenders in this respect. Fortunately the radiation is chiefly over the surface of the ground, and its effect is much reduced if the aerial system is well elevated.

Fading is liable to occur, but is generally of a different character to that experienced on lower frequencies, except over long distances, when variations in the ionised layers still have their usual effect. Rapid fading is exceptional, but slow fading, over a period of minutes or hours, is more common, and is probably due to variations of humidity and temperature of the lower atmosphere.

Echoes, which are often audible on frequencies lower than 30 Mc, and give trouble to commercial services, have only recently been recorded on the ultra-high frequencies. Magnetic storms give rise to " rushing " or " hissing " noises, rising to a peak and dying away again, but are not so strong or frequent as on the lower frequencies, from which it is assumed that the storm has to be of a very violent nature before it produces an audible effect. Thunderstorms occasionally cause atmospherics, but have a more noticeable effect on signal strength, which is liable to vary considerably, even at a great distance from the centre of the disturbance.

A somewhat peculiar form of interference makes itself felt on the ultra-high frequencies, and is often difficult to cure. Any two, or more, metallic objects (wires for instance) which scrape together, or form an indifferent or variable contact, will cause noises in the receiver. It does not make much difference if such objects, or wires, are free, or connected to other apparatus, and often such unlikely things as wire fences, steel clothes lines, etc., can give a lot of trouble, owing to the difficulty experienced in locating them. Tools lying loosely in a table drawer beneath the receiver have been found to cause serious noise of this kind. The effect is apparent over a considerable distance within the field of the aerial, from which it follows that attention should be paid to metal-work and wiring of any sort within the vicinity of ultra-high frequency

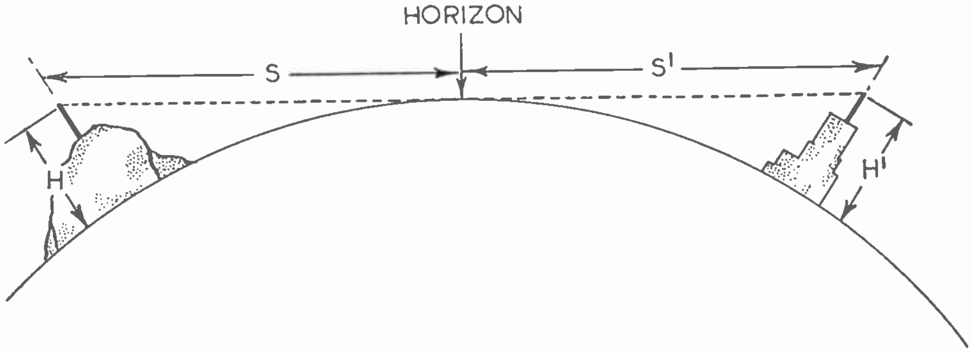
World Radio History

apparatus. Where possible, electrically bonding together and to earth will reduce or remove the interference.

Equipment Requirements

It should be emphasised that to study the various peculiarities outlined above, a superheterodyne, or straight receiver, is very desirable. A super-regenerative type usually has a high background noise level, which completely masks any unusual occurrences, and as this class of receiver possesses an inherent A.V.C. action it is difficult to detect any small or gradual change in signal strength.

On the transmitting side rough unstable signals are again unsatisfactory, because when weak they tend to merge into the background noise, and it becomes impossible to note any change due to propagation characteristics. A clean pure, signal, radiated on a single frequency, will travel a much greater distance, other factors being equal, which explains why stabilised c.w. or m.c.w. transmissions (possessing also the advantage of maximum readability) are now made by the majority of serious experimenters.



Sketch showing how the curvature of the earth determines the optical range between two stations of height H and H^1 feet respectively. The optical path will be the sum of the two horizon distances S and S^1.

Short Distance Communication

The 56 Mc amateur band is very suitable for communication over moderate distances, and it is made use of to a considerable extent in many of the larger centres for across-town work, thus avoiding much of the congestion which exists on the lower frequency bands. Its use for this purpose cannot be too highly recommended, but modern apparatus should be installed, as self-excited transmitters, and super-regenerative receivers are both capable of very serious interference to other stations within a few miles.

For local work of this type use is made almost entirely of the ground wave and it is difficult to predict the range which may be expected, as so many factors enter into the question. These factors include (*a*) height of the station above sea level, (*b*) height of the aerial above ground level, (*c*) nature of the intervening ground, (*d*) the site of the transmitting station, and (*e*) power input. One has also to take into account the same factors as they apply to the receiving station, and the sensitivity of the receiver. It often happens that a stronger signal is received at a station located at twice the distance away to a nearer one in a poor location.

Ground-Wave Variation

Considering factor (*a*) it will be realised that a site on the top of a hill, with the ground falling away on all sides, is the most favourable, which explains why such a situation is often chosen for field day work. From the top of a mountain, Snowdon for instance, the optical path is beyond 100 miles and contacts over fairly long distances are not difficult to achieve. Factor (*b*) is very important when the home station is being planned, because to work any reasonable distance it is essential that the aerial be well clear of all nearby objects, such as gutters, pipes, stay wires, house wiring, metal fences, etc. These will all tend to absorb power, as well as to distort the radiated field, resulting in very poor radiation in some directions. In the case of factor (*c*) propagation over water results in less attenuation, and in consequence the range, other things being equal, is greater. Propagation is also good over marshy land, but decreases over rocky ground, and is very poor where mineral deposits occur. A house, or "shack," set away from other buildings, trees, etc., is the most suitable. Houses near the site will cause some screening, and the same applies to trees. The latter do not affect the range very much in winter, but do so to a considerable extent in summer when they are in full leaf. Factor (*e*) explains itself. With a good aerial on a good site excellent results may be expected with quite a low input (three to ten watts) but in other cases it is often necessary to raise the input to a high level before the effect of the local screening can be overcome.

Horizon Distance

Since the ground wave range of a transmitter is so closely connected with its "optical range," or distance from the horizon, it will be helpful to state a simple expression by which this can be calculated. Such an expression can only be strictly accurate over sea, or perfectly level ground, but it serves as a useful guide in less ideal surroundings.

World Radio History

Suppose H feet be the height of the aerial above ground level, then the distance of the horizon in miles is given by :—

Horizon distance $S = 1 \cdot 42\sqrt{H}$. *

To obtain the most accurate result, H should be taken as the *excess* height of the aerial above sea level, over the height of the horizon above sea level, which might be found from an Ordnance Survey map. At sea the second factor is clearly zero, and so H can easily be known. On land the calculation is less simple, but for a rough estimate H will generally be taken as simply the aerial height above ground. Naturally the range thus found assumes that the distant station is at ground level. If it is also raised by a height H^1 feet, the total optical path between the two stations becomes :—

Optical range $= S + S^1 = 1 \cdot 42(\sqrt{H} + \sqrt{H^1})$.

In practice signals are likely to remain at good strength for a range about 20 per cent. greater than the above, owing to a slight diffraction effect by which the waves seem to pass somewhat beyond the horizon before rapid attenuation sets in.

Polarisation Effects

Ultra-short waves readily show the effects of polarisation, particularly when the ground wave is made use of for local communication. Thus if a horizontal dipole aerial be used at a transmitting station, it will be necessary to use a similar aerial at the receiver for optimum results. This aerial should also be parallel, or in the same plane as that of the transmitter. Similarly a vertical aerial will radiate vertically polarised waves, which will require the use of a vertical receiving aerial. Much weaker reception may be obtained from unsuitable aerials, because the polarisation of the waves is disturbed to some extent by reflection from intervening objects, and will contain both horizontal and vertical components ; whilst at considerable distances or when the space wave is being received, the form of aerial may be of little importance. There seems some evidence that horizontal aerials give the best results for local or moderate distance communication over hilly country, whilst vertical aerials are preferred at greater distances, and in cases where no directional effects are desired.

Portable Work

The 56 Mc band is very popular for field work using portable apparatus, and the reason is not far to seek. Small aerials can be made quite efficient, the apparatus can be compact and light, and batteries used to supply the power. This latter is usually small, but is compensated for by setting up the station on top of a hill and in open country, except in those cases where propagation over difficult country is to be studied. Much valuable information has been brought to light by keen amateurs working under intentionally poor conditions, which has added materially to their knowledge of ultra-short wave behaviour. Where it is desired to radiate or receive signals in one particular direction, it may be better to erect the station, not on top of a hill, but some little way down the side facing the desired direction. The waves reflected off the surface of the hill will add to the radiated waves, resulting in stronger signals. Similarly if contacts with stations in one particular direction are required, reflectors can be added to the aerial system, or a beam array set up, this having the effect of a great increase in power. A beam aerial for 56 Mc need not be a large affair, further it is not difficult to design one that can be easily transported.

Successful communication has been maintained between moving cars over three or four miles, but a much greater distance is possible between ground and aeroplane, or between two aeroplanes, because the intervening screening is very slight. Equipment has also been used by explorers and mountain climbers for the purpose of keeping in touch with the base or other parties, and, during the last Mount Everest expedition, reliable contact was maintained with low-power transmitters over considerable distances.

Portable transmitters have in the past usually been of the self-excited type, modulated either by speech or tone signals, the latter giving a greater range. Super-regenerative receivers are necessary to receive such signals. Receivers of this type vary considerably in their effectiveness, according to the design, layout, and valves used, these factors having a greater influence than when applied to the lower frequencies. Of recent years amateurs have led the way in the adoption of modern stabilised transmitters (often radiating a pure c.w. signal), and of superheterodyne or straight receivers. This tendency has led to a very marked increase in the range and reliability of communication.

Long Distance Communication

Greatly increased distances can be covered by setting up stations on mountain tops (a distance of over 200 miles has been achieved in Great Britain) but in such a case the ground wave is being used, although other factors may also enter into it. On the other hand two stations may be separated by only about 30 miles, but they may be low lying, with ranges of hills between, and for a contact to occur use must be made of reflected waves.

Up to several years ago it was thought that the Kennelly-Heaviside and Appleton layers simply absorbed ultra-short waves without reflecting them. It has since been proved that under certain conditions reflection can occur from these layers, and certain new layers, at much lower heights, have also been discovered. These have a big effect on ultra-short wave propagation, and by their aid some very long distances have been covered within the last few years.

Layer Reflection

Under the influence of solar radiation, ionised layers are formed in the upper atmosphere, the heights and densities varying according to the time of day and season. To reflect ultra-short waves the layers must be heavily ionised, and it therefore follows that propagation by reflected waves will vary considerably. Long distance communication is likely to be at its best when the higher

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* A table showing horizon distances from varying heights above ground level appears on page 237.

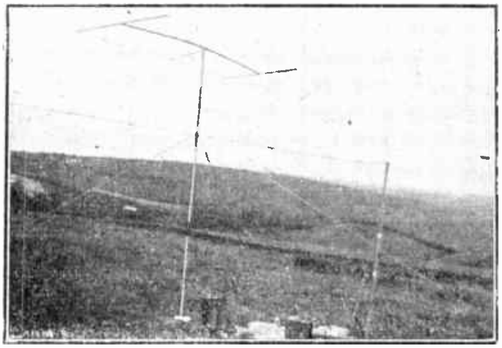
World Radio History

of the two chief layers (the F layer) is at a maximum density, and this occurs in the spring and autumn. The E layer, situated at a height of between 80 and 100 miles, is most strongly ionised in mid-summer resulting in conditions being suitable for communications over distances of up to 800 miles.

During 1935–36 a complete new series of layers were identified through the work of Dr. Watson Watt and the National Physical Laboratory. These are situated between the Troposphere and Stratosphere, that is to say, from four to eight miles above the earth. It has been proved that these layers, which are much thinner than the previously known layers, vary but little during the seasons, as their degree of ionisation is not mainly dependent upon, solar radiation. It is known that thunderstorms and electrical storms play a large part in maintaining the ionisation, which fact is curious, since such storms usually occur below the level of the layers, and it would seem that electrons are "sprayed" upwards. These low level layers may be responsible for medium distance communication, and may possibly explain why amateur 56 Mc signals and the London television signals have been received at ranges much beyond those predicted.

Propagation Radiation Angles

Propagation will be much affected by the angle of incidence which the transmitted wave makes with the different layers. In the case of the E and F layers low angle radiation is essential, and the aerial should be designed to give maximum radiation at an angle of between 15 and 25 degrees. It is probable that a higher angle, of between 30 and 50 degrees, will produce better results where the lower layers are concerned, but it will be appreciated that a large field of experiment lies open here, to find the effect on field strength at various distances with different types of aerial systems, arranged to radiate at different angles. Prior to the outbreak of hostilities amateur stations were actively engaged in the investigation of interesting effects of this kind, which include the influence of the sun spot cycle and of meteorological conditions upon ultra-high frequency signals. Regularly repeated schedules, organised listening, improved equipment, and that boundless enthusiasm which characterises the amateur movement were leading to most promising results, and it is hoped that the resumption of this valuable work will not be long delayed.



A 56 Mc. Portable Station set up on Devil's Dyke, South Downs.

The Development of Amateur Activity

Ultra-short wave signalling is not only one of the most recent, but also the oldest branch of radio science, for the classical experiments of Hertz, Lodge and Marconi were conducted at wavelengths measured in centimetres. The belief that only longer waves were capable of worldwide communication soon led, however, to a neglect of earlier methods, and inaugurated the "long wave era," during which modern radio technique was born, and the amateur movement developed. Thus the earliest amateur activity of an organised kind took place on wavelengths of 1,000 and 440 metres, followed as the years passed by 160 metre and shorter wave working.

Certainly during 1920, however, and perhaps much earlier, amateur activity existed in the ultra-short wave region, and experiments at 2·5 metres wavelength can be recalled. These experiments were not of a general nature, but involved groups of two or three workers communicating only with each other. Equipment was comparatively simple, and the distances covered, naturally small. At this time the ultra-high frequencies were believed to be free from the phenomena noticed on lower frequencies, and as a result communication did not, for many years, go beyond the "across town" scale of operation. While this popular belief was largely responsible for the stagnation in matters of technical advancement, it was not entirely so. The design of transmitting and receiving equipment was only considered in the light of its value as a means of *telephonic* communication, with very low cost, and intriguing simplicity. The general conception of the operators of such apparatus was that under the circumstances there was very little, if any, need for a change of "front," and so, for a time, technique was held up.

The first sign of a break in this conservative state of affairs occurred when harmonic telegraphic signals from European commercial stations were heard in South-eastern England on 56 Mc and adjacent frequencies. It was known that a similar effect could be, and often was, observed when the receiver was tuned to a frequency near to that of a transmitter in operation in the same room or building, and it was a long time before those who had heard the European harmonic signals could justify their claim of having heard them *via* the aerial of the receiver, and not through the proximity of a transmitter. It so happened, however, that these same amateurs had had first hand experience of commercial harmonic signals on the lower frequency of 28 Mc, and, bearing in mind the proved significance of such signals on that band, they duly considered the reception of similar signals on the much higher frequency of 56 Mc as being an indication of changing or variable "conditions" in that part of the spectrum which had hitherto been universally accepted as having quasi-optical characteristics.

Here was food for thought indeed. The possibility of long distance communication on these frequencies under favourable, or "freak" circumstances, was discussed by those with an urge to break fresh ground, and it was agreed that in the face of the lack of amateur activity in the countries whence the commercial signals originated, it would only be possible to check up on day-to-day conditions by means of extended periods of listening.

World Radio History

This idea was followed out in practice, and during the summer months of 1935 several commercial harmonics were heard at surprising strengths from Europe and North Africa.

This period of listening brought to prominence the fact that the super-regenerative, or "quench" type of receiver then in popular use, was unsuited to the reception of weak signals possessing low values of modulation. Thereupon began the first general recognition of the likely value of simple autodyne circuits, which, with their high sensitivity, and low noise level had rendered such yeoman service on the lower frequency bands.

A revival of interest in the ultra-high frequencies began to take shape during the spring of 1936. At first there were barely a half-dozen active stations grouped within the greater London area, but as time passed and it was found possible to obtain fresh contacts, the 56 Mc amateur band began to take on the aspects of the more fully occupied lower frequencies. The organisation of special tests between certain stations or localities from time to time kept the participants fully occupied in general observation work, and contributed greatly to the amount of fresh ground covered during the first year's efforts.

Before the end of 1936 there were stations regularly active in Africa, Australia, North and South America, Holland, Belgium and France. Interest was now world-wide, and the chances of establishing some long distance contacts were, on the face of things, good, but, with this large increase in known activity the problems of the solar activity cycle made a fine game of patience with the efforts of all concerned. However, patience being an inborn quality with radio amateurs in general, and 56 Mc operators in particular, activity and interest did not flag for a moment—in fact the DX workers continued to increase in numbers month by month.

During 1938, the number of telegraphy stations operating throughout the world approached the number which were active on 28 Mc when that band was first "put through its paces." At the same time, observations showed interesting changes in purely local signals. As an example, definite signs of fading, and echoes on signals travelling between points of from 50 to 100 miles apart, have frequently been reported.

Operating portable on 56 Mc during an R.S.G.B. Field Day

Ionisation Levels

It is desirable at this juncture to revert to the subject of "conditions" (ionisation levels) as pertaining to the 56 Mc amateur band. The general theory of this phenomenon is given elsewhere, but it will be interesting to observe how and when the ultra-high frequencies follow and keep in step with the behaviour of the lower frequency regions, or, conversely, fail to do so.

The effects of the Kennelly-Heaviside and Appleton layers of the ionosphere are frequently and abundantly displayed on the lower frequency bands, particularly on 7 and 14 Mc. When, however, observation is carried out on the higher frequency of 28 Mc it will be found that the variations become more erratic, and, from the point of view of reliable communication, produce lower *average* suitability for long distance working throughout the space of a year. On the other hand, when a spell of good conditions does exist, the contacts made by even very low powered stations are, to say the least, phenomenal. Again, when conditions are poor around this frequency the amount of work done at any station, irrespective of power, is very often nil for days or even weeks on end. Thus it will be seen that the region of 28 Mc is open to "highs" and "lows" but little sustained "average" conditions. The explanation of this unstable characteristic is to be found in the behaviour of the higher frequency radio signals in relation to the density and height of the reflecting and/or refracting layers in the ionosphere. This, the outer edge of our atmosphere, is the controlling factor as to whether or not signals describe the desired "skip" across the surface of the earth.

In accordance with modern propagation theory, the distance covered by this "skip" effect varies according to the frequency used, and the time of day or season of the year concerned, but the actual existence of such an effect is due to the amount of solar activity at certain periods (solar cycle). As the frequency is increased the "skip distance" becomes greater, until, at a certain point in the spectrum (the limiting frequency) the signal is not sufficiently refracted to come back to a distant point on the earth's surface—long distance communication therefore is no longer possible.

It will be realised therefore that peaks of 28 Mc activity will, under favourable conditions of solar activity, be expanded to such an extent as to provide periods of good conditions over the band 56 to 60 Mc. This has actually been the case, and at certain times in the solar cycle ionisation density is such as to produce DX signals up to about 59 Mc, but it must also be realised that such periods on these very high frequencies are, in reality, only the protracted "tips" of the peaks, which, on the lower frequency of 28 Mc, are more generous and lasting in the beneficial effect on radio communication over long distances.

So, likewise, is the periodicity of the good spells on the ultra-high frequency ranges. Whereas on 28 Mc there may be several peak periods each year

World Radio History

(with the usual rise or fall in what may be termed the "average" according to the age of the solar cycle), on 56 Mc the peak period is not a matter of months in a year, but of perhaps two years or more in the 11-year solar cycle.

Recent Long Distance Observations

A very brief account is now given showing how DX conditions have changed during the past few years in so far as the ultra-high frequencies are concerned.

Between 1928 and 1934 very few long distance signals were heard. A definite improvement occurred during 1935, many European commercial harmonics being heard by a number of listeners in Great Britain. This naturally increased interest considerably, and the winter of 1935–36 saw definite improvements in the design of apparatus and operating procedure.

During 1936, the reception of commercial harmonics was frequent, even from stations in Italy and North Africa. In America, amateur communication was effected from coast to coast and activity became evident in many parts of the world. Towards the end of the year conditions peaked noticeably, shown by the fact that British stations were heard in America, a Moroccan in Great Britain, and various Europeans in Morocco. The Alexandra Palace sound transmission on 42 Mc was also clearly received in South Africa.

These good conditions were maintained during the early part of 1937, when many long distance contacts were made in America and British signals were again heard there. Reports of reception in this country of European amateurs, and *vice versa*, were frequent and fresh signals were continually being noted.

During 1939 interest reached a new high level, spurred on by reports that two-way contacts had taken place on 56 Mc between Great Britain and Italy. The great improvements in operating technique coupled with the use of more efficient receiving and transmitting equipment were rapidly bearing fruit when hostilities caused a suspension of activities. American amateurs, however, continue their investigations, and numerous field events took place during 1940. Very considerable distances have consistently been covered in the U.S.A., and on one occasion a two-way contact between British Columbia and Japan was recorded.

From these remarks it will be seen that a steady improvement has been taking place since 1936, and it will be interesting to observe conditions during the next few years. There is little doubt that these will follow more or less those on the lower frequency bands, but it is not possible at this stage to say exactly to what extent the similarity will apply.

Need for Co-operation

The Propagation Group of the R.S.G.B. Experimental Section, who welcome the co-operation of amateurs interested in u.h.f. problems, are fortunate in being able to obtain important scientific data from observatories and other Government organisations. This information is distributed to members forming the Section, who are themselves urged to record in detail their own observations. It cannot be too strongly urged that co-operation is vital to the development of ultra-high frequency communication.

The *R.S.G.B. Bulletin* contains frequent references to ultra-high frequency equipment, and numerous important theoretical contributions have appeared in that journal during recent years.

The "ultra-highs" hold a great fascination for the keen British experimenter who, in spite of the curtailment of transmitting facilities, continues to carry out regular observations on these frequencies.

HORIZON DISTANCE

Horizon distance can be calculated from the formula :—

$$S = 1{\cdot}42 \sqrt{H}.$$

where S = distance in miles and H = height of the observer's eyes in feet.

The table which follows gives the horizon distance for various heights of aerial above ground level.

Height of aerial above ground feet.	Limit of optical range miles.	Height of aerial above ground feet.	Limit of optical range miles.
5	3·2	1,000	45·0
20	6·4	2,000	63·5
50	10·0	3,000	78·0
100	14·2	4,000	90·0
500	32·0	5,000	100·0

World Radio History

Chapter Seventeen

ULTRA-HIGH FREQUENCY EQUIPMENT

General Requirements — Valves — Frequency Measurement — Receivers — Concentric Line Tuned Circuits — Transmitters — Crystal Control—112 Mc Operation—Frequency Modulation—Pipe Line Transmitters—Aerial Coupling

IT has been proved time and again that to cover medium to long distances consistently it is necessary to use apparatus of a modern type, giving, with the aid of the high quality components now available, an efficiency greatly in excess of that obtainable a few years ago. Whilst ordinary components can often be adapted for use in a short-wave receiver or transmitter, it can be definitely stated that this policy does not pay when dealing with frequencies of over 50,000,000 cycles per second. Only components designed essentially for ultra-high frequency use should therefore be incorporated in transmitters, receivers, and associated apparatus intended for use on 56 Mc or higher.

GENERAL REQUIREMENTS

Insulation

The insulation of all parts of the circuit at high R.F. potential should be of ceramic, trolitul, or similar special material; bakelite and paxolin should be avoided, although there is no objection to their use in other parts of the circuit. Variable condensers should be physically small, and have the minimum amount of metal necessary to produce the desired capacity. As this is usually small it is essential that the minimum capacity be kept low by mounting the condenser away from a metal chassis, or the tuning range may be unduly restricted. Many manufacturers produce special chokes for 56 Mc use, and it is preferable to use these, as they have been designed to eliminate undesirable resonances, and consequent "dead-spots."

Condensers

Fixed condensers should be of the mica tag type for sizes greater than ·0001 μF; below this capacity the special ceramic condensers made by *Dubilier* and *T.C.C.* are much to be preferred, as they are very small, have lower losses, and remain remarkably constant under all conditions. A suitable capacity for a receiving grid condenser is 50 μμF, whilst for a by-pass position ·0003 μF should be chosen. A higher capacity confers no benefit, as this value presents minimum impedance. The so-called "non-inductive" tubular paper types should *not* be included in the high frequency parts of the circuit.

Coils

There is no necessity to make receiving inductances of very thick wire, nor should the turns be widely spaced. The reduction in self-capacity obtained by spacing the turns more than one diameter is negligible, but the reduction in inductance is considerable, resulting in an increased number of turns being required to reach the desired inductance value. The net result is a coil of higher resistance and lower efficiency. The special silver-plated coils mounted on ceramic bases made by *Eddystone* are to be recommended.

A compromise has to be struck in the design of transmitting inductances, and the use of coils made of copper tubing is deprecated, unless of a very small diameter, such as 1/8th inch. In modern circuits, of high L/C ratio, the current flowing is small, so that the power loss is also small, even when comparatively thin wire is used; but considerable eddy current losses occur through the mass of metal in copper tube coils being in a rapidly changing magnetic field. No. 12 or 14 s.w.g. wire is quite suitable for inputs up to 50 watts, and the skin resistance will be reduced if the wire is silver-plated. This can easily be done by first cleaning with a scouring powder, polishing brilliantly, and then rubbing vigorously with a dry mixture consisting of ¼-oz. silver nitrate, ¼-lb. cream of tartar, and ¾-lb. common salt.

Assembly

Apparatus should, whenever possible, be constructed on an aluminium or copper chassis, the stability being thereby improved. All earth returns for any one circuit should always be taken to the cathode or filament of the valve involved, either direct, or *via* by-pass condensers, by the shortest possible path. These precautions will ensure that circulatory currents are not set up in the chassis; such currents are very undesirable, as they tend to cause unwanted couplings with other circuits, and interaction and instability may result.

It is advantageous to mount each stage (other than audio-frequency) in separate metal boxes, connected to each other and to earth at one point

World Radio History

only. This principle has been adopted in the superhet receiver described later.

Great care should be exercised in the lay-out of ultra-high frequency apparatus, and it is essential that all leads carrying radio-frequency current be made extremely short. Difficulty in reaching the desired frequency, and in obtaining oscillation, will be encountered if long leads exist.

Hand capacity, when encountered, is usually very difficult to cure (presuming a good lay-out has been adopted) and for that reason it is wise to fit extension controls to the main tuning adjustments.

Valves

The performance of valves when incorporated in u.h.f. apparatus differs very much from that obtained on lower frequencies. While some " normal " valves will work satisfactorily up to 56 Mc it is well worth while to use the special types now obtainable.

The " Acorn " type has been specially developed for this work and can be had as triodes and R.F. pentodes. These are physically very small, have closely spaced electrodes and have no base, the connections being brought out to short wire pins mounted in the glass envelope. The R.F. pentodes will give a definite stage gain up to 300 Mc.

The Osram HA1 receiving Acorn triode valve has a mutual conductance of 1·7 mA/V and an impedance of 11,700 ohms.

Among other suitable valves are the " E " type made by *Mullard* and *Tungsram*. There is a wide range of these and with careful layout and choice of components they will give excellent results. The *Osram* HL2/K (now only supplied to order) and *Hivac* D210SW and midget valves give useful results for battery and portable work and many other normal valves have been used successfully.

With transmitting valves it is necessary to take into consideration factors which are negligible at lower frequencies. Owing to the flow to the valve elements of heavy charging currents at u.h.f. there is a risk of lead heating whilst the valve efficiency is reduced due to transit time and impedance losses. Further, the circuits employed are usually somewhat inefficient and in themselves constitute a heavy load for the valve. For these reasons ordinary valves have to be run at considerably reduced excitation and plate voltages (making for even lower efficiency) and triodes are difficult to neutralise. Pentodes have the disadvantage of having very high input capacities.

The most suitable valves for u.h.f. use are those having (*a*) low interelectrode capacities, together with close spacing of the electrodes to reduce transit time ; (*b*) a high amplification factor and (*c*) a low or medium optimum load impedance. Some of these requirements are conflicting but among those valves which strike a happy medium and have been produced especially for the work are the *Standard* 4316A, an enlarged version of the receiving Acorn triode which will operate at full ratings up to 600 Mc ; the *Standard* 4074A or *Raytheon* RK34 which will operate on full ratings up to 240 Mc and a number of higher power valves such as the *Mullard* TY1–50, *Osram* DET12, etc. Of the more normal valves which give quite satisfactory results may be mentioned the *Raytheon* 6E6 ; *Osram* KT8 (a beam tetrode of the RK39 type) ; *Taylor* T20, *Ediswan* ESW20, *Mullard* TZ08–20, and others of this class, and the *Tungsram* APP4G (pentode). For battery portables the *Osram* LP2 is an excellent valve and good results can be obtained with the *Hivac* PX230SW which has grid top cap and ceramic base.

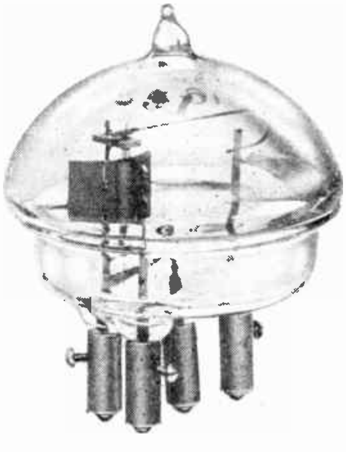
All filamentary type valves, receiving or transmitting, should have a fixed mica condenser of from 100 μμF to 300 μμF connected across the filament at the valveholder, and also similar condensers from each side to earth, in order to reduce the impedance to R.F. to a low value. Indirectly heated cathode type valves should have the heaters similarly connected to earth. At frequencies above 60 Mc it is essential that R.F. chokes be inserted in the filament leads.

It is very important that the filament voltage, as measured at the valveholder, be kept at the full rated value. The efficiency of a valve falls off very quickly if the voltage is low, and becomes more pronounced at ultra-high frequencies, when ample emission is essential for good results. This point is one often overlooked when newly built apparatus fails to come up to expectations.

The valves specially designed for 56 Mc can be run at full ratings, but the anode voltage should be reduced on other types, or the excessive dissipation will unduly shorten the life.

Frequency Measurement

Measuring frequencies of the order of 56 Mc presents a difficult problem to those who have had little previous experience. It is only too easy to imagine that the frequency range is correct, when, in fact, it is many kilocycles out.



Type 4316A Standard Telephones and Cables transmitting Acorn suitable for operation up to 600 Mc.

Two types of wavemeter are desirable, one of the absorption and one of the heterodyne type, the latter being preferably modulated, so that it will provide a source of signal voltage for testing and lining up receivers. The absorption type gives very definite indications to a reasonable degree of accuracy, provided no lamp is included in series with the tuned circuit. Such a lamp flattens out the resonance curve far too much, and reduces the sensitivity, so that the meter has to be held much nearer the circuit under test than is desirable. A suitable wavemeter can be made by mounting a 40 μμF variable condenser in parallel with a 25 μμF air-spaced trimmer, and fitting a single 2-inch diameter loop of wire across the terminals. This combination will open out the band on the dial, and resonance will be indicated in a receiver by a sharp click in the telephones as oscillation stops and recommences. When used with a transmitter, a loop and bulb is placed near the tank coil, resonance of the wavemeter being indicated by a dimming of the bulb. A kick upward will also occur in the anode milliameter.

A suitable form of heterodyne wavemeter circuit is shown in Fig. 1. A H.T. voltage of 60 should be ample for normal purposes. The pitch of the note will depend on the transformer and R_2, which should be varied between 1,000 and 10,000 ohms until a pleasant high-pitched tone results.

Both of these meters can be calibrated by hanging up, as clear as possible, an 8 ft. length of wire, and connecting one end to a small variable condenser, of the 3/30 μμF type, and the other to the tuned circuit by a lead not more than 3 or 4 inches long. If the receiver is oscillating in the 56–60 Mc band a point will be found on the dial where oscillation ceases, due to aerial absorption. Disconnect the aerial to make sure that this dead spot is not due to a choke resonating. Reducing the aerial length by 5 inches will give a different dial reading, after which the limits of the band can be obtained by picking up the harmonic of a crystal oscillator or a calibrated receiver oscillating on 28 or 14 Mc.

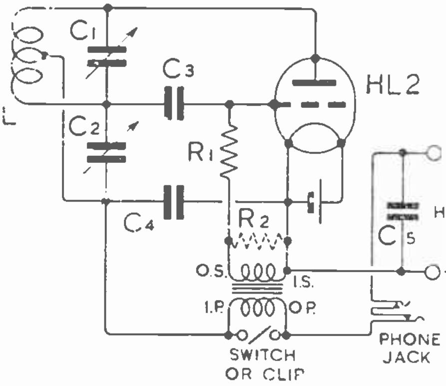


Fig. 1.

Recommended circuit for a heterodyne wavemeter for use at frequencies around 60 Mc. Transformer primary connections should be reversed if audio oscillation does not occur.

C_1	3/30 μμF, mica trimmer.	R_1	1 megohm
C_2	15 μμF, variable.	R_2	See text.
C_3	.0001 μF, tag type.	L	3 turns, ¾-in. dia. double spaced.
C_4	.0003 μF, tag type.	Trans.	3 to 1 ratio.
C_5	2 μF, paper.		

RECEIVERS

Receivers fall into three main types (*a*) super-regenerative (also known as quench), (*b*) straight and (*c*) superheterodyne. Each type possesses, peculiar advantages and disadvantages.

(*a*) The super-regenerative receiver has a high degree of sensitivity, and is discriminating to ignition interference, which can be very troublesome near main roads. It is also very unselective, consequently a signal, which varies from any cause, can easily be held. At the same time, the noise level is high, and as a result it is difficult to decipher weak signals. C.W. cannot be received, and it is necessary to modulate a carrier, either by telephony, or tone signals, if reception is to be intelligible.

(*b*) The straight receiver is much more selective, and, as the background noise is low, two audio-frequency stages can be used to bring up the strength of weak signals. Telegraphy signals can be received as well as telephony, but it is essential that the carrier carrying the speech modulation be clean, with little or no frequency modulation. A self excited oscillator when used on 56 Mc suffers from bad frequency modulation and as a consequence the carrier is liable to split. Such signals will only be heard as rough noises, received over a wide range of frequencies.

Weak signals are much easier to decipher, owing to the lower background noise of a straight, as compared with a super-regenerative receiver.

(*c*) The superheterodyne gives much greater sensitivity and selectivity, the latter being so high that it is usually impossible to hold signals other than those transmitted from a stabilised oscillator. By fitting variable selectivity to the I.F. stages this can be partly overcome. Tuning will be sharp, and interference from nearby stations kept very low.

Operating Difficulties

The chief troubles encountered with the first two types of receiver are hand capacity and threshold howl. Both result to some extent from details of the design and lay-out but if the R.F. currents are prevented from straying, these troubles will not occur. The leads to the power supplies often accidentally resonate; altering the lengths sometimes effects a cure. A liberal number of by-pass condensers and chokes in the telephone leads will also help. Threshold howl is sometimes due to a microphonic valve, but is more likely to be caused through R.F. reaching the A.F. stages, in which case grid stopper resistances usually overcome the trouble.

Smooth reaction control is very desirable, and for that reason it is advantageous to combine the capacity and potentiometer control methods. The reaction condenser is set to give smooth oscillation, with the potentiometer, of fairly low value (say 10,000 ohms) at middle setting, and fine control is carried out on the latter. Frequency variation will be at a minimum if this method is used. The reaction coil should consist of as few turns as possible, tightly coupled to the grid coil.

World Radio History

Band spread is more than ever essential, and the ratio of the band spread to the band set condenser will depend upon the type of signals it is intended to receive. With unsteady or creeping signals the band set should be fairly large, say 40 $\mu\mu$F, with a two-turn coil, and a band spread capacity of about 10 $\mu\mu$F, under which circumstances it is not difficult to hold and read very unstable signals. With steadier signals both capacities can be reduced to 25 $\mu\mu$F and 7 $\mu\mu$F respectively, which, with a larger coil, will result in greater sensitivity.

Whatever type of receiver is in mind the fitting of a tuned R.F. stage confers many benefits. A certain amount of signal amplification will be secured; radiation, will be prevented; a swinging aerial will not cause the signals to "wobble"; the aerial load will be removed from the detector stage, (resulting in improved reaction control), whilst dead spots (due to aerial resonance), will be eliminated.

The Straight Receiver

The principles previously outlined have been incorporated in the circuit, Fig. 3. The aerial is inductively coupled to the fully tuned radio-frequency stage, and, as tuning is not extremely critical, only one variable condenser is required, whilst a slow-motion dial, although undoubtedly desirable, is not essential. A very small ceramic condenser couples V$_1$ to V$_2$, but better results may sometimes be obtained if inductive coupling is used at this point, although careful adjustment in the number of turns of the anode coil, and of its distance from L$_3$ will be necessary.

In this particular circuit allowance is made for the received signals being of poor stability, and, as mentioned previously, the capacities of C$_2$ and C$_3$ may be decreased, if desired. C$_3$, as purchased may be too large in which case one or two of the fixed vanes should be removed.

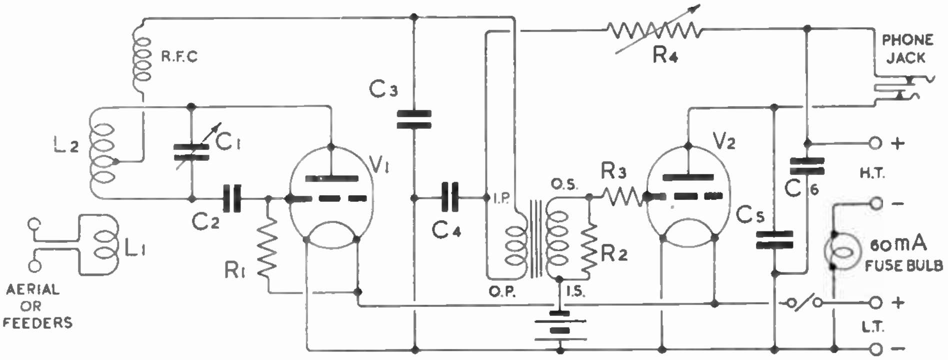


Fig. 2.

Circuit of a self-quench type of super-regenerative receiver.

L$_1$	3 turns, 1050 Eddystone.
L$_2$	5 turns, 1050 Eddystone.
C$_1$	15 $\mu\mu$F, midget, J.B.
C$_2$	50 $\mu\mu$F, ceramic cup, T.C.C.
C$_3$	500 $\mu\mu$F, M, T.C.C.
C$_{4,6}$	2 μF, 65, T.C.C.
C$_5$	300 $\mu\mu$F, M, T.C.C.

R$_1$	3 megohms, 0.5 watt, Dubilier.
R$_2$	250,000 ohms, 0.5 watt, Dubilier.
R$_3$	25,000 ohms, 0.5 watt, Dubilier.
R$_4$	50,000 ohms, variable V/4, Polar.
V$_{1,2}$	Battery, HL2/K and HL2 Osram. Mains, HL4g, Tungsram.
R.F.C.	Type B, Q.C.C.

An untuned stage will give some of these advantages, but is liable to bring in harmonics of stations on lower frequencies. Broadcast break-through may also occur when used in the vicinity of a broadcasting station.

The Super-Regenerative Receiver

A typical circuit of the self-quenched type of super-regenerative receiver is shown in Fig. 2, which is capable of giving a very good performance. The quench action depends upon the condenser C$_3$, and it is sometimes desirable to vary the capacity of this either side of that specified, in order to obtain constancy throughout the tuning range. R$_1$ also affects the performance, and an interesting experiment is to use a grid leak of 10 megohms connected between the grid and H.T. positive. R$_2$ and R$_3$ will prevent threshold howl. The aerial coupling should be fairly tight, and as both sides of C$_1$ are at high R.F. potential, an extension control must be fitted to this condenser.

It will be noticed that whilst the tuning condensers are placed across the whole coil, the grids, in both stages, are tapped a turn or two down the coil. This method reduces the heavy damping imposed on the circuit by the input grid impedance, and results in sharper tuning, increased selectivity, and an increase in amplification.

Reaction is controlled in the first place by C$_4$ and finally, by R$_8$. According to the valve used, some adjustment of R$_5$ may be necessary in order to ensure both smooth reaction and efficient coupling to the A.F. stage. The circuit around the latter follows normal practice, although, as will be seen, several precautions have been taken to prevent stray R.F. getting through. A second A.F. stage may be added, using either resistance or transformer coupling, but in this case triode valves should be used in both stages, as the noise level will otherwise become noticeable.

A really good slow-motion dial, free from noise and backlash, must be used to control C$_3$, when the

World Radio History

receiver, as a whole, will be found as easy to handle as one operating on lower frequencies. The first tuned stage should be kept in resonance, indicated by a slight rise in background noise as the condenser is rotated.

The actual method of coupling the aerial will depend on the aerial or feeder system used. In most cases the three-turn coil specified should be connected, either one side to aerial, and one side to earth (or a counterpoise of 4′ 1″ in length) or both sides to 600 ohm feeders. The distance between L_1 and L_2 will require initial adjustment. If 72 ohm feeders are used, and they are to be recommended, all that is necessary is to arrange a one-turn coil around the low potential side of L_2.

The performance of this type of receiver is naturally largely bound up with the valves incorporated in it. For battery use V_1 can be the *Hivac* SG220SW, whilst, if a mains model is required, the *Tungsram* VP4B, or *Osram* W42 are suitable. All these valves have top grid caps, an advantage of which full use should be made when considering the lay-out. In the detector stage the *Hivac* D210SW or *Osram* HL2K are excellent battery valves to fit, and the *Tungsram* HL4g is a very good mains valve.

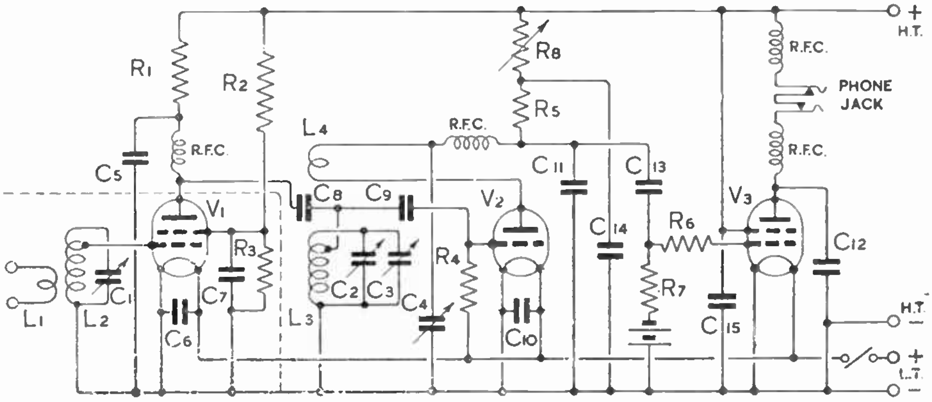


Fig. 3.

Circuit of a sensitive T.R.F. receiver, recommended for 56 Mc. telegraphy reception.

$C_{1,2}$	40 μμF, Webb's.
C_3	15 μμF, Webb's.
C_4	100 μμF, Webb's.
$C_{5,6,7,10,11,12}$	300 μμF, M, T.C.C.
C_8	10 μμF, ceramic disc, T.C.C.
C_9	50 μμF, ceramic cup, T.C.C.
C_{13}	.05 μF, 341 T.C.C.
$C_{14,15}$	2 μF, 65 T.C.C.
R.F.C.	Type B, Q.C.C.
R_1	1,000 ohms, 0.5 watt, Dubilier.
$R_{2,3}$	30,000 ohms, 1 watt, Dubilier.
R_4	5 megohms, 0.5 watt, Dubilier.
R_5	40,000 ohms, 1 watt, Dubilier.
R_6	25,000 ohms, 0.5 watt, Dubilier.
R_7	500,000 ohms, 0.5 watt, Dubilier.
R_8	50,000 ohms, variable, Dubilier.
V_1	Battery, VS24/K Osram.
V_2	Battery, HL2/K Osram.
V_3	Battery, KT2 Osram.
V_1	Mains, VP4B Tungsram.
V_2	Mains, HL4g Tungsram.
V_3	Mains, APP4C Tungsram.

It will be noticed that no grid bias is applied to the grid of the R.F. valve, and therefore the screen voltage must be kept reasonably low. If mains operation is used a certain minimum cathode bias should be incorporated, together with additional variable bias to provide volume control.

When the mains are used to supply the power for any of the foregoing receivers, R.F. filters and by-pass condensers should be fitted, to prevent modulation hum. Any such power supply should be earthed, but it is not essential to earth the receiver itself, as, in general, little difference in performance will be noted with or without an earth connection.

Superheterodyne Receivers

It is difficult on ultra-high frequencies to obtain any great degree of amplification in the radio-frequency circuits, and the principle of changing the incoming signals to a lower frequency, at which much greater amplification is possible, enables a receiver to be built possessing much greater overall sensitivity. At the same time the design of a superheterodyne for 56 Mc is not a simple matter and several points have to be taken into consideration. Second channel interference is unlikely to be encountered, except possibly in big centres, but image interference may easily occur when the comparatively low intermediate frequency of 465 kc is used, since the amateur band covers from 56 to 60 Mc. The best way to avoid this condition is to include a sharply tuned and properly aligned R.F. stage, which also confers the further benefit of higher signal to noise ratio.

If it was intended to receive television signals a very high intermediate frequency, of the order of 4 Mc, would be necessary to accommodate the wide band of frequencies, and this would entail special I.F. transformers. For the reception of telegraphy and telephony signals the standard I.F. of 465 kc is quite suitable, and has the advantage that use can be made of the numerous commercial I.F. transformers designed to give high gain.

The selectivity will naturally be considerably greater than that of a T.R.F. receiver, but this is an advantage, provided crystal control or some other method of frequency stabilisation is used at the transmitting station. When self-excited oscillators are used the selectivity of the superhet receiver can be reduced by fitting resistances across the I.F. transformer windings, but this is not recommended as the gain will be much reduced.

The most important stage in a superhet receiver is the frequency changer, from which it follows that care must be exercised in the valve chosen to perform this function. For frequencies higher than 56 Mc, or when the best possible results are desired, it is practically essential to use the Acorn type of valve. Particulars of a special design which incorporates three of these valves are given later.

Until recently, the normal type of triode-hexode frequency changer gave very poor results when applied to the ultra-high frequency bands, but recently, new types have made their appearance and, due to the incorporation of the principle of beaming the electrons, their performance on the ultra-high frequencies is satisfactory in every way and a perfectly normal type of short wave circuit may be used with them. The valves referred to are the 6K8G, made by *Standard Telephones* (*Brimar*) and *Tungsram*; the 6K8 made by *Raytheon* and *R.C.A.*; and the X65, made by *Osram*. The input impedance of these types being high, the grid may be connected directly to the "hot" end of the input circuit without affecting the latter, so rendering it unnecessary to make arrangements to tap down the grid on the coil. Pulling being absent, it is quite possible to tune the grid circuit through resonance without any change being audible in the beat note of a signal being received on 56 Mc. The gain obtainable is considerably greater than that given by the older types.

The usual care must be exercised in the lay-out of the ultra-high frequency circuits, whilst the I.F. and output stages can follow normal practice. A separate oscillator, working on a frequency of about one kilocycle above or below that of the intermediate frequency, should be included, so that it can be switched in at will, when it is desired to receive telegraphy.

A Practical 56 Mc Superheterodyne Design

In designing a superheterodyne receiver for operation on 56–60 Mc, the most important factor, to ensure success, is the choice of valves. In the practical design described three *Osram* Acorn valves have been used, a triode for the electron-coupled oscillator, a pentode for the radio-frequency amplifier, and another pentode as frequency changer, with suppressor grid injection.

The circuit, Fig. 4, shows only the three stages referred to, which are all enclosed in separate metal boxes, and it is necessary to ensure efficient coupling to the I.F. amplifier. This, preferably, will be a separate unit, although a normal receiver can, if desired, be pressed into service. Methods of coupling will be discussed later.

Taking the circuit in detail, the three main tuning coils are identical, being of the *Eddystone* 5-turn silver-plated type mounted on Frequentite bases. They are each centre-tapped for the grid connection whilst the oscillator coil has, in addition, a cathode tap one turn away from the "earthy" end of the coil. These taps are very short lengths of 18 s.w.g. tinned wire soldered on, connection to them being made by tiny clips, obtainable from

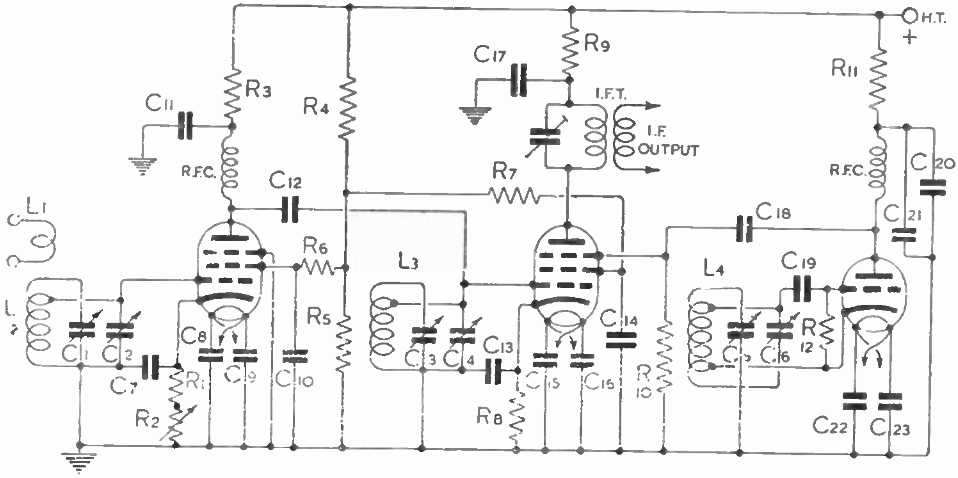


Fig. 4.

Circuit giving details of the radio frequency, frequency changing and oscillator portions of a 56 Mc. superheterodyne receiver. In this circuit the junction between C_5, C_6, C_6 and L_4 (lower end) should be shown earthed.

$C_{1, 3, 5}$	15 $\mu\mu$F, Webb's.	$R_{3, 6, 7,}$	1,000 ohms, 1 watt, F, Dubilier.
$C_{2, 4, 6}$	25 $\mu\mu$F, Polar.	$R_{4, 5}$	20,000 ohms, 2 watt, F, Dubilier.
$C_{7, 8, 9, 10, 11, 13, 14, 15, 16, 20, 22, 23}$	300 $\mu\mu$F, M, T.C.C.	R_{10}	100,000 ohms, 0.5 watt, F, Dubilier.
C_{12}	10 $\mu\mu$F, ceramic, T.C.C.	R_{11}	20,000 ohms, 1 watt, F, Dubilier.
C_{17}	.01 μF, 300, T.C.C.	R_{12}	50,000 ohms, 0.5 watt, F, Dubilier.
$C_{18, 19}$	50 $\mu\mu$F, ceramic, T.C.C.	L_1	3 turns, 1050, Eddystone.
C_{21}	1 μF, 250, T.C.C.	$L_{2, 3, 4}$	5 turns, 1050, Eddystone.
R_1,	100 ohms, 0.5 watt, F, Dubilier	R.F.C.	1011 Eddystone.
R_2	10,000 ohms, J, Dubilier.	$V_{1, 2}$	ZA1 Osram.
		V_3	HA1 Osram.

World Radio History

Bulgin. Crocodile clips, which are usually made of ferrous metal should not be used as they introduce severe losses due to being in the field of the coil.

The condensers C_1, C_3 and C_5, are identical, but, if used as purchased, the 56 Mc band will only occupy about 20 degrees on the dial. To increase the band spread it is desirable to remove two of the fixed vanes on each condenser. The condensers C_2, C_4 and C_6 fulfil two functions, in that they serve as trimmers, to line up the circuit, and also act as band setters. The latter condensers are not connected across the whole coil, but only across that part between the centre tap and earth. This makes trimming adjustments less critical. R_2 varies the bias on the first valve, and, except when strong local signals are being received, will be set to give full gain from the radio-frequency amplifier.

All the components mentioned are of small physical dimensions, and it is not difficult to build each stage in a box measuring 4″ long, 5″ wide and 5″ deep.

The screen grids of V_1 and V_2 are fed through decoupling resistances from the R_4, R_5 resistance network. Separate by-pass condensers are necessary, one in each box.

The third stage is likely to prove the trickiest, as here strong steady oscillation must be maintained at constant amplitude over the whole band. The particular circuit shown, in which coupling to the F.C. valve is purely electronic, thereby imposing little or no load on the oscillator (tuned circuit) has been found very successful. The method, often used, of connecting the suppressor grid straight on to the grid of the oscillator is not to be recommended, as it loads up that stage too heavily, and erratic operation results.

The first valve is mounted so that the anode pin projects through from the first box into the second, so cutting out a long lead, and making the screening more effective. The tuning condensers are mounted on the sides of the boxes. Condensers C_3 and C_5 serve to hold the boxes together, and in addition they make the only electrical connection between them. The three boxes should, of course, be firmly secured to a wooden base. C_2, C_4 and C_6 are mounted on small metal brackets bolted to the sides of the boxes near the top, so that they are easily accessible for adjustment. The resistances can be secured to small paxolin mounting boards, the condensers and R.F. chokes rigidly soldered in the wiring, and the other components firmly bolted to the sides. The tuning condensers are finally ganged to each other, and to the slow-motion dial, by means of flexible couplers and short extension spindles.

The secondary of the I.F. transformer shown will normally be connected one side to earth and the other to the grid of the first I.F. valve by means of a screened lead. If a transformer is already fitted in the amplifier a ·0001 μF condenser should be interposed. Alternatively, a screened broadcast choke may be fitted in place of the transformer primary shown in Fig. 4 and a screened lead taken to the input transformer (again *via* a fixed condenser). This method is the one to adopt when a receiver is used in place of an I.F. amplifier.

Lining Up Procedure

The first operation is to set the oscillator frequency. This is done by locating the oscillations on a frequency meter, or on a calibrated receiver, tuned for preference to the 28 Mc band. This operation should not be difficult, as the receiver should pick up a fairly strong signal, when placed close to the oscillator, which will be open at the top. With the dial set at a central position the trimmer condenser C_6 should be adjusted until the oscillator frequency falls as close as possible to the middle of the band, *i.e.*, 58 Mc. Care must be taken to ensure that a wrong harmonic has not been selected by testing with an absorption wave meter held near the oscillator coil—the beat note should jump as the meter is tuned through resonance.

The test oscillator, the circuit of which is given in Fig. 1, is now loosely coupled to the input of V_1, and the middle trimmer C_4 adjusted until an output is obtained from the amplifier. As it is a well-known fact that the ear is comparatively insensitive to small changes of volume, some form of visual indicator should be used to measure the output. Two settings of C_4 will be found—the highest capacity being the correct choice. C_2 is next adjusted, and, as this will bring up the volume level, it will be necessary to loosen the coupling to the test oscillator. The above remarks presume that the I.F. amplifier has been previously lined up—if this is not the case it should of course claim first attention.

Aerial Coupling

If low impedance (72 to 80 ohm) feeders are used for coupling the aerial to the receiver, L_1 will consist of a single turn closely coupled to the "earthy" side of L_2. In the case of 600 ohm feeders an *Eddystone* three-turn coil should be mounted in close proximity to L_2, and be arranged to rotate, so as to vary the coupling. The same coil will prove suitable when an ordinary single wire aerial is used, one end being connected to the aerial, and the other to the chassis (or earth), or, better still, to a 4′ length of insulated wire, which will act as a counterpoise.

A further improvement in signal strength may result if a series condenser (40 μμF) is interposed between the aerial and L_1, and varied to bring the aerial circuit into resonance.

CONCENTRIC LINE TUNED CIRCUITS

During recent years the limit of the efficiency of tuned circuits involving coils of conventional design and size appears to have been reached. It has been appreciated for some time that a length of transmission line can be used as a tuned circuit for the frequency at which it is resonant. Owing to the fact that the losses in such a line can be reduced by the use of conductors of adequate dimensions, the efficiency of such tuned circuits is very much greater than can be achieved by using ordinary coils. Perhaps the most efficient form is that of a line consisting of two concentric tubes or pipes.

Even at such high frequencies as 112 Mc quarter wave-length lines, although feasible in a transmitter, become very cumbersome in receivers where several tuned circuits are generally required to be used in a compact space.

World Radio History

It has recently been found practicable to reduce the length of the line considerably and to tune it to resonance by means of an added condenser. In other cases it has been proposed to utilise some adjustable length of line by the use of a "trombone" slide arrangement. Although such schemes appear to be a compromise between the fully resonant line and the normal tuned circuit the increase in the Q of the circuit so produced is considerable. In fact it can be said that such methods are the only possible ones by which tuned circuits, comparable in efficiency with those commonly employed for the lower frequencies can be made.

Methods have been further developed by which superheterodyne circuits can be accurately tracked in the usual manner when using such concentric lines. Detailed information on the subject was published in the March and May 1940 issues of *The T. & R. Bulletin.*

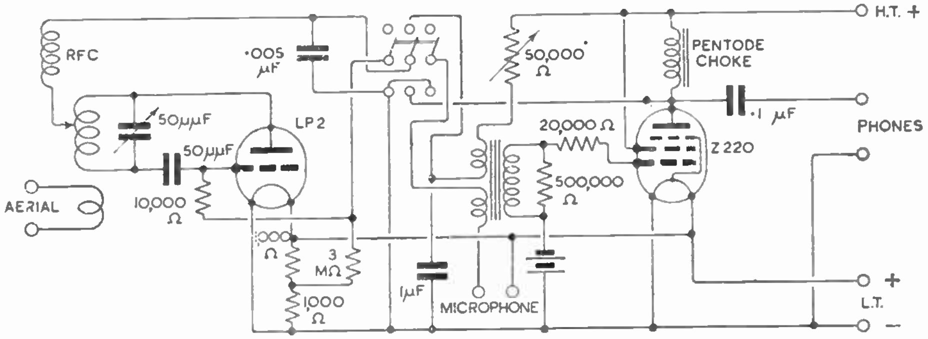


Fig. 5.

Circuit of a typical battery operated low power Transceiver.
In the above circuit the 1 μF condenser should be connected to LT-(earth) from the opposite side of the transformer primary.

TRANSMITTERS

Self-Excited Types

Developments during the few years prior to the war tended to relegate self-excited transmitters into the background, it having been found that for serious experimental work a stable form of carrier was essential.

A popular form of self-excited arrangement, used chiefly for portable work, was that known as a transceiver, which as the name conveys is a combination of transmitter and receiver. They were usually battery-operated, although the improved performance which mains valves give could be taken advantage of if ample power supplies (a car battery for instance) were available.

A typical circuit is given in Fig. 5. The first valve (an LP2 or similar type) acts as a self-quenched detector in the receiving position, and as a power oscillator when transmitting. The second valve is a pentode, which acts alternatively as the output, or as the modulating valve. A combined A.F. and microphone transformer, saves space, and simplifies the switching necessary. A sensitive carbon microphone is essential, as no speech amplifier is available.

The oscillating circuit (known as the "ultraudion") is one which can be relied upon to give results with almost any valve. A separate self-excited transmitter may be quickly and cheaply constructed using this circuit and, provided it is built with due care and attention to detail, a fairly stable note is obtainable from it.

For serious work, however, the self-excited transmitter is not satisfactory. The frequency is liable to creep as the valve heats up, vibration of the apparatus, or swaying of the aerial in the wind, will cause the frequency to vary, and only a low percentage of modulation is permissible—not more than 50 per cent. Beyond this, serious frequency modulation occurs, the side bands are cut up and the carrier may even split. This latter effect is not noticeable when the signals are received on a super-regenerative receiver, but on a straight, or superhet receiver, the speech becomes unintelligible.

It is anticipated that when amateur transmitting recommences in Great Britain self-excited u.h.f. equipment will become as obsolete as spark transmitters were in 1939.

The Resonant Lines Oscillator

A great improvement over the normal self-excited oscillator is the type incorporating two parallel quarter wave lines in either the grid or plate, or both, circuits. Once the lines are adjusted to the operating frequency the valve has little effect, and, provided the elimination of vibration has been taken care of in the construction, the output is very steady, and unaffected by external influences. Half-inch copper or aluminium tubing is the material usually used for the lines and this should be very rigidly mounted, with a spacing between centres of approximately $1\frac{1}{2}''$. It is often advantageous to connect the grids some distance down the lines, instead of to the ends, as shown in Fig. 6 which illustrates the method of using a *Standard* 4074A valve. The actual length of the tubes will be rather less than a quarter wavelength each, owing to the loading effect of the valve capacities, and 3′ 6″ is approximately correct. When a similar circuit is used on the anode side the lines should be mounted at right angles to the grid lines. The frequency is varied by means of a sliding shorting bar, which being at a voltage node, is the point at which connection should be made to the grid leak, power supply, etc.

The particular circuit shown, which is very efficient, may be used with inputs of from 5 to

World Radio History

25 watts, as the valves specified have unipotential cathodes, thereby preventing carrier modulation when A.C. is used on the heaters. Further they have been specially designed for the ultra-high frequencies.

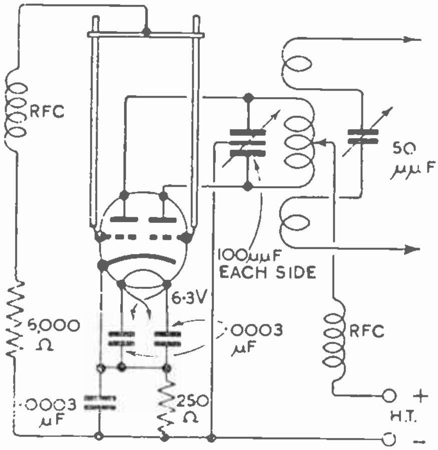


Fig. 6.

Resonant lines oscillator circuit, incorporating a type 4074A valve.

The Master Oscillator-Power Amplifier

Several variations of this type of transmitter are possible. The master oscillator may be either (*a*) an ultraudion, or similar circuit, designed to give higher stability, and therefore incorporating a low L/C ratio in the tuned circuit, (*b*) a resonant lines circuit similar to that shown in Fig. 6, or (*c*) an electron-coupled oscillator, preferably with the cathode circuit tuned to approximately 19 Mc, and the anode tuned to the third harmonic, which arrangement gives just as much output, but with greater stability, than when the second harmonic is used. Whichever circuit is chosen the valve should be run well below its ratings, and it is desirable to use one in the M.O., of similar type to that in the P.A., *e.g.*, a 4074A valve, driving another 4074A in the final stage would be an excellent arrangement. If method (*c*) is favoured a *Standard* 4061A (equivalent to the American RK25) could be used in the first stage, and a 4074A in the second.

Driven Transmitters

In the past there had been difficulty in obtaining satisfactory results from driven transmitters with efficiency and economy, but as valves and components improved the problem became easier.

The chief advantages to be expected are (*a*) the emission of a very much steadier signal and (*b*) a sharp wave. Such a transmitter is also capable of being modulated to a greater degree. In the case of (*a*) the signal can be received on a super-heterodyne receiver, and in consequence it is much easier to hold or copy on any receiver; (*b*) means that the transmitted energy is confined to one frequency, instead of being spread over a band. As a result the distance covered is likely to be considerably greater.

The modulation of a self-excited transmitter has to be kept low, because the variation in anode potential results in frequency variation, *i.e.*, frequency modulation. When a driven transmitter is used the frequency of the final stage does not (or should not) vary with anode potential, and a high degree of modulation may be used, whilst the energy is still confined to a narrow band of frequencies. Master oscillators do suffer, to some extent, from frequency modulation when a high percentage of modulation is used, due to the varying valve input reacting back on the primary oscillator.

On very high frequencies it is difficult to construct a self-excited oscillator (under which class must be included the E.C.O.) which is absolutely steady. On first switching on, the frequency usually creeps considerably, through the valve heating up. It will settle down after some time, if left running, but this will be very inconvenient during reception periods. It is also difficult to avoid a chirp when using telegraphy as the keying varies the load in some part of the circuit. If a low frequency oscillator is used the necessity of many doubler stages is a disadvantage, and it must be remembered that any slight drift or variation in the first stage will be serious—for instance, a half kilocycle variation on a fundamental of 3,500 kc will result in a change of eight kilocycles in the 56 Mc final stage.

For these reasons the use of crystal control is very desirable and it is incorporated in the practical transmitters described.

The choice of valves is an important consideration, especially in the final or power amplifier stage. The desirable characteristics of a suitable valve have been mentioned earlier, but it can be stated, as a general rule, that with one or two exceptions, pentodes are not suitable for the final stage, although they will be useful in earlier stages, where a lower frequency is applied. The reason is that both the input and output capacities are high, and the usual advantage of low grid drive is more or less lost.

The modern types of high efficiency triode, such as the *Ediswan* ESW20, have been found to give the best results.

When pentodes are used in any stage great care must be taken to see that the harmonic selected in the anode circuit is the correct one, as both second and third harmonics will give practically equal outputs, whilst many higher ones may also be found to light a loop and bulb. The only safe way to check is with an absorption meter, when the indication of resonance will be a very definite one.

The chief requirement of the final stage of a transmitter is ample driving power, and this has been one of the difficulties which have had to be overcome. The various stray capacities of the components and valves employed have the effect of partly by-passing to earth the available energy. Some of these capacities, being in parallel with the tuned circuit, have made it necessary to use a very small inductance, so reducing the R.F. voltage developed. It must therefore be borne in mind that considerably more driving power must be provided than is normally called for.

From 28 Mc upwards the size of condensers used for inter-stage couplings should be very small—not more than 50 μμF, and usually less.

Whenever possible, inductive coupling, with separately tuned circuits, is preferable ; links may be used for this purpose.

The ratio of inductance to capacity in the anode circuits must be kept as high as possible, in order to allow high R.F. voltages to develop. The final valve often acts as a doubler from 28 Mc to 56 Mc, but there is no reason, provided care in the lay-out is exercised, why a straight power amplifier should not be used, with a worth-while increase in output.

Two valves connected in push-push, *i.e.*, grids in series and anodes in parallel, is a much more effective arrangement for power doubling than a single valve. The output tank circuit receives a "kick" every half-cycle instead of every cycle, and, consequently, the output is greater in proportion.

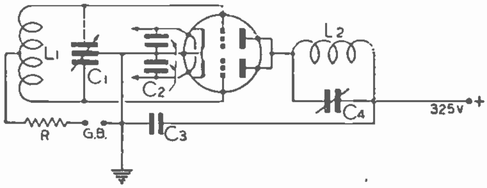


Fig. 7.

Circuit of a Push-push Doubler Stage.

C_1	**25 $\mu\mu$F (50 + 50).**
C_2	**300 $\mu\mu$F, mica.**
C_3	**100 $\mu\mu$F, ceramic.**
C_4	**18 $\mu\mu$F.**
R	**5,000 ohm, 1 watt.**
G.B	**—21 v. grid bias.**
L_1	**11 turns, 16 s.w.g., 1¼" dia., 1½" long.**
L_2	**4 turns, 12 s.w.g., 1⅛" dia., 1¼" long.**

Fig. 7 illustrates a *Standard* 4074A (or RK 34) valve used in this manner. The split-stator grid condenser should have a working capacity of 20–25 $\mu\mu$F (40 to 50 $\mu\mu$F each side) while an 18 $\mu\mu$F microdenser serves admirably for the plate tuning condenser. If the valve is mounted horizontally it will facilitate the layout enabling the heater and anode by-pass condensers to be connected, with very short leads, direct to the cathode pin of the valve holder.

The drive from the previous stage (28 Mc) is best transferred by means of a link, connected to one or two turns placed round the centre of the grid coil, whilst one turn at the "earthy" end of the tank coil, connected to *Belling-Lee* 80 ohm cable, provides a convenient means of feeding the aerial.

Type 4074A Standard Telephones and Cables twin triode suitable for use at 28 or 56 Mc having two separate triodes within the bulb, each anode connected to a top cap.

A Two Valve Crystal Control Design

Due to the advent of crystals developed to work on a fundamental frequency within the 28–30 Mc amateur band it has become possible to use crystal control on 56–60 Mc without resort to a series of frequency multipliers. Until these special "thick cut" crystals became available it was necessary to use either a 7 or 14 Mc crystal.

A 56 Mc transmitter embodying a 28 Mc crystal has the following advantages :—(*a*) it need occupy only a very small space ; (*b*) it can be run entirely off one moderately rated power supply ; (*c*) it will utilise only two valves ; (*d*) it will give a really useful output on 56 Mc, and (*e*) it will be simple to adjust. The crystal and valves are rather expensive, but against this can be placed the saving in the number of valves, and quantity of components required.

The 28 Mc. crystals are quite robust, but the type of valve used with them must have a low input capacity, as a high capacity will act as a by-pass condenser, and prevent much R.F. voltage developing. The *Standard* 4074A (or RK34) twin triode valve has the proper characteristics, and both space and wiring are saved by using one section as the crystal oscillator, and the other as the doubler.

A suitable circuit is given in Fig. 8. The first tuned circuit has a fairly low L/C ratio (which results in a greater radio-frequency output), whilst a fairly high L/C ratio is used in the doubler anode circuit. Coupling is capacitative, and bias for both stages is obtained partly by the cathode resistance R_3 and partly by the rectified grid current flowing through R_2. The by-pass condensers C_6 and C_7 are returned direct to the cathode, which is separately by-passed through C_5 to the chassis. This form of construction, which should always be adopted in high frequency apparatus, prevents circulatory currents in the chassis, which would result in undesirable coupling with other stages, tending towards instability. The first two stages are metallically screened from the power amplifier, in which an Acorn transmitting valve is used. This valve, the *Standard* 4316A, possesses more of the previously mentioned desirable features than any other. No base is fitted, but connections are made, by means of small metal sleeves, direct to the short pins projecting from the hard glass of which the valve envelope is constructed.

The R.F. energy appearing in the circuit C_2 L_2 is transferred by means of link coupling, one turn being adjusted close to the low potential ends of L_2 and L_3. Careful attention to the adjustment of the actual coupling is necessary in order to obtain maximum drive.

A special by-pass arrangement is adopted, whilst bias is obtained chiefly by means of a 60-volt battery. Neutralising is, of course, necessary, but as it is undesirable to introduce a large mass of metal (as would occur with a commercial condenser), one of special type should be made by mounting two small copper plates on an *Eddystone* 1051 base.

The transmitter which formed the basis for this description was built on an aluminium chassis, measuring 15" by 9", and incorporated a *Partridge*

World Radio History

transformer to provide the filament voltages. Other supplies were connected *via* a *Belling-Lee* 5-pin plug and socket. The power supplies could well be built on a similar chassis, and mounted, rack fashion, below the transmitter proper.

The tuning adjustments follow the usual practice, except in the case of neutralising the power amplifier. This is best done by applying about 250 volts to the anode of the 4316A, and varying the distance between the two plates of the neutralising condenser, until self-oscillation does not occur, no matter what may be the position of the grid and tank-tuning condensers.

When tuning the anode condenser through resonance a much greater dip of current will be noticed compared with that usually obtainable in 56 Mc transmitters.

There is one further advantage available in a transmitter of this type. There are three tuned circuits on 56 Mc, therefore it is impossible for the original frequency to reach the final circuit. If a low impedance feeder is used, the junction of feeder and aerial is an absolute mismatch to any frequency lower than 50 Mc from which it follows that no signals are radiated except on the intended frequency.

A Crystal Controlled 56 Mc Portable Transmitter.

The crystal controlled transmitter shown in Fig. 9 was designed especially for portable work on 56 Mc. It is capable of being operated from H.T. batteries, a small convertor or a vibrator. Constructional details and an outline of the initial experiments leading up to the final design, appeared in the July 1939 issue of *The T. & R. Bulletin.*

When operated at 250 volts plate supply, the power consumption is about 20 watts, and the output 5 watts. At a voltage of 100 on the plate the total drain is 3 watts and the output a little over half a watt.

The components are mounted on a chassis measuring 12" long, 8" wide and 3" deep, a clear appreciation of layout being seen from an examination of the side elevation photograph, Fig. 10.

A 7 Mc crystal is employed in conjunction with a double pentode valve (V_1) of the ELL 1 type, one half of which is used as a straight C.O and the other as a 7 Mc to 14 Mc doubler. The coils L_1 and L_2 are both wound with 22 s.w.g. D.S.C. wire on a 1" diameter paxolin tube, the former having 20 turns close wound, and the latter 14 turns spaced to occupy 1 inch.

V_2 is a 6V6G valve operating as a 14 Mc to 28 Mc doubler, the output being applied in push-pull to the grids of V_3 which is a *Standard* 4074A or a *Mullard* TV03/10 valve. L_3 comprises 6 turns of $\frac{1}{8}$" copper tube, 2" diameter, centre tapped. The trimmer C_{13} is adjusted to have a capacity equal to that of the anode to all other electrode capacities of V_2, and is intended to balance the capacity at either end of L_3 in order to maintain an equal drive to each grid of V_3.

V_3 is a double triode of the push-push type, operating as a power doubler, to 56 Mc, the anodes being effectively in parallel. The resistances R_8 and R_9 are employed only for the purpose of preventing parasitic oscillations.

The tank circuit of V_3 (L_4, C_{16}) which is of the series-tuned type is used because this arrangement

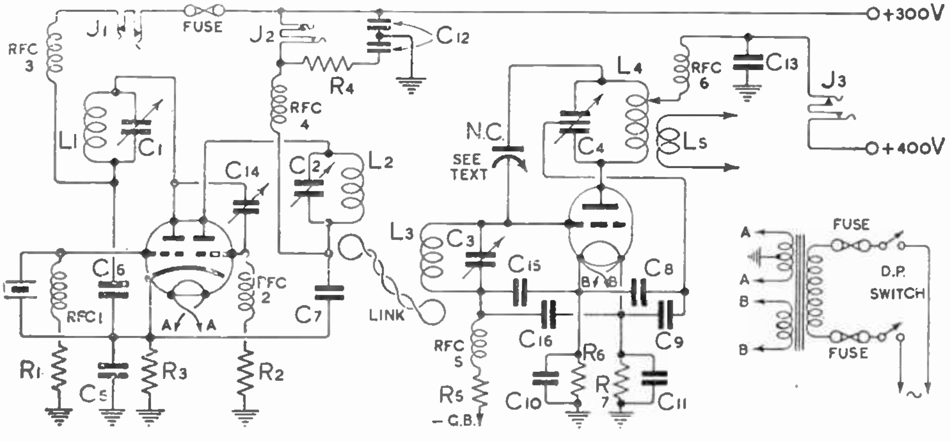


Fig. 8.

Circuit of a 25 watt crystal controlled transmitter employing a 28 Mc (10 metre) crystal.

R_1	1,000 ohms, 1 watt, Dubilier.	C_{12}	.1 × .1 μF, paper, 87A/2, T.C.C.
R_2	35,000 ohms, 1 watt, Dubilier.	C_{13}	.0003 μF, 340, T.C.C.
R_3	400 ohms, 2 watt, Dubilier.	C_{14}	4/30 $\mu\mu$F, trimmer, 1023, Eddystone.
R_4	1,000 ohms, 2 watt, Dubilier.	$C_{15, 16}$	100 $\mu\mu$F, ceramic cup type, T.C.C.
R_5	5,000 ohms, 2 watt, Dubilier.	$RFC_{1, 3}$	R.F. chokes, A, Q.C.C.
$R_{6, 7}$	50 ohms, 1 watt, Dubilier.	$RFC_{2, 4}$	R.F. chokes, B, Q.C.C.
C_1	45 $\mu\mu$F, single midget with S/M, J.B.	$RFC_{5, 6}$	R.F. chokes, 1011, Eddystone.
$C_{2, 3}$	15 $\mu\mu$F, single midget C_2 with S/M drive, C_3 without, J.B.	V_1	4074A, Standard.
		V_2	4316A, Standard.
C_4	15 × 15 $\mu\mu$F, twin midget, J.B.	$L_{1, 4}$	8 turns, 1050, Eddystone.
C_5	.001 μF, mica, M, T.C.C.	$L_{2, 3}$	6 turns, 1050, Eddystone.
C_6	.0005 μF, mica, M, T.C.C.	L_5	3 turns, 1050, Eddystone.
$C_{7, 8, 9, 10, 11}$	.0003 μF, mica, M, T.C.C.		

enables an inductance approximately four times greater to be achieved than would be possible with normal parallel tuning. L_4 comprises 8 turns of ⅛″ copper tube 1½″ diameter, spaced to occupy 2″. The aerial is coupled by a single turn link-wound around the centre of L_4. The bias resistances R_5 and R_7 restrict the current to normal in the event of the drive failing, whilst R_2 protects V_1 in case the crystal fails to oscillate. For telephony work V_3 can be anode modulated, in which case a power of 5 watts, at an impedance of 6,000 ohms is required.

A Three Valve Crystal Controlled Transmitter

The transmitter pictured in Fig. 11 differs from the design just described in that it employs a 7 Mc crystal and has a "normal" type of valve as the power amplifier. It comprises two units, both mounted on *Radialloy* chassis, one being the power supply and the other the transmitter proper. The valves employed for the latter are: *Mullard* or *Tungsram* 6V6G as a tritet (14 Mc output); *Standard* 4074A as a two stage doubler (28 Mc and 56 Mc outputs); *Tungsram* OQ 15/600 as a neutralised Power Amplifier (56 Mc). Reference to Fig. 12 will show that the circuit arrangements follow normal practice.

There are, in effect, three separate units mounted on the one chassis, the tritet being coupled inductively to the first doubler, while the output from the second doubler is link coupled to the grid of the P.A. This link (a short length of *Belling-Lee* 80 ohm cable) can clearly be seen in the photograph.

A *Q.C.C.* plug-in crystal holder is used and the cathode tuning of the tritet being aperiodic, the whole of the 56–60 Mc band can be covered simply by changing the crystal and slightly retuning the three controls at the front—namely second doubler anode, P.A. grid and P.A. anode.

Three *Bulgin* midget meters are included to give current readings in the P.A. anode, P.A. grid and both doubler anodes. This latter is achieved by means of the switch on the right. The left hand switch allows the P.A. anode supply to be cut off when making preliminary adjustments, etc. A jack at the rear of the chassis allows the tritet anode current to be measured on an external meter.

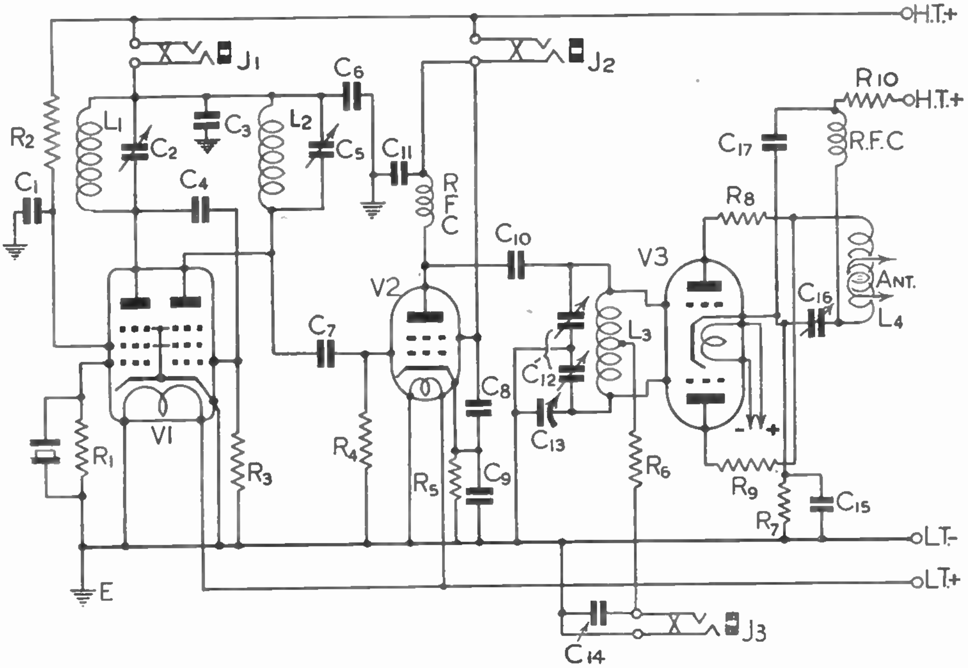


Fig. 9.

Circuit of a 56 Mc Crystal Controlled Portable Transmitter.

$C_{1,9,14}$	.01 μF, mica, 975W, Dubilier.	R_1	50,000 ohms, 1 watt, Erie.
C_2	50 μμF, Webb's.	$R_{2,3,4}$	100,000 ohms, 1 watt, Erie.
$C_{3,4,6,7,17}$	100 μμF, mica, 675, Dubilier.	R_5	400 ohms, 1 watt, Erie.
C_5	15 μμF, Webb's.	R_6	20,000 ohms, 2 watts, Erie.
C_8	500 μμF, mica, 675, Dubilier.	R_7	150,000 ohms, 1 watt, Erie.
C_{10}	100 μμF, ceramic, C.C., Dubilier.	$R_{8,9}$	5 ohms, 0.5 watt, Erie.
C_{11}	1,000 μμF, mica, 975W, Dubilier.	R_{10}	250 ohms, 3 watts, Erie.
C_{12}	40 μμF, split stator, 1068, Eddystone.	V_1	ELL 1, Tungsram.
C_{13}	3-15 μμF, 340115, Dubilier.	V_2	6V6G, Mullard.
C_{15}	200 μμF, mica, 675, Dubilier.	V_3	4074A, Standard
C_{14}	18 μμF, 1094, Eddystone.		

Coil data is referred to in text.

World Radio History

Eddystone silver-plated coils are used for the first doubler (8 turns); second doubler (6 turns); and P.A. anode (8 turns centre tapped and opened out to one diameter between turns). The tritet cathode coil comprises 11 turns of 14 s.w.g. wound to the same diameter as the other coils, the correct spacing of turns being determined experimentally.

The tritet anode (12 turns of 20 s.w.g. DCC close wound) and first doubler grid coil (9 turns 34 s.w.g. DCC close wound) are wound on a *Denco* former with plug base as are the P.A. grid coil (5 turns double spaced 20 s.w.g.) and two turn link coil, seen clearly in the photograph. *Denco* Polystyrene stand-off pillar insulators are used to raise the power amplifier coils above the chassis.

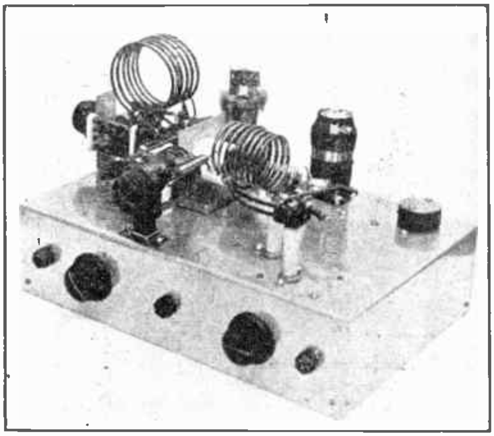


Fig. 10.

Side elevation of 56 Mc. Crystal Controlled Portable Transmitter.

The power amplifier plate tuning condenser is worthy of special mention as its small physical size makes it most suitable for u.h.f. work.

Bias is obtained in the earlier stages by cathode resistors and grid leaks, this method giving some protection to the valves in the event of excitation failing. For the P.A. stage battery bias (about 45 volts) and a grid leak are used.

The aerial is energised by 80 ohm feeder cable connected to a single turn round the centre of the power amplifier anode coil.

The remarks on tuning adjustments and power input given for the previous transmitter apply equally to this. Listening on a monitor or receiver gives a better indication of oscillation in the P.A. stage than the usual loop and bulb method, as the removal of this from the P.A. plate or grid coil, after balance is obtained, is liable to upset the adjustment.

The transmitter is completed by a dust cover made up of 1/8" *Masonite*, enamelled grey to match the chassis. This is removable for neutralising, etc., and being non-metallic it does not affect any adjustments when replaced.

OPERATION ON 112 Mc

The very high frequencies (or metre wavelengths) have for long evoked considerable interest among radio amateurs whilst during the past few years the possibilities offered by such frequencies have become increasingly recognised by the fighting services.

Recent developments in valve design have enabled circuits to be evolved which give efficiencies of a high order.

Crystal control has become standardised in many types of amateur and commercial equipment, but usually when a relatively high output is required a series of doubler and/or tripler stages must be employed. For low power amateur experiments however, good results may be expected from a 28 Mc crystal and frequency multipliers.

In addition to crystal control, two other methods of stabilisation are used, *viz.* concentric and resonant line grid control.

Resonant Line Grid Control

As this method of control is a convenient arrangement the necessary adjustments will be described in some detail.

Having determined the power it is intended to use, a pair of valves suitable for the dissipation required must be obtained. Valves with the grid and anode led out at the top of the bulb (such as the *Standard* 4304B) are best, but other types may be used, with a possible reduction in efficiency and stability. The circuit of a 112 Mc resonant line controlled transmitter is shown in Fig. 13.

The anode circuit consists of two parallel copper tubes or pipes preferably silver-plated, spaced 1½" apart, and 18" long. The grid circuit comprises two copper pipes of as large a diameter as possible (not less than 1") spaced a little less than their own diameter apart. The grid connections are made to tappings on the grid control pipes at approximately one-third the way up. The earth return is made to a copper strap, clamped round the far ends of the pipes. This earthing strap is very important, and must have a sufficiently large surface area to have a negligible voltage drop, as the R.F. current is of a high value (several amperes). It should be constructed so that it can be slid up or down the pipes, in order to adjust the frequency. It may be pointed out here that the closer the grid taps are to the earth clamp the greater the control exercised by

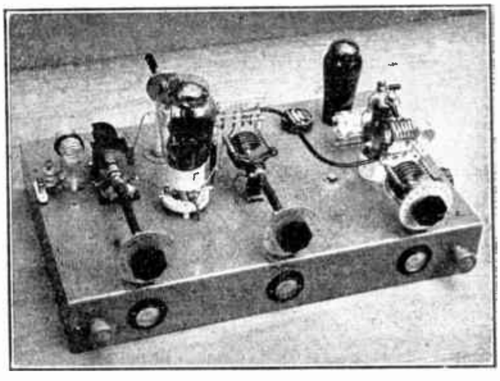


Fig. 11.

General view of the Three Stage 56 Mc. Crystal Controlled Transmitter shown diagrammatically in Fig. 12.

the grid pipes. The pipes should be so fixed that the leads to the valve electrodes are not longer than 1″.

For 112 Mc operation the grid pipes should be so cut in length that the distance from the top of the pipes to the earth clamp is 24″. The anode circuit adjusting-bridge should be slid along the tubes to the far end and the variable resistance set to approximately 50,000 ohms. The grid taps are adjusted to be 8″ from the earth clamp, and the power supplies switched on. A reading will now be observed on the anode milliameter, the actual reading depending upon the valves and high tension voltage, but it should never be more than the maximum safe rating. The anode circuit bridge is then slowly slid along the tubes, watching the anode current all the time. A position will be found where the anode current is at a minimum, and the bridge is usually fairly close to the valves. At the minimum anode current position, the circuit is oscillating, and the frequency controlled by the grid pipes. The next step is to increase the stability if possible. This is achieved by adjusting the grid taps closer to the earth clamp, and again sliding the anode circuit bridge. If the minimum anode current reading is less than before the stability has been increased, and again the grid taps should be brought closer to the earth clamp, and the anode circuit adjusted. This grid tap adjustment should continue while there is a possibility of still further reducing the minimum anode current reading. A point will ultimately be found where the circuit refuses to oscillate at all. It is to be noted therefore, that maximum frequency stability is achieved when the minimum possible anode current is obtained at anode resonance.

The second step is in the adjustment of frequency. This can conveniently be measured by coupling a lecher wire system to the anode circuit, and actually measuring the distance along the wires between each current peak. This is a quarter wavelength. The frequency may be altered by adjustment of the earth clamp.

The dissipation of the valves can only be adjusted when the aerial is affixed. The aerial connections can be connected to the anode circuit with series fixed condensers, as shown in Fig. 13. The aerial should preferably be of the dipole or similar type, and coupled to the transmitter by a low impedance line. The optimum matching conditions can easily be obtained by sliding the feeders along the anode circuit until maximum current is observed in the feeders but the anode bridge must not be adjusted when coupling up the aerial. The dissipation can now be controlled by a variation in the grid series resistance.

The photograph Fig. 14, is of an actual transmitter used by Dr. Lemon (G2GL) for experi-

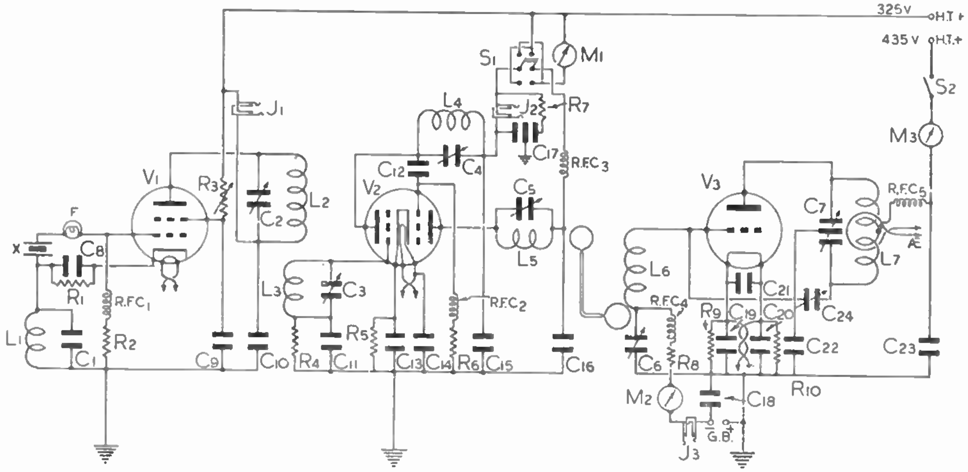


Fig. 12.

Circuit of a Three Stage 56 Mc Crystal Controlled Transmitter.

$C_{1, 11, 18, 19, 20, 21}$	300 μμF, ceramic, Erie.
$C_{8, 13}$	3,000 μμF, mica, F, Erie.
$C_{9, 10, 14}$	2,000 μμF, mica, F, Erie.
C_{15}	500 μμF, ceramic, Erie.
$C_{16, 23}$	150 μμF, ceramic, Erie.
C_{12}	100 μμF, ceramic, Erie.
C_{22}	50 μμF, ceramic, Erie.
$C_{2, 4}$	50 μμF, Webb's.
C_{3}	50 μμF, C801, Polar.
C_{7}	2 × 30 μμF, C603, Polar.
$C_{5, 6}$	18 μμF, 1094, Eddystone.
C_{24}	Neutralising, 1088, Eddystone.
C_{17}	Suppressor, 87A/02, T.C.C.

R_{1}	500 ohms, 2 watts, Erie.
R_{5}	600 ohms, 3 watts, Erie.
R_{2}	15,000 ohms, 1 watt, Erie.
$R_{4, 6}$	30,000 ohms, 1 watt, Erie.
R_{7}	1,000 ohms, 1 watt, Erie.
R_{8}	2,000 ohms, 1 watt, Erie.
$R_{9, 10}$	50 ohms, 0.5 watt, Erie.
R_{3}	50,000 ohms, 4 watts, Bulgin.
$CH._{1, 2, 3, 5}$	R.F. Chokes, Denco.
$CH._{4}$	U.H.F. Choke, 1011, Eddystone.
V_{1}	6V6G, Mullard.
V_{2}	4074A, Standard.
V_{3}	OQ15/600, Tungsram.

Coil data is referred to in the text.

World Radio History

mental work on 56 and 112 Mc. For 56 Mc the grid pipes are extended to 4′ by means of further plug-in copper pipes. The anode circuit is then only 2′ long, as this length is sufficient for 56 Mc operation. The complete transmitter is an extremely simple one to operate and adjust, and the results are exceptionally good.

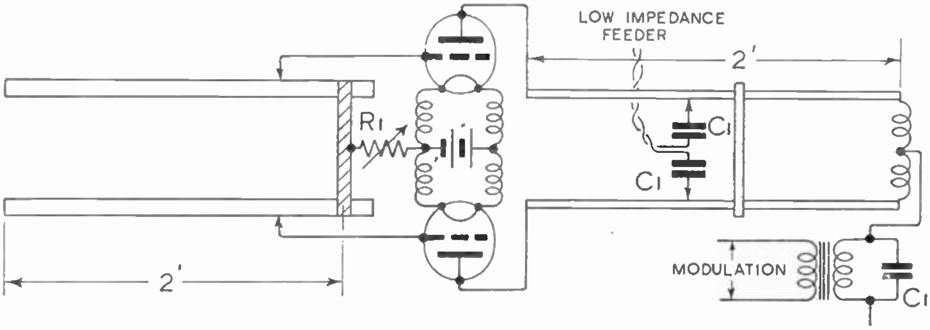


Fig. 13.
Circuit of a resonant line controlled 112 Mc transmitter.

Crystal Control

The transmitter illustrated in Fig. 8 and incorporating a *Standard* 4316A valve, will work very well on 112 Mc, the power amplifier then acting as a regenerative power doubler. The anode coil may conveniently be an *Eddystone,* of 4 turns, whilst the bias will require to be increased from the previous value of 60 volts to 120 volts or more. On applying the drive, the anode milliameter should show 25 to 30 mA, and quite a distinct dip will occur at resonance, with the condenser vanes at about half mesh. It is possible to strike a neon lamp against the tank coil, even with the comparatively low power employed. Closing up the vanes of the neutralising condenser (so increasing the regeneration) increases the output, but it will then be necessary to re-neutralise on returning to 56 Mc.

Frequency Modulation

During 1940 considerable interest was shown by amateurs in the application of frequency modulation principles to 112 Mc transmitters. Due to the very wide band of frequencies available this system offers great possibilities, as it is claimed that the difficulties caused by man-made static can be reduced to a minimum. By suitable choice of operating frequencies it is believed that a large number of amateur stations can be operated simultaneously without mutual interference. A frequency separation of only 50 kc is considered to be sufficient to avoid interference.

A further advantage of this system is that the cost of the speech equipment required is much less than for other methods of modulation.

AERIAL COUPLING

Actual aerial and feeder systems are discussed in Chapter 12, therefore only methods of coupling at the operating end will be discussed here.

The simplest aerial is, of course, the resonant end-on type, of one or more half wavelengths, and this can be coupled direct to a receiver *via* a very small (3/30 µµF) variable condenser. The length of wire on the receiver side of the condenser must be very short, and the condenser adjusted for smooth operation, and maximum signal strength. Coupling to a single valve transceiver, or self-excited transmitter can be identical, but this method must not be used with a neutralised driven transmitter, or the balance will be upset, and the valve(s) thrown out of neutralisation. In such cases a separate aerial circuit is desirable, loosely coupled to the transmitter tank coil. One end should be earthed

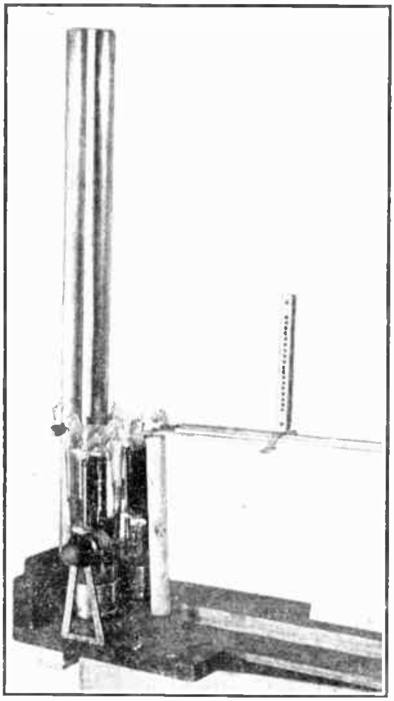


Fig. 14.
A resonant line transmitter for operation on 56 or 112 Mc.

(*i.e.*, held down by connecting to the chassis, etc.) and the optimum degree of coupling secured both by adjusting the tap on the aerial coil, and by altering the coupling of this coil to the transmitter. This method also applies when tuned feeders or Windom feeders are used.

The disadvantage of an end-on aerial is the difficulty of erecting it in the clear. It is recommended that, for best results, the aerial be erected as high and clear as possible, and fed by means of *Belling-Lee* 80 ohm feeder cable. As no high voltages are being dealt with the losses are very small, and a very good match can be obtained at both aerial and apparatus end. At the aerial end the feeder will be connected at the centre of a half wave, an insulator separating the two ends, with the smallest distance (an inch or so), between them. At the other end a single loop (which can be fashioned out of the cable wires themselves) is coupled at the "cold" end of the first tuned circuit in the case of a receiver, and either at the end or the centre of the tank coil of a transmitter, depending on whether a single or balanced circuit is used. Adjustment of coupling is made, either by varying the distance of the loop from the end of the coil, or by making larger or smaller the diameter of the loop itself.

This method is simplicity itself, and it is all the more efficient because of it, since there are few points where losses can occur. A separate tuned circuit is also dispensed with.

The other type of feeder in common use is the 600 ohm type, and this is coupled similarly to the 80 ohm line, with the difference that a greater number of turns are necessary.

Experiments with these will probably be well repaid but to commence with, two turns are recommended.

World Radio History

Chapter Eighteen

Station PLANNING & BUILDING

Indoor Planning—Typical Layout—Wiring—Receiving Position—Control Circuits—Outdoor Planning—Surveying the Site—Great Circle Maps—Construction of Masts and Aerials—Insurance.

SUCCESS in Amateur radio depends chiefly on the skilful use of efficient apparatus, but the full enjoyment of the hobby is only obtained when care and forethought is taken in the assembly of that apparatus and the general layout of the station. Skill comes with practice, whilst the efficiency of the apparatus depends on a proper understanding of basic principles as laid down in other chapters. The problems involved in planning and assembling the station are the subject of this Chapter, its aim being to show how to make the best use of whatever facilities are available.

The problems involved in the planning of a radio station fall naturally into two groups—those concerned with the actual layout of the electrical equipment and operating conveniences, and those concerned with outdoor equipment such as aerials and masts, and possibly also (if one is sufficiently fortunate) the question of the choice of a location. No attempt will be made to describe the "perfect" radio station for with unlimited facilities this presents no real problem. Attention will therefore be directed to the task which faces the majority of amateurs, namely that of "making do" with the space available.

INDOOR PLANNING

Choice of Room

Sometimes circumstances dictate that the gear shall be placed in a shed, but if at all possible, the actual operating position should be indoors, even if it is necessary to place the majority of the apparatus outside and use remote control. One of the most important things to consider is personal comfort. If amateur radio is to be carried on with average enthusiasm long watches will be spent at the operating position, maybe at very late or very early hours of the day; comfort therefore is an important point. Incidentally an indoor operating position is likely to be more comfortable in both summer and winter, whereas an outside shed position practically discourages the use of the transmitter in the early hours of the morning, a time of day when some of the most successful results are achieved.

If space indoors is limited, consider first the possibility of building the apparatus as a piece of furniture which may exist without intrusion amongst more domestic objects. Alternatively, if an ambitious station is planned, consider placing the receiver and the essential controls of the transmitter in a desk or in a corner of the living room, and the transmitter (operated by remote control) in the roof, garage, or garden shed.

If, however, it is essential to work outside, then a building of the portable garage type should be built, or purchased. This should be mounted a few inches off the ground by placing bricks under the floor joists, and lined inside with wood or builder's board to make it habitable and comparatively proof against dust and damp. The wire employed for the mains supply should be substantial, so that electric heaters may be used without appreciable loss of voltage. Power wiring should of course comply with local regulations, and from the radio point of view it is desirable to use lead-sheathing, well bonded and earthed.

Where indoor space is restricted an alternative "home" for a station can often be found in the loft, in which case collapsible stairs can be obtained which slide up through the hatch when not in use. If a skylight is fitted this may be used for the aerial entry, boxing it round with wood so that when closed there is a board through which lead-in insulators can be fitted.

Typical Layout

The modern £700–£1,000 house is usually constructed with one small room over the hallway, and as this often becomes the "radio room" it will be taken as an example in which to illustrate various requirements and possibilities. There are three main items to dispose: first the receiving position, second the transmitter, and third the workshop, and as this room is often not more than 6′ wide, care must be taken not to waste space.

There are two ways in which work can proceed; if experiments are to be mainly connected with the design of apparatus then flexibility of layout must be provided, but if it is desired to conduct experiments in radio wave propagation, aerial design, etc., the indoor equipment can be a fixed accessory. In either case the receiving position must be well established, and a good location for this is just inside the door (Fig. 1) where the daylight is behind the operator.

In the case of indoor experimental work the workshop will be given slight preference to the transmitter, and if this must be accommodated in the same room it is best to build a bench along one wall, say in front of the window, and to mount the transmitting equipment on a tall narrow rack. The rack is probably the best type of construction for experimental work, for however limited the floor space may be, there is always a fair amount of room to build upwards.

In the second case, where the equipment will be more or less of a fixed type, a box frame 3′ × 2′ and about 6′ high will accommodate the transmitter, or it can be built on high shelves round the wall leaving the floor space free.

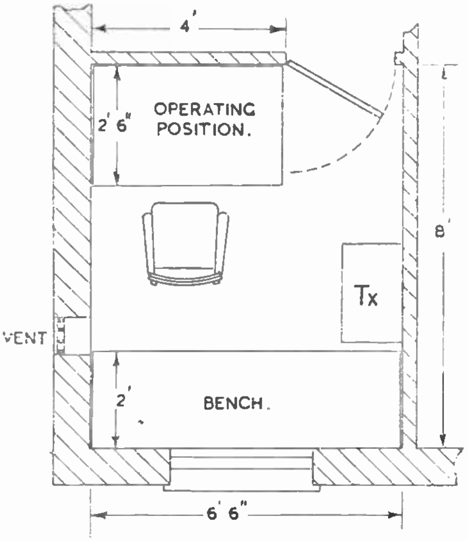


Fig. 1.
Typical station layout for a small room, for example, the small bedroom of the " standard " three bedroom house. Three features are essential : a comfortable operating position, bench room for workshop and experimental work, and a suitable style of layout for the transmitter. The aerial leads may be taken through the ventilator which is always provided in this room.

Wiring

Having decided on the best positions for the receiver and transmitter, it is usually necessary to provide a certain amount of control wiring between the two, and this is best done before the room is occupied by benches and gear. The wiring can then be laid under the floor and brought up to junction boxes in convenient places. The mains may be brought up separately to the two points, but between the two a number of circuits will be needed for (*a*) starting and stopping the transmitter, (*b*) keying, (*c*) the modulation circuit, and (*d*) a high-frequency link, if it is desired to retain the master oscillator at the operating position. These leads should all be screened to prevent interference and instability, and the sheathing bonded to the mains earth. Twin lead sheathing may be used for all wiring, although an R.F. concentric cable is preferable for (*d*). Circuits (*c*) and (*d*) should be provided with separate junction boxes in order to prevent inter-couplings. The inclusion of a spare circuit may also save much trouble later.

When moving into a new house it is a good plan to inspect the electrical wiring, and ensure that the lead sheathing or conduits are well bonded and earthed, also see that loose joints or rubbing metallic contacts are dealt with. Attention to these points may prevent a considerable amount of noise or interference occurring in the receiver. If necessary the mains earth system can be used as a general earth for the whole equipment, and if the station is located off the ground floor this will probably be the best earth available.

Receiving Position

In the receiving position the question of comfort and ease of operation is important. There should be ample writing space in front of the receiver, for log books, etc., whilst the transmitting key should also be placed in the most suitable position. Control switches need not occupy table room; these can be mounted on a vertical panel beside the receiver, or below the top of the table.

Fig. 2 shows a well thought out operating bench which was built to " fit the operator." This bench was built for a room similar to that shown in Fig. 1, but the dimensions can be varied to suit individual requirements. Remember, however, that a very important dimension is the *height* of the table-top, and in this connection it is advisable to experiment with a board, using the chair which will normally be employed. Before finally deciding on the height above floor level, select the height which allows comfortable operation of the tuning dial of the receiver together with easy operation of the telegraph key. A matter of half an inch may make all the difference between comfort and fatigue, especially during long sessions. The height shown, 28″, is a good average.

Reference to the photograph which also illustrates the bench shows that the space in the centre houses the receiver and the C.W. monitor, the output of which may be wired permanently into the audio circuit of the receiver. Other essential instruments, such as 'phone monitor, radiation meter, and the master oscillator, are mounted on the shelf above, whilst a space is provided for stationery. The box to the left contains the microphone first stage amplifier, whilst the microphone is mounted on the bench. The right-hand box contains all the controls, including a fuse-box and a pilot light for the transmitter. Under the bench is a shelf, which, in the type of room chosen as our general example, is very often the boxing over the headroom of the stairway below. This can accommodate secondary apparatus such as power packs.

Control Circuits

The permanent wiring should be arranged so that, apart from a few minutes spent in " warming up " the valves, the whole station can be brought into action by simply switching on. Provision must, however, be made for a speedy change-over from receiving to sending conditions. This can be accomplished by having one master switch on the transmitter and one on the receiving equipment,

World Radio History

through which all subsidiary switches feed. The transmitter is then arranged to be in a " quiescent " condition, with all valve and rectifier filaments heated, and the bias supply in operation. These precautions are important, because valves may be damaged if the filament and H.T. are switched on together.

The change-over operation consists simply in switching-on the primaries of the H.T. transformers and changing over the aerial, if the same aerial is used for both sending and receiving. The switch for the H.T. primaries should be located at the operating position, using one of the interconnecting circuits for the control. If mains bias supply is used, the H.T. primary switch should be taken from the " dead " side of the bias switch ; thus it becomes impossible to put H.T. on the valves before the bias is applied. The aerial switching may be some distance from the operating position, in which case it can be carried out with the aid of cords and pulleys or by means of a relay. In this way the operation of changing from receiving to sending can be carried out almost instantaneously.

If the transmitter is located at any appreciable distance away from the operating position, and particularly if it is remote controlled, a relay should be used for the starting switch.

The keying arrangements depend to some extent on the transmitter circuit, but it is never advisable to bring out the H.T. circuit to the key itself. If a high tension point is keyed, a relay should always be used. Even so, the key itself should have a surge absorbing condenser across its contacts to prevent radiation of clicks.

Relays for various purposes are not expensive to purchase, but for the mechanically minded amateur they can be contrived from bell or buzzer magnets, whilst charging cutouts from old cars also offer possibilities. An aerial switching relay should have well insulated parts, and the armature should be extended with an insulating strip so that the contacts can be kept away from the main body of the relay. Contact strips for relays may be taken from old telephone jacks.

It is now common practice to switch off the H.T. supply to the receiver when the transmitter is working, in order to prevent electrical damage to the first valve in the receiver, but this is no safeguard unless the screen voltage is also removed. It is best to open-circuit the cathode resistor of the first valve by means of a switch, but this of course involves an extra operation when changing over. Two alternative methods present themselves :— the switch which operates the starting relay of the transmitter can be arranged to earth the cathode when the transmitter is " off," or a second relay can be used in parallel with the keying relay. In the latter case the contact would be open with the key depressed.

After all wiring has been completed it is a good plan to prepare a large diagram showing the position of all leads. This will overcome the necessity of tracing out complicated wiring when a breakdown occurs. It is unwise to depend upon the memory of circuit details, particularly if the wiring is at all involved.

It is also desirable to maintain a separate note book into which can be entered particulars of all changes made to the wiring of the station.

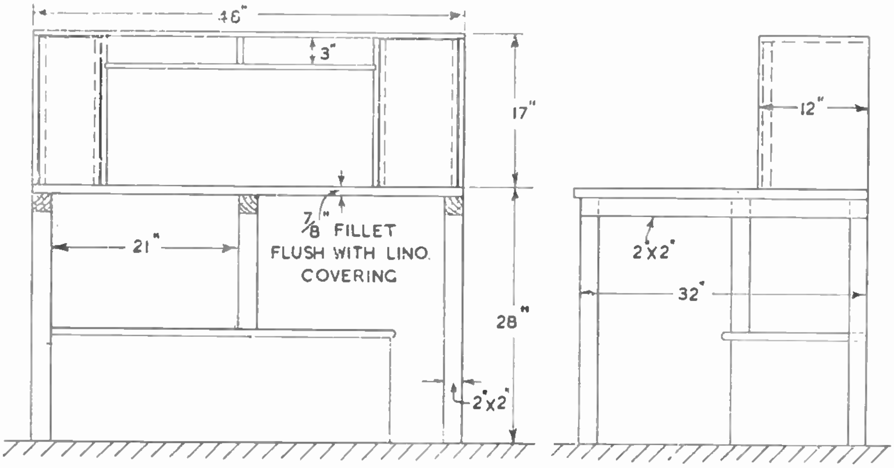


Fig. 2.

Suggestion for a bench for the receiving position. Its functions are illustrated in the photograph, and described in detail in the text. The dimensions may be varied to suit circumstances, but the height should be adjusted to suit the operator.

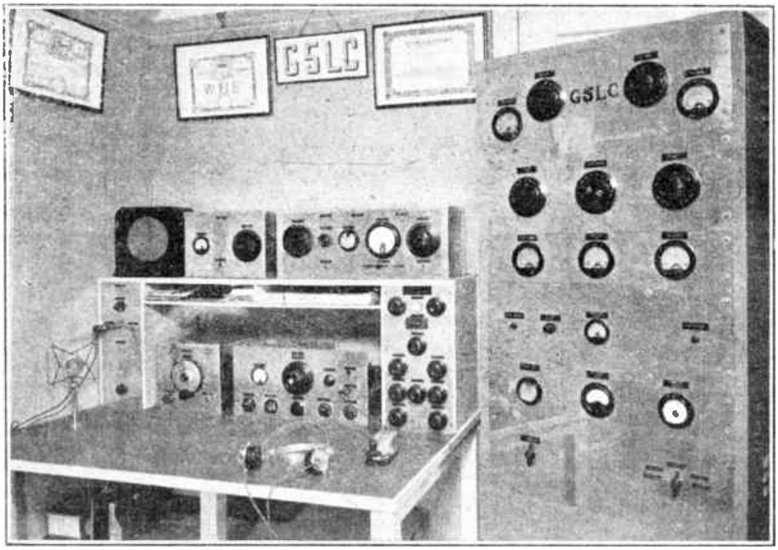
World Radio History

OUTDOOR PLANNING

Location

The ideal situation for a radio station would be at the top of a hill with no obstructions. Although such a site is usually selected for "field day" operations, it is seldom that an amateur can choose such a location for a fixed station. If one *is* free to choose, the next best situation is in clear open flat country, preferably with damp subsoil. To the majority, however, these are just ideals, and the only possible location is a suburban garden or even the space between buildings in a town.

In "making do" with a location, it is obviously necessary to try and place the aerial as high as possible above surrounding obstructions, but the chances of doing this become less as the centre of a town is approached. In a suburban location it is nearly always possible to erect masts, and in this connection a North/South direction usually permits easier aerial planning than an East/West direction. There should be room for 140′ of aerial plus any space needed for the supporting masts, but again this is seldom possible.



A typical operating position suitable for a small room. The receiver is in the centre of the bench and other essential apparatus and controls are within easy reach. The transmitter which has been moved round for the photograph is an example of box-frame construction, and is normally in the position indicated in Fig. 1.

The first step towards taking the best advantage of a given site is to survey it roughly and make a scale plan on which various possible aerial systems can be laid out. Then, with a study of their theoretical properties, and the use of a *Great Circle map* it is possible to determine to some extent what results may be expected. It should be remembered, however, that the theoretical properties of an aerial are only repeated in practice if there are no local obstructions. Trees absorb radiation to some extent, whilst a building will tend to obstruct the waves if it is higher than the aerial. Where there are serious obstructions, only high angle signals can escape, so that a little experimenting with the height of the aerial may help partly to avoid these obstacles.

Surveying the Site

A rough plan of the site may be made by measuring up along the sides and across various diagonals, followed by a little work with a rule and a pair of compasses. Mark in any likely points of aerial suspension, and as a check take more measurements than are fundamentally necessary. Do not trust angles that appear to be 90° as they are often quite deceptive. A compass bearing should be taken along some major line; check that the bearing in the opposite direction is 180° different, as concealed iron may cause a false bearing. The best compass, if it can be obtained, is a prismatic type, but beware of steel-rimmed eyeglasses when using it. The bearing, if given by the compass as so many degrees East of North, will be about 11° greater than the true bearing from North, for the London area. (Consult Whitaker's Almanack for the position of *Magnetic North.*) A little elementary trigonometry will be helpful in this survey, especially if heights are to be judged.

The Great Circle Map

In Chapter 12 and elsewhere reference has been made to Great Circle Maps, whilst in Chapter 13 details are given concerning Great Circle Routes and the construction of these maps. In the present Chapter, Fig. 3 shows a rather uncommon projection of the Earth's surface. This sketch represents a Great Circle Map *centred on* London.

The chief features of these maps are :—

(1) All places are in their true *direction* from the centre.

(2) All *distances* from the centre are *to scale.*

Finding the direction and distance of a place on the earth's surface cannot be achieved with ordinary maps because such maps attempt to show the world on a uniform scale.

In Fig. 3 distances, except along the radii, are badly distorted and the edge of the circle is really the antipodean point to London. New Zealand which is roughly the same size as Great Britain, as a consequence spreads around the edge.

This type of map cannot be applied to other measurements but it can be drawn with any place as centre (see Chapter 13).

The illustration, which is to the scale of 10,000 miles to an inch, is too small for accurate work, but an excellent map ten times as large, is now available from *Webbs Radio Ltd.*, (price 4/6).

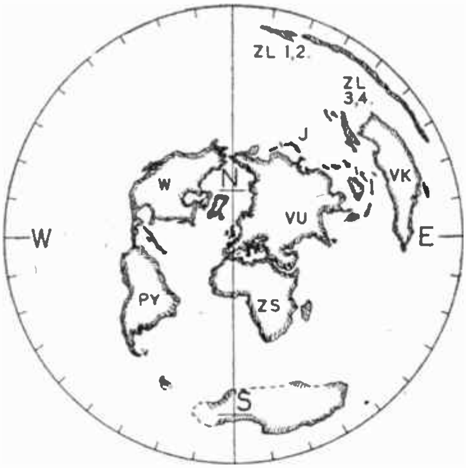


Fig. 3.

A Great Circle Map centred on London. All directions and distances from the centre are true to scale. The zones marked are the North and South poles, U.S.A. (W.), Brazil (PY), S. Africa (ZS), India (VU), Japan (J), Australia (VK) and New Zealand (ZL).

Radio waves in general travel around the earth along great circles, and so by tracing out the polar diagrams (see Chapter 12) of various aerials, it is possible to determine fairly accurately what a given aerial is likely to do. Furthermore, a great circle map allows us to choose the best direction for the actual radiating system. For example, one could take the "long wire" polar diagrams shown in Fig. 21 of Chapter 12, and note the directions of the major lobes of radiation with respect to the direction of the wire. If a thread is then pinned across the centre of the map in the direction of the proposed aerial, it is then easy to estimate where the radiation will be mainly directed. Alternatively it would be possible to draw a copy of the polar diagram on tracing paper and pin it to the centre of the map, rotating it to find the optimum wire direction. In this way it will be found that a 2λ wire lying along the line 100° E. of N. offers a signal to practically all continents.

The accuracy required in setting out an aerial depends, of course, on the extent of its directivity. For example, suppose it were desired to erect a beam aerial which just covered the whole of the Australasian Continent, and that the beam is to be made as sharp as possible in order to give the greatest signal. The map shows that a beam 40° wide will just do this if it is centred 70° E. of N. A few degrees error in the setting up of the beam would result in the loss of signals in either VK6 or VK4. In setting up the aerial, using bearings E. of N., it is necessary to *add* the magnetic variation to find the compass reading.

MASTS AND AERIALS

One of the chief items in the outdoor work of a station is the finding of supports for the aerials. Space does not permit a complete treatment of mast construction, but a few suggestions may be helpful to those who have had little or no previous experience.

Aerial Supports

Where parts of a building are used to support an aerial this brings no great disadvantage unless the building is much higher than the aerial. The radiating elements should not be brought too near the roof, as there may be wiring or pipes, just inside, but a chimney stack may be approached fairly closely. Gutters and pipes should be avoided as far as possible, as in many cases they have been found resonant.

Trees are often used as supports, but the actual aerial should not be brought too close to them, whilst due allowance should always be made for a considerable amount of sway in the wind. It is a good plan not to tie down the halyards, but to counterbalance the pull of the aerial with a weight, for example, a bucket of stones, with a hole in the bottom to release water.

Beam aerials, such as, for example, the Krauss, require rigid supports, and strong masts are always desirable. Further, some of these aerials rely for their performance on the correct spacing of the elements, and this must be maintained in spite of wind.

Masts can be divided into two main classes: (1) poles, and (2) structures. Either type can be self-supporting, or they may need guys. Where space is very limited it is often necessary to use a strong self-supporting mast, but guyed masts are usually cheaper and easier to erect. Steel poles may disturb the aerial radiation, consequently wooden masts are generally used in amateur stations.

Poles

Larch scaffold poles are the strongest type available, as they weather well and usually have a narrow taper. Unfortunately, they are not easily obtainable over 30′ long, and the price rises much more rapidly than the length. Fir poles may be obtained when they grow locally, but they are usually heavier in the butt.

The pole should first be cleaned and treated with creosote (or given two coats of paint), and a cap fitted to weatherproof the end. The pulley should be lashed with wire, and allowed to swing freely. When guys are used the butt can be boxed in on three sides with 1″ boards sunk 2′ or 3′ in the ground and projecting about 18″. The box may be used as a stop when pushing up the pole, and when up it can be clamped into the box by iron plates and bolts.

If the pole is to be self-supporting, a *tabernacle* should be used. This is a strong post, set in the ground, to which the mast is bolted and clamped. The tabernacle may be an oak gatepost or an old railway sleeper, but it must have a length equal to at least one-sixth of the height of the mast. The post for a 40′ mast should be about 7′ long, of which 3′ should be set in the ground, or in concrete if the earth is very soft. The post should be tarred up to a point above the ground level to prevent rotting, and for the same reason the butt of the mast should be blocked up slightly.

The use of poles of appreciable length is practically limited to cases where they grow locally, as the cost of transport is very high and often town byelaws prohibit their carriage. It would then be much cheaper to buy timber and build a structure.

Mast Structures

Although many designs for structures have been described in various amateur radio journals, it has been decided to refer here to only two types, both of which have stood the test of time. In assessing the reliability of a design, solidity should be sought in self-supporting structures; if they can be climbed with safety then they will withstand heavy winds. In the lighter guyed structures an important feature is the liberal use of guy wires, so that the mast cannot bend or sway in the middle.

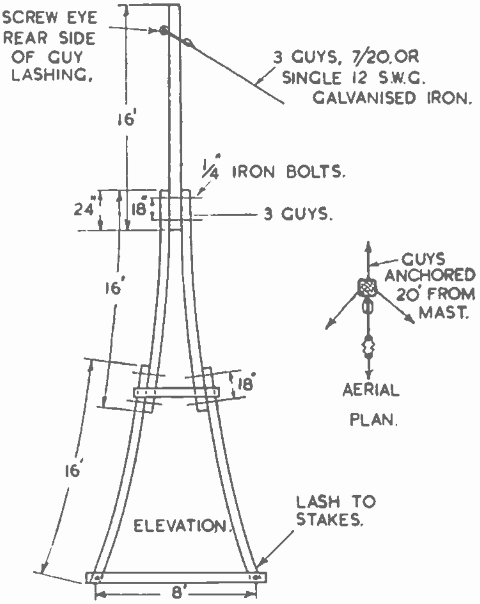


Fig. 4.
A cheap but effective mast. For details of assembly see text. The timber required is five 16′ lengths and one 8′ length 2″ × 2″ and one odd bracing piece. Good quality deal may be used, but a somewhat heavier pine will produce a much stronger mast.

Fig. 4 illustrates a five section type which originated in America, but which has become popular in this country. It is favoured for portable stations because it can be packed and is easy to erect. The dimensions for a 45′ mast are given, a height which is about the maximum for this type.

The mast can be made from three 24′ pieces of wood, but the excessive cost of such lengths make the five section design more desirable. The wood can be 2″ × 2″ but it should be remembered when making up bolts or clamps that 2″ × 2″ "prepared" (planed) timber is only about 1¾″ square. The timber should be straight-grained, and if common deal is used it should be free from large knots. Columbian or Oregon pine is better, being much stronger, but it is heavier and more expensive.

The pieces are best assembled on flat ground, care being taken to see that the bolt holes register correctly, and that no cracks occur in the ends. After assembly the joints should be coded with a chisel. The mast should then be dismantled and all pieces given two coats of good protective paint.

By the time the mast is ready for erection, the guy anchors should be already in position, and if on the ground level they should be not less than 20′ from the mast. Three guys are needed for holding the top and three are advisable for lower points, the directions being about 120° apart. If two sets of guys are used, the lower set should be a few feet below the top joint, but if the mast is to stand in an exposed place then, unless the bottom can be bolted to a wall, sets of guys will be needed at both joints.

It will be found that if the bottom is pushed against two substantial stakes, two people can push the mast up and carry it into position, but for safety it is better to have three or four persons present.

A Box Mast

Fig. 5 shows the essential details of a box mast. It will be seen that the mast is made of flat boards assembled into a hollow square cross-section. In this way strength and lightness are combined. Deal may be used but it must be of good quality—straight, well seasoned, and free from splits and large knots. Warped timber will result in a twist in the assembled mast which cannot be corrected. A tougher wood such as pine or larch is better, though somewhat heavier.

The timber should first be cut and prepared to the finished sizes given so that the two sections will fit together. It should then be painted all over before assembly. After this the pieces are collected into groups of four equal length sections, using the best wood for the lower parts. Three of the bottom lengths are then cut as shown in Fig. 5 (A) and the ends 1a, 2a and 3a are transferred to the top, as (B). In this way all the pieces are staggered. The assembly of the box then proceeds according to Fig. 5 (D), the best edges being selected for the free corners. Good advice is—work on flat ground and assemble the complete box progressively. Plenty of screws should be used, at two or three foot intervals, and clearance holes drilled in the outer faces. If the edges are kept in alignment as the assembly work proceeds the resulting mast will be straight and true. A carpen-

World Radio History

ter's brace fitted with a screwdriver bit is a great time-saver in this operation. Team work is also a great help, one man drilling, one fitting and keeping the box true, and the third screwing up. After assembly the sections should be given another coat of paint, working well into the seams. When dry, the mast is ready for bolting together, the fitting of the guys and halyards, and its final erection.

Erection

A three-sided boxing should be set in the ground for the butt, which can be used as a stop when erecting. The erection is carried out by pushing as high up from the bottom as can be reached, followed by a pull from behind on a cord looped about a point two thirds of the way up the mast (not the top). It is a good plan to have one of the centre guys temporarily fixed as a check against pulling-over beyond the vertical. If the pull can be made from a point some height above the ground erection will be much easier. It should be remembered, however, that in attempting to push up a mast there is a great danger of the butt jumping free since the mast is very topheavy in this process.

"Brute force" push erection should not be attempted with anything longer than about 40′, or for that matter with any mast which is too heavy for two people to lift. A mast may be pushed up by means of a ladder provided the butt is well secured and means are provided to hold it sideways.

To those who have had no experience of the work involved in rigging and erecting a large mast, it is recommended that help be obtained from a contractor.

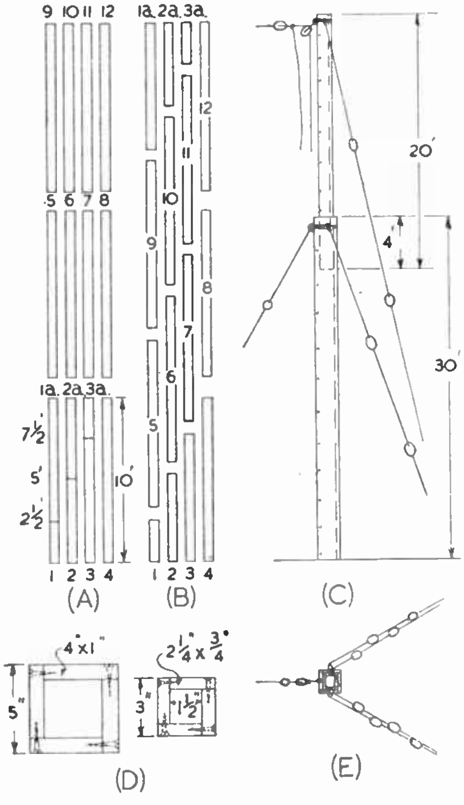


Fig. 5.

Details of a 46′ box mast. (A) and (B) show how to arrange the pieces for assembly of one section. (D) is the cross-section, (C) and (E), elevation and plan of the completed mast. The dimensions give a rather heavy mast, but if three sets of guys are used the bottom section can be of 3″ × ¾″ and the top section correspondingly smaller but adjusted to fit the lower section.

Materials :—

12 10′ lengths 4″ × 1″.
8 10′ lengths 2¼″ × ¾″ (finished sizes).
½ gross 2″ No. 10 csk. iron screws.
½ gross 1½″ No. 8 ditto.
300′ 7/20 or 7/18 galvanised iron wire, insulators pulley, and 100′ halyard.

Guys

For masts up to about 50′ high, single 12 S.W.G. galvanised iron wire may be used, or better 7/20 S.W.G. galvanised and stranded wire. The usual types of stranded wire sold at ironmongers often consist of six strands of wire with a centre of string. Standardised 7/20 wire will last much longer and this can be obtained from manufacturers of telegraph pole equipment or reputable dealers. For heavy masts it is necessary to use stronger wire, such as 7/18 S.W.G.

The guys should be broken into short lengths by means of insulators, about ⅓ the wavelength of the shortest waves it is proposed to use, *e.g.*, 12′ lengths for frequencies not higher than 28 Mc. They will then not disturb the radiation of the aerial. The wires should be locked through the insulators, so that they still hold if the insulator collapses; egg type insulators are suitable. The guys should be lashed two or three times round the mast and screws, or screw-eyes used in order to prevent slipping; they must not take the direct pull. It is a good plan to paint or tar all jointed ends, as these are most likely to be the first points to show signs of rotting.

Three guy directions are shown in Fig. 5; when this number are used it is necessary to space them fairly accurately at 120° if they are to hold the mast safely. The extra cost of a fourth anchorage is well worth while, as the mast will then be held securely against winds in all directions. Furthermore, it is infinitely easier to hold it upright and straight.

The distance from the base to the anchors should not be less than half the height of the mast. Shorter distances lead to excessive strains. Where a self-supporting pole or structure is used, one guy may be used to hold against the pull of the aerial, and if space is limited, this may be set only a yard away from the base, with a king post fixed a few feet from the top as shown in Fig. 6 (C).

Galvanised iron guy wires may be expected to last about three years, after which they may become unsafe. They should be inspected periodically, and replaced when rust begins to appear.

Anchors

Where the soil is firm, stout wooden or angle-iron stakes may be driven in as anchors for the guys, but where the soil is soft the methods shown in Fig. 6 are recommended. The centre sketch shows a means whereby immediate support can be obtained, as the earth, which takes the strain, need not be disturbed. Where walls, etc., are used to hold anchors, a ring bolt should be passed through the wall, and an iron plate fixed behind the wall to distribute the pull.

During rough, squally weather, guys and anchors are subjected to a continual tugging, and the forces may considerably exceed those experienced in a steady gale. Anchors should, therefore, be very substantial, and allowance made for stretching of the wires. The lashings of the ends should be simple though effective, so that they can be remade with a minimum of effort. Turnbuckles may be used for dealing with small stretches, or a lashing about a foot long, consisting of several loops of thinner wire passed through an eyelet in the end of the guy, can be employed.

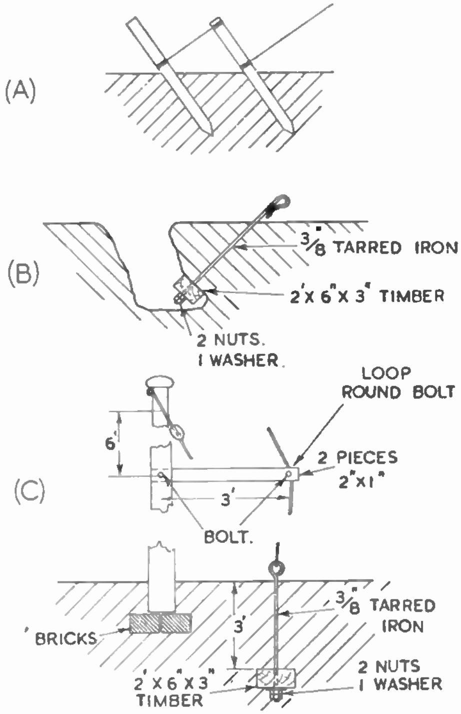


Fig. 6.
Special types of guy anchor. (A) and (B) are suitable where the soil is very soft. (B) is very strong and can be prepared without disturbing the earth which takes the pull. (C) is a backstay anchor for use where space is limited. Buried parts should be well tarred.

Halyards

Care must be taken in selecting and using halyards, owing to the great difficulty of replacement once they come off the pulley. They should, therefore, be weatherproof, and arranged as a continuous loop with the ends well knotted. A feature of all untreated cords is that they shrink up to about 5 per cent. in length when wet, and if taut when they dry, they may break when wetted. One method of overcoming this is to use a counterweight for the aerial, which hangs on the line, instead of lashing the bottom to the mast. This, however, will not prevent rapid decay from weather in ordinary lines such as sash cord, consequently it is much better to use specially prepared line. Cords can be weatherproofed by soaking in linseed oil and then allowing them to dry. On the other hand, several of the rope and sash-line manufacturers make a special halyard consisting of a fibre core surrounded by a braid which is impregnated with suitable waxes. These lines, which will be found very strong, last at least three years before replacement is necessary. Brands such as " Everlasto " and " Orion " are commonly available. The cost of these is of the order of 6s. per hundred feet.

Like guy wires and masts, halyards should be inspected periodically, and replaced when signs of age begin to appear.

INSURANCE

There is a certain amount of risk attached to an amateur radio station which is not normally covered by ordinary domestic insurance. There is the possibility of fire from the apparatus, danger to life or limb from the high tension supplies, danger from lightning, and last but not least, the risk of damage to other people, or their property, from falling masts or aerial equipment. These special risks are covered by *Lloyd's* Radio Policy, and details may be obtained from insurance companies. The annual premium is not excessive, and is well worth while, compared with the difficulties in which one might become involved by an accident.

World Radio History

Chapter Nineteen

TELEVISION TECHNIQUE

Fundamental Principles—Scanning—Image Shape—Flicker—Interlacing—Transmission Systems—Photo-cells—Electronic Transmission—Cathode Ray Reception—Focusing—Time Bases—Vision Aerials

Introduction

THE High Definition Service of the B.B.C., at present suspended, is likely to be resumed at the termination of hostilities, unchanged in essentials for a few years. When that time comes a wide range of receiving experiments will again become possible, and it behoves those amateurs who are interested to use the intervening time to further their knowledge of the subject by paying particular attention to developments in those countries where television is still available.

The production and transmission of television signals is inherently more complex and certainly more costly than that of telegraphy or telephony. However, a few amateurs have done good work in that field, generally with non-radiating equipment, but the majority have found the cost of transmitting experiments too expensive. The preliminary broadcasting of Baird 30-line signals by the B.B.C. gave rise to a period of receiving activity, since the transmissions could be picked up with inexpensive equipment. Unfortunately the service was short-lived and the results possible from it very moderate, but there can be no doubt that the experience and knowledge gained proved useful to many.

In this Chapter it is proposed to outline only the system of television employed by the B.B.C., and no attempt will be made to deal with those used abroad, which for the most part do not yet constitute a public service.

Fundamental Principles

Television involves the reproduction of a scene with all its detail and movement at a distant receiver, employing a radio or cable communication channel to transmit the necessary signals. As in the case of speech, which is translated into electrical variations by the microphone before transmission as radio telephony, some method must be found of translating the scene into an electrical form suitable for the modulation of a carrier wave.

What are the factors which make up a scene? First, there are the changing values of light and shade pertaining to each part. These can be translated into variations of potential with the help of the photo-electric cell and then used to control the amplitude of the carrier. The brighter the illumination, the greater the carrier amplitude, just as in telephony systems a loud sound results in deep modulation. Actually the momentary increase in the mean carrier of a " controlled carrier " system is a better analogy.

Second, there is the factor of colour. This cannot easily be transmitted, and it is omitted from most present television methods, the scene being reproduced in monochrome just as are most photographs or illustrations. The only satisfactory methods known for coloured television involve the sending of separate images for the three primary colours, and the recombination of these in the receiver on lines analogous to colour printing. To achieve this result involves so much additional equipment and general complication that it is not practicable for a public service.

Similar remarks apply to the transmission of stereoscopic vision, giving the impression of solidity which is obtained through the combined use of both eyes. This might be possible if two television images were transmitted as viewed from two points separated by the distance between the eyes, but the duplication of equipment needed makes this also beyond present commercial scope. The scene is therefore viewed from a single point by means of a single lens, and is reproduced in a plane just as in cinematography. To do even *this* effectively taxes technical resources to the utmost.

Scanning

There remains the most essential factor of all which goes to make a scene, *viz.* the relative positions of all the objects which compose it. Desirable as it would be, it has proved impracticable to transmit the scene as a whole. Consequently the methods used in newspaper printing, whereby the scene is divided up into a very large number of small " dots," have been adopted. In television these are termed *elements*, and the process used to divide the scene into these elements is termed " scanning."

If the elements are small enough each can be regarded as of uniform brightness over its whole area, and can thus be transmitted electrically as a single impulse.

The number of elements into which the field of view can be divided, or their smallness in relation to the whole image, determines the *definition* of the transmission. Since one element is the *unit* from which the received image will be built up, we cannot see any object distinctly if it was originally

World Radio History

smaller than an element. There is nothing imperfect or unnatural in the idea of dividing a scene into elements, for even the finest printing or photograph shows a granular structure when highly magnified, due to the grain of the paper or of the photographic emulsion. The retina of the eye is built up of numerous small cells, and it is true to say that all vision is fundamentally built up from minute elements in this manner.

Various attempts to transmit all the elements simultaneously over a single communication channel have proved unsuccessful, and would seem impossible unless a separate channel is used for each element! The alternative is to transmit them *successively* over a single channel, when the process of analysis becomes *sequential scanning*. Modern television operates on this principle, which is the only one that has proved workable in practice, and which incidentally is also responsible for most of the special problems which arise.

Sequential scanning can now be considered in more detail. If the many elements are to be dealt with in succession, they must be taken in some definite sequence, for clearly if the scene is to be correctly reproduced, the receiver must at any instant be reproducing the element which corresponds in position to the one undergoing transmission at that instant. Hence not only must the number, size, shape and position of all elements be identical at both transmitter and receiver, but they must be dealt with in the same order and at the same rate in both cases. This is another way of saying that the scanning process must be strictly synchronous, which means that the scanning of all receivers must be adjusted to correspond exactly with that of the transmitter. Naturally, since the scanning processes must be synchronised, the equipment used to effect scanning must also work synchronously.

There is an almost unlimited choice of sequences in which the elements might be taken, and several have been used or advocated for one reason or another. In practice, however, the simplest seems one of the most suitable, this being the one known as *plain sequential scanning*. It is illustrated diagrammatically in Fig. 1. Here the elements are considered to be arranged in uniform rows or "lines" across the image field, and are scanned along each row in turn with uniform speed.

It is proposed to make a few simplifications of the strict theory for the present explanation, and to regard each element as a minute square, when the width of each *scanning line* will be equal to that of an element.

If the image field of view is square as shown in the illustration and is divided into *N* lines, then there will be a total of *Ns* elements to be transmitted. If the field is not square, but has a ratio of breadth the height of *b* to *a*, then the number of elements becomes *b a Ns*.

Image Shape

In practice the shape of the cinema screen is a convenient one to use, when the factor *b a* becomes 5 4, and will not modify the total number of elements very drastically. It is usual to specify television definition by stating the number of scanning lines *N*, and to assume tacitly that the image is not far removed from the square shape, also that the elements approximate to squares, and that they are equally spaced in both dimensions. The definition will then be the same along the scanning lines as it is across them, a condition which is by no means essential, but has been found the most satisfactory compromise when the total definition is not quite as great as might be desired.

There remains the choice between a vertical and horizontal direction of scanning. This is not found of primary importance, but since the equipment is somewhat simplified and the number of lines kept down if the image be scanned along its longer dimension, the present cinema-shaped field is scanned horizontally.

Consider now that the scene has been scanned in this manner and the light collected from successive elements applied to a photo-cell to set up proportional electrical potential. This potential will fluctuate with time as the successive elements of differing brightness are scanned, and it will therefore possess a wave-form of some kind. This could be analysed into a series of sine waves by the Fourier theorems, and is capable of providing the modulation for a radio transmitter. Thus from the point of view of the experimenter television may be regarded as a new form of modulation, which could be applied to his transmitter, if this is suitable in the several respects mentioned later.

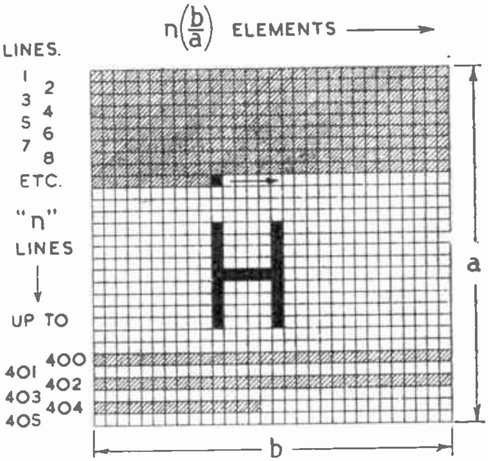


Fig. 1.

A typical television image showing how it is analysed into elements and lines by sequential scanning. The shaded area is that already scanned when the aperture has reached the position shown in full black.

As a guide to practical methods it is necessary to consider the form of modulation that the television signals will comprise. Unlike telephony modulation, which is very similar in characteristics irrespective of the transmitter used, television modulation differs fundamentally according to the number of elements, and the rate at which scanning is carried out, or speaking more broadly with the "definition standards" adopted.

Flicker and Interlacing

The rate of scanning is determined by two factors; first the motion of the scanning process must be sufficiently rapid to appear continuous to

World Radio History

the eye, and second, the whole field must be scanned a sufficient number of times each second to give the impression of continuous movement in the final image. It must also be fast enough to prevent excessive flicker from being noticed by viewers. In this respect " persistence of vision " assists, *i.e.*, the fact that the visual impression of an object remains on the retina for a fraction of a second after it has actually ceased. In the cinema this allows a succession of still scenes to appear as continuous vision. In television, however, this convenient defect of the eye is even more important, for at any instant there is not even a still image, but merely a single element moving with an extremely high velocity.

The number of complete scannings per second necessary to give these effects is dependent upon the actual brightness of the picture. About 10 per second will reproduce movement effectively, but some 25 are required to eliminate flicker when a received image is rather dim, and at least 50 when it is brilliant. The rate at which these scannings follow each other is referred to as the *frame frequency*, or sometimes as the *traversal frequency*. This variation occurs because the eye seems more sensitive to rapid changes in illumination when the latter is intense.

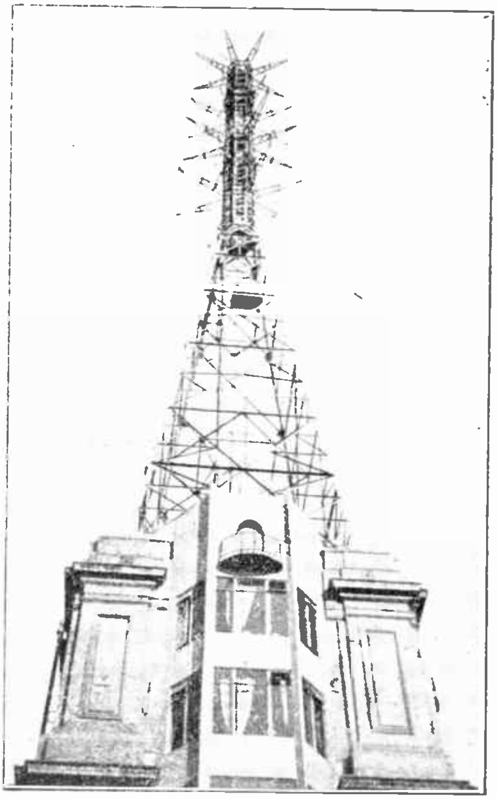
It is clearly undesirable to raise the frame frequency to 50 or more merely in order to overcome flicker, when a lower speed would be adequate to reproduce satisfactory movement within the image. It may be difficult to use some types of scanning equipment at high speeds, also, as will be seen later, a high frame frequency increases the side-band width of a television transmission undesirably. Unfortunately, however, the increase would be unavoidable if it were required to receive a really bright image by plain sequential scanning methods.

The difficulty has been overcome by the method known as *interlaced scanning*, which is employed in the *Marconi-E.M.I.* system. It can be explained by reference to Fig. 1. Alternate lines of the image are first scanned. Thus the aperture may commence with line 1 as a plain sequential scanning, but will then proceed to lines 3, 5, 7, etc., alternately until line 405 is reached; omitting all the *even* numbered lines. It thus scans in the order shown on the left side of Fig. 1.

In completing this process only half of the total image area will have been scanned. If one-twenty-fifth part of a second were required to scan the whole 405 lines, then only one-fiftieth of a second would be needed to scan alternate lines, but in so doing the whole field will have been evenly illuminated, and since the eye cannot perceive the scanning of individual lines, an effect equivalent to one complete illumination of the image will be seen.

Scanning is now continued by a repetition of the process, in which the element returns to the upper left-hand corner of the field and scans the *even* numbered lines alternately, from line 2, 4, 6, etc., up to line 404 in the right-hand column of figures. This part of the process is illustrated by the shading of these latter lines in the drawing. Again the effect of complete illumination will be perceived, and to an observer the field will have been illuminated *twice* during the twenty-fifth of a second normally employed to complete the full 405 lines. The flicker frequency has, however, been raised from 25 to 50 cycles per second, and is in consequence much less noticeable, but the actual rate of scanning has not been increased. It would be possible to effect triple interlacing, *i.e.*, scanning every third line in three groups, thus raising the flicker frequency by three. This was done with success by Sanabria in early American experiments, but double interlacing is considered sufficient for present-day requirements.

From the point of view of detail there is no loss through interlacing, since every element of the image is scanned once in the same interval of time as before, although in a somewhat different order. Practically an improvement results, since certain types of motional distortion are reduced, and the electrical frequencies set up by large objects within the image are raised to a higher and more convenient part of the spectrum. It is of course essential that similar interlacing be used at the receiver, and that the two processes be strictly synchronised. It might be thought that the image of Fig. 1 would be divided into two sets of 202 and 203 lines respectively, but it is found better to divide it equally into two sets of 202½ lines each, since by so doing it is possible to interlace the field of cathode ray receivers automatically. The reason for this will be given later.



A view of the Alexandra Palace Television Transmitting Aerial System, taken prior to September, 1939.

World Radio History

Frequencies involved in Television Transmission

When considering the theory of scanning it will be seen that the elements are not transmitted one after the other along the lines in a series of jumps or hops. It is in fact an *exploring aperture* of the size and shape of an element which moves along the line, picking up the changing values of illumination over which it passes. In early equipment an actual hole in a rotating disc or shutter effected this exploration, whilst in later systems complex optical devices of lenses, mirrors or prisms swept a narrow beam of light along the lines or picked up the successive small areas. To-day electrical methods are used, a cathode ray being the exploring beam, swept along the successive lines by deflecting fields.

Whatever form the exploring aperture may take in practice, its action can only be strictly examined by methods using integral calculus, because its motion along each line is continuous. Such analysis shows that if changes of light (or electrical potentials) of infinite rapidity could be transmitted, it would be possible to see objects decidedly smaller than the scanning aperture itself. This increased definition would only occur along the line however, and not in the perpendicular direction; whilst to transmit infinitely high frequencies would involve infinite sideband width, which is clearly impossible.

No serious error will be made in practice if it is assumed that the time taken to scan one element is the shortest period that need be considered, and that the single pulse of potential each produces is the smallest electrical unit involved. On this basis it can be said that as the scanning aperture passes over each element an electrical pulse is produced, which will be similar to a sinusoidal half-wave in form, and of amplitude proportional to the illumination of that particular element. Since the elements follow at uniform rate, these half-wave pulses will combine to produce a high-frequency modulation, of frequency one-half that at which the elements follow each other. Detailed calculations by experts differ as to what this frequency should be, giving its values from that stated above up to twice that figure. This value is termed $f(max)$ and represents the highest frequency which need be transmitted by a television system to provide uniform definition in all directions across the field of view.

Let us estimate $f(max)$ for practical cases. If there are N scanning lines across a square field, there will be N^2 elements, and if the frame frequency be F, then the number of elements scanned per second will be N^2F. Hence $f(max)$ on the basis taken will be $N^2F/2$; and will certainly not need to exceed N^2F. This is the highest frequency therefore which the communication channel used for television must handle without serious loss, and as will be seen later may be several megacycles.

Taking arbitrary figures, it is considered that 10,000 elements represents a good moderate definition, and that a frame frequency of 25 is about the minimum desirable. The maximum modulation frequency is therefore $10{,}000 \times 25 \div 2 =$ 125,000 cycles/second. This is the order of that used in many foreign systems during past years, and would suffice for many amateur experiments.

The original Baird 30-line low definition system produced a maximum frequency of about 13,000 cycles, which is just within the limit possible as modulation for a medium-wave broadcast transmitter such as the London National at local range. It could therefore be transmitted from that station successfully. The definition, however, was far too low for general entertainment or film transmission, although it was sufficient for fair reproduction of a close-up.

The B.B.C. service from the Alexandra Palace, which increased definition considerably, was able to handle quite complex scenes with adequate detail. With the 405 lines used in these transmissions the $f(max)$ was about two million cycles. Such a high frequency cannot possibly be used to modulate a transmitter in the medium or moderately short wave regions, where the carrier frequency would be of the same order, hence there was no option but to employ an ultra-high frequency carrier. Any frequency above about 20 Mc would have been suitable; but the difficulty of fitting in a carrier modulated to a total band-width of 4 Mc between existing services, and the necessity of avoiding all types of fading, which affect television more seriously than they do telephony, led to the use of carrier frequencies around 40 Mc, *i.e.*, 7 metres wavelength.

Summing up the requirements of a television transmission channel, whether radio or cable, it will be seen that it must be able to handle without serious loss the maximum frequency involved, which reaches several megacycles. This implies either a high frequency (short wavelength), or special cable of very low internal capacity and losses. It must also be able to handle all lower frequencies down to at least the *frame frequency*, and for the best reproduction down to zero frequency; namely, a direct current. Moreover, it must do this without marked phase changes, truly a formidable task! Change of phase will affect the relative positions of portions of a television image causing distortion or shadow effects. This is most marked in the lower frequencies which correspond to larger dark or light areas of the scene, and it may even be better to omit these rather than to have them present with serious phase displacement.

These considerations of complete phase and frequency linearity determine the design of television circuits and their chief differences from the more usual forms used in telephony. Their influence is particularly important in amplifier design, where many circuit devices commonly met in A.F. practice, such as transformer coupling, are entirely unsuited to television work.

The disposition of energy at other frequencies should also be noted. The television modulation contains energy at all frequencies from $f(max)$ down to the *line frequency*, namely that at which the scanning lines follow each other, and this is irregularly distributed according to the nature of the scene. Since many features will repeat themselves for several successive lines, there is a very strong component at the line frequency, often the largest single frequency to be detected. No energy is believed to occur below this point until the frame frequency is reached, which is also comparatively intense, whilst a progressively diminishing amplitude exists at lower frequencies down to zero

World Radio History

frequency. The adoption of interlaced scanning will not alter the line frequency, or the energy distribution above this frequency, but will raise the effective frame frequency from, say, 25 to 50 cycles per second. The importance of frequencies below this may be slightly reduced, but *f*(*max*) remains unchanged.

It will be noticed that two chief concentrations of energy occur, at the line frequency and frame frequency respectively. At all others energy is as a rule much less, and is changing continuously with the changing image, much of it being in the form of transients. Thus, on listening to a television signal, two steady musical notes will be heard, within the audible scale if the definition be low, but in some cases above it. The characteristic tone of the Baird 30-line signals was built up mainly of a line frequency of 750 cycles per second, and a frame frequency pulsation at 12·5 cycles. The B.B.C. transmissions showed a strong frame frequency at 50 cycles, but the line frequency was at 10,125 cycles and therefore not so easily heard. Much of the remaining signal energy was at still higher frequencies, largely above audibility, and so the volume of sound heard in ordinary headphones gave a very imperfect guide to the actual intensity of vision signals.

Simple Systems of Transmission

A very good understanding of television methods can be reached through the study of the simpler types of transmission. Whilst these early methods have given place to Cathode Ray systems in the broadcast studio, they are of fundamental technical interest; further, they offer a field for amateur experiment.

The type of equipment now to be outlined is capable of handling up to 60-line definition without difficulty, at which it is possible to reproduce a single head and shoulders " close up " excellently. With skilful design and adequate lighting its use can be extended to over 100 lines, the limit depending to a large extent upon the efficiency with which each part is constructed and used. Television is less simple than most branches of radio communication, and experience with elementary gear is almost essential before anything approaching high definition transmission is likely to prove successful.

Fig. 2 illustrates the essentials of a vision transmitter; and until the recent introduction of electronic transmission, all systems worked very much on these lines. Similar methods are still used in some types of high definition film transmission and are suited to amateur use. S represents the scene to be transmitted, which if not in strong daylight must be illuminated by powerful floodlights. Illumination reflected from the scene is picked up by the lens L to form a real image in the plane of the scanning device, at I. This process is exactly similar to that used in photography, and L may well be a photographic objective of large aperture. The image thus formed is now scanned, being divided up into lines and elements as explained in the previous section. Transmitters differ, mainly in the form of scanning devices used, and this will be referred to later. After scanning, the light, corresponding to one element only, is allowed to fall upon the photocell P, which sets up a potential corresponding to the instantaneous value of illumination of the element being picked out by the scanner at that instant. This potential will vary continuously as the scanning takes place, and after adequate amplification, provides the vision signal which can be transmitted over cable or applied to modulate a radio transmitter.

Transmission in this manner is termed *Floodlit* or *Direct Pick-up* television. Its chief limitation lies in the difficulty of obtaining adequate illumination, which has always been the major obstacle to television progress. There is a fundamental loss of light involved in the process of scanning because, for example, a 100-line scanning involving 10,000 elements would allow only ·01 per cent. of the total illumination of the scene to reach the cell. In practice the proportion would be much less, perhaps only ·0001 per cent., since the lens L can pick up only a small fraction of the total illumination, whilst there are many incidental losses in even the best scanning arrangements. The loss of light must increase very rapidly as the definition is raised, being at least proportional to the square of the number of lines used. This is the basic reason why optical-mechanical television methods become difficult to apply at high definitions, and why they cannot be used above about 100 lines unless certain recent, rather involved, optical processes are resorted to.

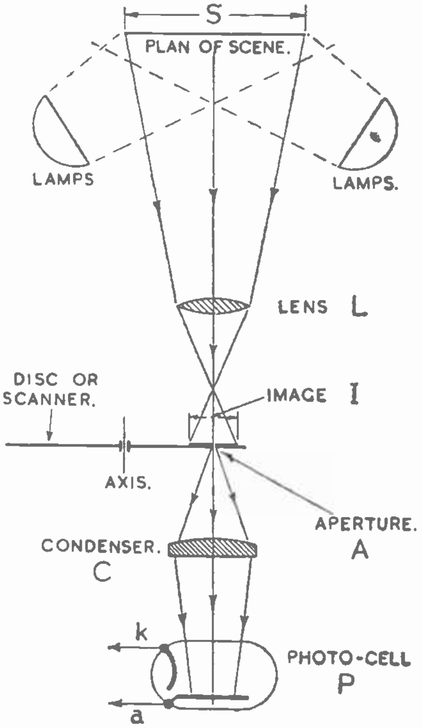


Fig. 2.
Arrangement of the essential parts of an optical television transmitter.

J. L. Baird introduced a second type of transmission designed to reduce this difficulty, which is often referred to as the *Flying spot* system. In this system the position of the light source and photocell shown in Fig. 2 are interchanged, an arc lamp being placed at the point P, whilst the floodlights shown are replaced by several photocells all connected to the main vision amplifier. The process of transmission is virtually the same, but the path of the rays is now reversed. An intense beam of light from the arc lamp will now be projected through the scanner and the lens L, to fall on the scene and illuminate one element of this at any instant. Thus instead of scanning an image of the scene, the scene itself is scanned by a beam of light which covers the area of a single element only at any instant. The remainder of the scene must be in relative darkness, although a little constant illumination will not matter because only changes in illumination will produce an alternating potential in the vision amplifier. Steady illumination will correspond to a direct current from the cells, which is not necessarily transmitted.

The advantage of inverting the process in this way lies in the fact that a higher intensity of scanning beam can be obtained from the arc lamp than could be tolerated from floodlighting. This intense beam is moving so fast that it gives the impression of feeble illumination and is not objectionable to the person televised. In other words, although the particular element being dealt with is very strongly illuminated, the average illumination is small. This is clearly more efficient than to flood the whole scene with intense light, which, besides being expensive and dazzling to the artistes, may also be accompanied by a very objectionable amount of heat. Spotlight scanning is, however, only suited to small studio scenes, and was the method employed in the original 30-line B.B.C. service. For many subjects, including outdoor scenes, it will be inconvenient or impossible. Direct illumination of the scene is also desirable on the same principle as that shown in Fig. 2, when the subject is a photograph, or a transparency such as a cinematograph film. In this case ample illumination is possible and optical scanning methods have given some of the best results yet obtained.

It will be noticed that beyond explaining the process of scanning little has been said about the methods employed to achieve it. Numerous systems have been evolved, but except for a few which are still being actively developed by such firms as *Scophony* and *Mihaly-Traub*, they are now obsolete. The earliest and certainly the simplest of practical television scanning devices was the Nipkow scanning disc, which has been so widely described that it will be familiar to most readers.

The Scanning Disc

This consists simply of an opaque disc, usually of aluminium, pierced with a number of holes equal to the number of scanning lines to be used. These lie on a spiral track about the axis of rotation, and are equally spaced along it, so that the angles subtended by the radii on which any two successive holes lie will be equal at the centre of the disc. Thus this angle will be $360/N$ degrees for an N line disc, and the spacing between the holes would be $1/N(2\pi r)$ if they all lay upon a circle of radius r. Actually this is not quite the case, since the holes lie on a spiral, and the radial distance of the first and last hole from the centre will differ by a small amount. For an horizontally scanned image with a breadth to height ratio of b/a, this radial distance will equal a/b times the mean circumferential spacing. Thus the area between the two extreme holes will be approximately a rectangle (having slightly curved sides, which can be neglected) of the shape ratio a to b, and will represent the image frame.

As the disc is rotated, the several holes pass successively across this frame, scanning it in a series of lines. If we imagine such a disc at the position shown in Fig. 2, with the image of a scene projected upon it so as just to fill the area swept over by the spiral of holes, then these will analyse the image into a series of parallel (very slightly curved) strips. At any instant, only one hole will be allowing light to pass, and this becomes the scanning aperture, picking out one element of the scene for transmission. Hence, just as the number of holes determines the number of scanning lines, so their shape determines that of the element. Similarly their size relative to that of the image determines the size of the element. Since the whole frame is scanned once for each rotation of the disc, the latter must rotate at the rate at which successive images are wanted, say 25 times per second, *i.e.*, 1,500 r.p.m.

It is important that each hole should accurately fill the width of each scanning strip, so that lines of demarcation will not be too noticeable between them. The television image should always be viewed at the optimum distance, from which the eye cannot quite resolve individual lines. The image will then seem quite continuous. This is practicable where definition is high, the lines being numerous and relatively narrow, but is seldom done at lower definitions since the image would appear too small from that distance. To minimise line effect the holes may be round so that the strips overlap slightly, or hexagonal as in certain foreign discs. If rectangular they need to be made very accurately.

A satisfactory medium-definition transmitter using the disc could be built on these lines by the amateur. Definitions above 100 lines should not be attempted, as sufficient illumination is impossible unless more advanced scanning methods are used, or transmission confined to film only. In any case experience at lower definitions is desirable at first, 30 lines being a suitable starting-point for which a disc can be obtained, whilst 50 or 60 lines is a very good medium standard. If the floodlight system be used, a minimum of 300 watts of illumination is essential and even more is desirable for good results. Too much illumination can hardly be used, provided the subjects can be made to stand the heat! Still pictures such as photographs or postcards can be dealt with at a lower illumination. The *flying spot* system will be found easier to use and more economical, a small automatic feed arc lamp running at from 10 to 15 amps. being ideal to flood the back of the disc through a condensing lens as shown in Fig. 2. Metal filament or exciter lamps are of little use here for the scanning of living subjects, as their intrinsic brilliance is too low, but they can be used for small photographs, or *stills*.

World Radio History

The lens L should be of the largest aperture obtainable, not less than F/4, and of magnification sufficient to cover the desired scene. A lantern projection combination might be used. The disc can best be run directly upon the spindle of a synchronous motor; speeds between 750 and 3,000 r.p.m. being suitable and 1,500 r.p.m. a good compromise. If a receiving disc is used it should be run from the same mains, thus achieving synchronisation. Means should be provided for rotating one of the motor frames in order to get the two into phase, *i.e.*, to obtain correct *framing*. If a cathode ray receiver is used it could be synchronised from the mains or from the image signal as will be explained later.

Other well-known scanning systems such as the mirror drum, lens disc, or mirror screw are equally applicable, and the interested amateur can learn about the necessary optical modifications from several of the textbooks listed in Chapter 22.

Photo-cells

Photo-cells used in television should be of high sensitivity and of the caesium on silver oxide type. Sodium or potassium cells have too low a sensitivity and are not suitable. Photo-cells fall into two classes, the *gas-filled* type in which traces of inert gas contribute to the ionisation current and increase the output, and the *vacuum* type in which only true photo-emission is made use of. The latter type are almost free from frequency limitations, and are essential for high definition work; but the gas-filled variety can be employed with fair success at definitions below about 60 lines. They possess, however, a slight time lag owing to the ionisation of the gas filling not being quite instantaneous, and this reduces their output above about 100,000 cycles, thus blurring the finer detail of the images. Caesium cells are sensitive to the " red end " of the spectrum, as well as much of the blue-violet, which makes them effective with incandescent filament lighting; further, they improve the light sensitivity much as do panchromatic films in photography. They have made possible the effect which has been termed " Noctovision " by J. L. Baird, in which the scene is scanned by infra-red light invisible to the eye. A scene is thus televised when in apparent darkness.

The small potentials produced by photo-cells must be amplified before they can modulate a carrier wave or operate a receiver. This problem is a more difficult one than the amplification of sound, and its solution has called for considerable research, on account of the very wide frequency range involved. It is also necessary to maintain the original phase relationships between the higher and lower frequencies, for a degree of phase distortion that would be negligible in sound amplification may be very serious in the case of television.

In transmission a pre-amplifier is usually placed directly adjacent to the cell or cells, keeping the connecting lead very short. The pre-amplifier and cell may be housed in one box and heavily screened. Every precaution will be necessary to prevent noise pick-up, for the output from the cells will be very small. Live inter-stage leads must be of the lowest possible capacity to earth, since good definition demands that the highest frequencies be retained. The amplifier may be of one or two stages, and can be direct-coupled with advantage. It is advisable for the best image quality to retain the direct photo-cell current, which corresponds to the average image brightness. This helps to distinguish between a dark scene and a brightly lit one, which would be reproduced with the same average brightness without it.

The main transmitting amplifier should be resistance-capacity coupled, carefully designed to retain both the extreme high and low frequencies with minimum phase change. The valves used should be of a high mutual conductance type, having at the same time relatively low impedance and inter-electrode capacities. The anode resistances should be kept down to a few thousand ohms in order to minimise the by-passing effect of stray capacities which form a low parallel reactance at high frequencies. A small air-cored inductance may be joined in series with these resistances, since the added inductance imparts a reactance to the circuit which rises with frequency, and if suitably calculated to match the valves it will provide a level amplification up to very high frequencies. The maintenance of the extreme low frequencies is more difficult, but fortunately it is not absolutely essential for moderately good image quality. It can be approached at considerable cost by the use of very large by-pass and coupling condensers, but it has been shown in recent research that careful choice of the values of anode decoupling condensers and resistances can introduce a compensating action which levels out the response very effectively. It still remains difficult to stabilise a high gain amplifier when the response near to zero frequency is good, and very stable H.T. and bias regulation is essential. *Paraphase* construction is used as one method of overcoming this instability, whilst in others the amplifier is designed to cut off at near the frame frequency, and a separate channel used to amplify the lower frequencies.

The amateur interested in conducting experiments will find that a resistance-capacity coupled amplifier built and screened as carefully as possible on the foregoing lines provides a good starting point. From five to eight stages are likely to be required, according to the illumination reaching the photo-cells, the limit being set by valve noise and Thompson effect. Battery operation of the cell pre-amplifier is likely to be necessary.

Electronic Transmission

The almost insuperable difficulties encountered in mechanical scanning at high definition have led to the use of electrical methods, based on the cathode ray tube. The first suggestions for the practical use of the cathode ray tube in television were made by the late A. A. Campbell-Swinton, one-time President of the Radio Society of Great Britain. His proposals were furnished with considerable detail and bore a striking resemblance to modern methods, but unfortunately the crude tubes available at that time were not adequate for its practical fulfilment.

Fig. 3 shows the principle underlying the " Iconoscope," a successful transmitting tube evolved by Zworykin of the *Radio Corporation of America*. This principle has been further developed

World Radio History

by the *Marconi-E.M.I. Television Co.*, forming the basis of the Emitron Camera as used by the B.B.C.

An illumination scene is picked up by the lens L and a real image formed on the surface of an electrode, which in itself forms the photo-sensitive caesium cathode of a photo-cell. This electrode which is the heart of the system consists of a fine granular structure of caesium globules, deposited upon a mica plate by a chemical process, which individually insulates them. The back of this plate is metallised. Thus each caesium globule forms a minute photo-cell, having an electrical capacity to the metal coating behind it, the mica forming a dielectric. The image formed upon this special surface is scanned by a cathode ray beam in the manner to be explained later. The whole is enclosed in the evacuated glass envelope of a cathode ray tube, and can be used in a camera-like case, resembling a cinematograph camera.

The image formed by the lens L falls upon the caesium surface continuously, and each globule will produce a small photo-electric current proportional to the light falling upon it. This will in turn charge up the small condenser which the globule forms, at a rate depending upon the illumination of that portion of the scene. As the scanning beam passes over each group of globules (the area of the beam representing the scanning element is much larger than a single globule) it picks up the charge which has accumulated upon them during the scanning interval and transfers it to the external amplifier input circuit. The beam thus merely serves as an inertialess electrical commutator or collector.

This system is considerably more sensitive than the older mechanical systems because all light collected by the lens, and not merely that light corresponding to a single element, is producing photo-electric current all the time. The cathode ray collects most of this energy as it scans the caesium surface, and thus a very large proportion of the light available is effectively used. There is no loss inherent in the scanning process, but only that due to practical or constructional imperfections. The system can transmit good images from scenes in ordinary daylight, and is claimed to work up to 800-line definition or more, were it possible to transmit the resulting enormous frequency band by radio. In addition the system is more convenient since it is entirely electrical and employs no moving parts.

Many attempts were made to bridge the gap between mechanical transmission and the electronic methods which have recently been developed. One of these which achieved considerable success was the *intermediate film* system, whereby a film is taken of the desired subject at the time of transmission, developed in a few seconds, and immediately transmitted while still wet by optical means. Sufficient light can be passed safely through a moving film to allow of high definition scanning, even by disc methods. The film can be dried for storage, or the emulsion cleaned off and recoated for use over again. This method may seem somewhat cumbersome and costly, but it is one which had given quite useful results, particularly under "news-reel" conditions. A serious difficulty lay in the provision of the necessary few seconds' delay for the accompanying sound transmission. It was necessary to record this also on disc or film, and to reproduce it a few seconds later. A loss of quality was however inevitable.

Intermediate film processes have also been used in television reception, providing one of the few successful methods able to fill the full-sized cinema screen. A disc or cathode ray receiver can provide a small image, bright enough to be easily photographed on to film. The latter is then quickly processed, and can be passed through the cinema projector whilst still wet. This system provides a larger, brighter, image than any other, and also a permanent record of the received scenes. It has however the drawbacks mentioned for intermediate film transmission, and is fast being superseded.

Television Reception

In the earlier days of television, reception always took the form of a reversal of the transmitting process, essentially that of Fig. 2. In place of the photo-cell was placed a light source capable of varying in intensity to correspond to the incoming signal amplitude, the neon lamp being the best known and probably the first used with success. Alternatively a source of constant brightness such as an arc or filament lamp was used, and the light modulated to correspond to the signals by a *light valve* such as the Kerr cell.

The beam then passed through a scanning device, identical with, or equivalent to, that at the transmitter, and synchronous therewith. It was then projected by a lens on to a reflecting translucent screen, and viewed much as would be a cinema image. Such methods are quite practicable at low definition, but possess the same defects as mechanical transmitters, the most serious of which is a very

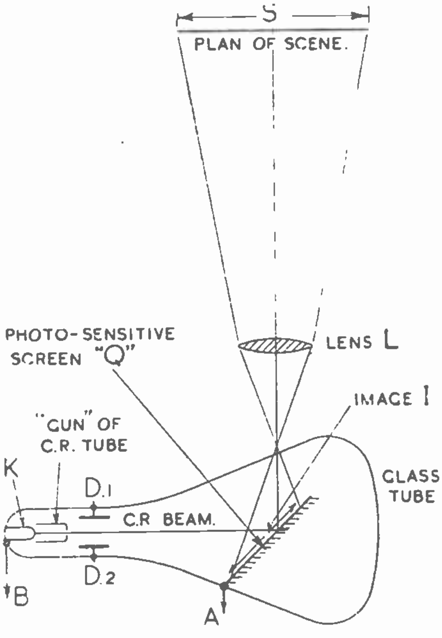


Fig. 3.
The principle of an electronic transmitting tube.

World Radio History

poor illumination of the screen as the number of lines is increased. They have therefore been largely abandoned for home use in favour of the more effective cathode ray methods.

Cathode Ray Reception

In the cathode ray tube a means is provided of tracing upon a fluorescent screen a luminous curve connecting two variable quantities, and it was for such work that it was originally developed exclusively. The tube has more recently been found very effective in television reception.

An untouched photograph of a London programme picture transmission received on a Cathode Ray Tube.

Fig. 4 shows the constructional features of a modern receiving tube. In some respects it resembles a valve, consisting of a highly evacuated glass envelope, fitted with a cathode at the neck. This is generally of indirectly heated construction, and may be suitable for use on A.C. The cathode produces the usual emission of electrons, and these are to some extent concentrated and prevented from straying in all directions by the negative or Wenhelt cylinder. A stream of electrons passes out through a hole in the closed end of this cylinder to form the "ray" or scanning beam.

The most usual method for modulating the intensity of this stream is to apply vision signals to the negative cylinder, varying its potential with respect to the cathode. In other tubes an auxiliary modulating electrode, or grid, is inserted at a later point along the electron stream. Following the cylinder is the first anode, which is held at a fairly high positive potential and this accelerates the electron stream into a high velocity beam. Moving rapidly along the tube, this strikes the fluorescent coating which covers the inside of the end of the tube, where it produces a glow proportional to the beam intensity or beam current.

Unless certain precautions are taken the beam will disperse during its journey along the tube, producing a diffused spot upon the screen. To overcome this effect it must be focused in order to arrive there as a small sharp spot, which is now the scanning element that builds up the received image. Two methods of focusing are in use, one the earlier method termed "gas focusing," and the second a more recent and perfected development termed "electron focusing."

Focusing

A gas focused tube is not completely evacuated, but a trace of some inert gas is permitted to remain. It thus more nearly resembles a gas-filled triode or neon lamp than a modern hard valve. The residual gas is ionised by the passage through it of the cathode ray, a number of electrons and positively charged ions being liberated. The electrons, combined to a large extent with those forming the ray, thus augment the beam current and help to provide a bright screen at a relatively low anode voltage. Consequently a gas focused tube works well at low voltages and is easy to use. The positive ions on the other hand are considerably more massive. Their inertia prevents them from being carried along with the beam, and instead they form a cloud in the surrounding space, which resembles a space charge in many ways. Being positively charged they attract the electrons forming the beam, and draw them inwards towards the axis of the beam, which is thus prevented from dispersal. Whilst this concentrating effect is not strictly focusing, it has an identical influence in keeping the beam narrow.

Gas focusing is very effective when the beam is deflected at low speeds so that there is time for a cloud of ions to form as it moves. At the higher rates of beam oscillation encountered in high-definition scanning however, no effective ion cloud

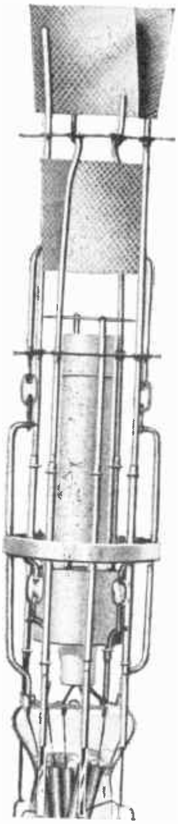


Fig. 4.
The electrode assembly of a typical cathode ray tube, as used in television reception. The long cylindrical tube is the gun. Above are the two pairs of deflector plates.

has time to form, and the focusing action breaks down. Hence such tubes are not well suited to television.

To overcome the difficulties mentioned, modern tubes are highly evacuated, and focusing is carried out through the action of electrostatic or electromagnetic fields. It is found that such fields have a similar effect upon the beam as do materials of varying refractive index upon a beam of light. Just as a dense glass will reduce the velocity of rays passing through it, so an intense field will change the velocity of an electron beam. Curved fields act similarly to the curved surfaces of a glass lens, and it is possible to set up *electronic lenses* which concentrate and focus the cathode ray in the same way as glass lenses do a ray of light. Thus a new branch of science, termed Electron-optics, has been built up, and provides a method of focusing which is instantaneous, remaining effective at the highest rates of beam movement used in television.

Both receiving and transmitting tubes are now electron-focused, the most general method being electrostatic. Here a second, and perhaps a third anode, are introduced, which are at progressively greater positive potential above the first anode. These are shaped and placed so as to set up the focusing field, the beam as it passes through them being both accelerated and caused to converge to a sharp spot upon the screen. Magnetic fields set up by coils surrounding the neck of the cathode ray tube can alternatively be used to effect focusing. Their use reduces the number of electrodes within the tube, thus reducing the cost of replacements, and because of this fact magnetic methods both of focusing or scanning are gaining ground commercially. For the amateur however the electrostatically focused and deflected tube remains the simplest, since a more elaborate internal structure enables simpler external circuits to be employed.

However excellent a system of focusing may be used, there is a limit to the minimum spot size possible, and therefore to the width of scanning line it can trace; which means that too small a screen cannot be used if a large number of lines is to be accommodated. This is one of the difficulties in projecting an image from a small bright tube, on which a sufficient number of distinct lines cannot be accommodated with the smallest spot at present obtainable. Cathode ray screens vary from 1″ up to some 6″ in diameter when intended for measurement work, and from 7″ through an average size of 12″ or 14″ up to about 24″ for television purposes.

Having obtained a sharp spot it is necessary to sweep the beam in parallel lines across the screen to produce scanning. This can be done because the beam of electrons behaves like an almost inertialess wire carrying current, and will be deflected sideways by either an electric or magnetic field. In electrostatically deflected tubes the beam passes between two pairs of *deflector plates* in mutually perpendicular planes as illustrated in Fig. 4. To one pair of these is applied a suitable potential at the line frequency, whilst to the others is applied the frame frequency, serving to displace the lines into a " raster," and to return the spot back to its original position after the screen has been completely scanned. A similar effect can be produced by two perpendicular coils carrying oscillatory current, when the magnetic fields deflect the beam in precisely the same manner. One electric and one magnetic deflector are sometimes used in the two planes respectively as a matter of commercial convenience.

In cathode ray reception therefore, the image is built up upon the fluorescent screen of the tube by the beam, which acts as a scanning device. The brightness of any element is determined by the beam intensity, modulated electrically by the vision signal, while the beam area (size of spot) determines the size of scanning element. A potential variation of 10 volts is sufficient to modulate a modern tube from black to full brilliance, so very little signal energy is needed. The system owes its efficiency to the fact that the screen illumination follows quite different laws to those of a beam of light. The energy of illumination comes from the beam, being provided by the anode current of the tube, and is independent of the speed with which the beam is deflected. The average illumination thus tends to be independent of the number of lines, and is maintained up to very high standards of definition.

The Vision Circuits

Fig. 5 shows schematically the parts which make up a complete receiver for radio vision signals. Two radio receivers are necessary, for sound and vision respectively, and it is assumed that each of these contains its own power supply. The sound receiver feeds a speaker placed near to the vision

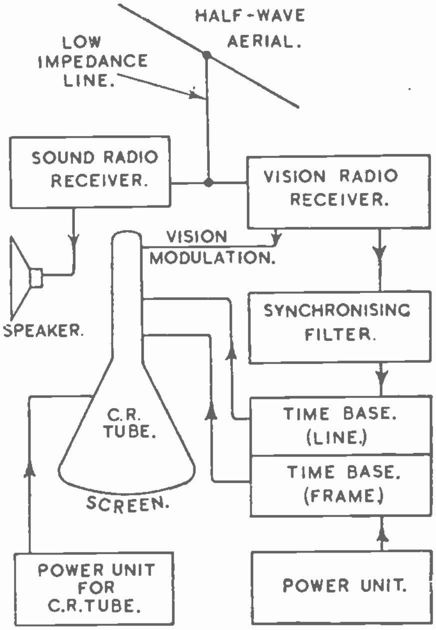


Fig. 5.
Schematic diagram of the parts which are needed to make up a complete television receiver.

World Radio History

screen, whilst the vision receiver provides two outputs. One of these feeds the modulating grid of the cathode ray tube. To avoid distortion and to retain the D.C. component of the rectified signal, it is best to provide this directly from the diode detector (or second detector if a superheterodyne is used) which works at " high level," delivering a swing of 10 or more volts. Alternatively, a single amplifying stage may be used following a diode working at a lower level.

Some means must clearly be provided for synchronising the scanning process in the receiver with that of the transmitter, and this is done by the vision signals themselves. An examination of the waveform of a typical vision signal (given in Fig. 6) will show that at the transmitting station a synchronising impulse of rectangular waveform has been inserted at the beginning of each scanning line. A special generator inserts these impulses which are arranged to reduce the carrier to zero, whilst modulation is also suppressed for a longer period at the completion of each frame. It has been decided to limit the vision signal to the range of from 100 per cent. modulation for the high lights to 30 per cent. modulation for black. Zero carrier thus corresponds to " blacker than black," which cannot further darken the screen, but owing to the amplitude of these synchronising impulses being lower than that of any portion of the vision modulation, they can be separated therefrom by an amplitude filter. The second circuit from the vision receiver output therefore goes to such a filter unit as shown in Fig. 5. This may consist of a saturated pentode valve, so biased that any increase of modulation above 30 per cent. cannot further increase its anode current, thus preventing any vision signals reaching the anode circuit. A carrier below 30 per cent. of the peak value, however, reduces anode current below the saturation value, producing in the anode circuit sharp impulses at the line frequency, which can be used to synchronise the deflecting oscillators, or *time base generators* as they are termed.

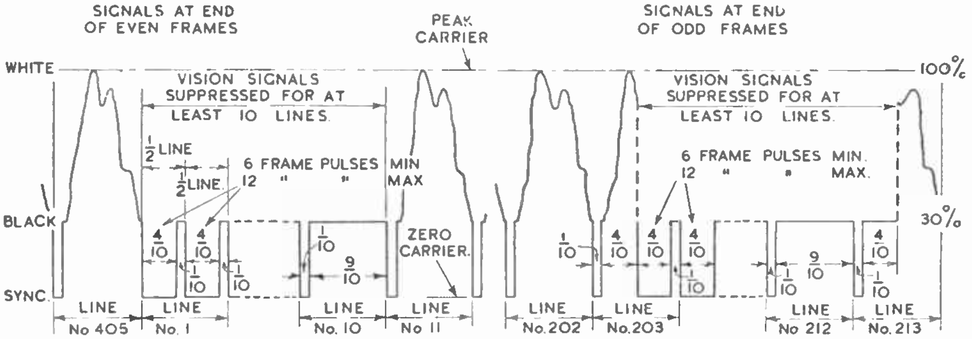


Fig. 6.
The waveform of a television signal as transmitted by the E.M.I. system.

Time Base Circuits

Time base oscillators which are an essential part of the television receiver are not found in other types of radio equipment. The duty of such an oscillator is to produce a voltage at the line or frame frequency which can be used to deflect the cathode ray and so build up a " raster." The oscillation must not however be sinusoidal because it is required to sweep the spot across the screen with uniform speed for each line, and then to return it for the next in the shortest possible time. This necessitates a " sawtooth " waveform, having a strictly linear rising portion followed by a steep and brief return as shown in Fig. 7; and in the simplest methods is produced by the charging up of a condenser at constant current, followed by its sudden discharge at an instant determined by the synchronising impulses received from the transmitter.

Fig. 8 illustrates this type of circuit, which apart from its use in television is commonly required when using a cathode ray tube for measurement purposes. The condenser C is charged up from the H.T. supply. For the potential across this condenser to rise linearly with time the charging current must be constant, which can be approached if the charging takes place through a high adjustable resistance as shown. The process is actually exponential rather than linear, but if the H.T. be high relative to the maximum potential built up across C, then the result will be sufficiently linear for most purposes. It is for this reason that the H.T. should be at least ten times the peak potential across C; 1,000 volts being desirable. By suitable selection of C and adjustment of R, the time period of charge can be adjusted to any desired value. C may be of the order of ·1 μF to ·5 μF for frame frequencies, and about ·0005 μF for 405-line scanning.

The simplest method of discharge is provided by a gas-filled triode, VT, containing mercury vapour for low speed work, or a gas such as argon or helium for higher speeds. Such a tube passes no current until the anode potential reaches a critical value determined by the grid bias, when the anode resistance drops suddenly to a low value. Connected across C as shown it will thus discharge every time the potential reaches a certain value, determined by the grid bias which should be provided by a battery or separate stable eliminator, thus providing the necessary sudden return to zero which the sawtooth waveform demands.

If C, R, and the bias be set to give an oscillation

World Radio History

period slightly longer than the desired line frequency, and the synchronising impulses be applied to the triode grid, they will momentarily depress the bias potential. Since this was only slightly above that for discharge, the exact instant will be determined by the impulse, the condenser C discharges and commences to provide a fresh scanning sweep at the correct instant.

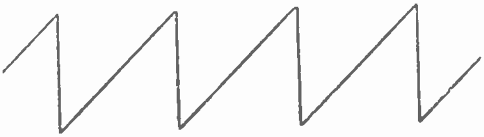


Fig. 7.
Typical saw-tooth waveform of time-base oscillator output, showing long linear scanning periods and short fly-back or discharge periods.

A single pair of deflector plates could be connected directly across C, as is frequently done when a cathode ray tube is used in the laboratory, an unknown voltage being applied to the other pair of plates. It is found however that many television tubes suffer from a defect termed *trapezium distortion* when one deflector plate is earthed, the "raster" becoming trapezium-shaped rather than rectangular. To prevent this the deflector plates are driven in push-pull, each being at an equal potential with respect to cathode. A symmetrical potential gradient then exists within the tube. In addition large tubes may need several hundred volts of deflecting potential. The output directly obtainable from a time-base oscillator is limited, hence an amplifier is added to increase the oscillatory potential to that order. This amplifier can conveniently serve the additional purpose of push-pull excitation to the plates, being arranged in the manner often termed a *phase-splitter*.

To the right of the dotted line in Fig. 8 is shown a simple but effective method for achieving the desired result, in which only a single triode valve is needed. The amplifying valve V_2 is provided with equal load resistances R_3 in both the anode and cathode circuits, and is directly coupled to the oscillator to preserve an undistorted waveform. The potentials which are built up across the two resistances will be in phase opposition and are applied to the deflector plates. Whilst this simple arrangement illustrates the principle, it would not usually be chosen in a vision receiver, since its use demands a separate and insulated H.T. supply for V_2, whilst the oscillator is raised above earth potential. Moreover the high voltages needed for large tubes are more easily handled by a pair of valves, each dealing with only half the total oscillatory voltage, as in more normal push-pull amplifiers. Special triodes now available for this work are able to withstand an anode voltage of 1,000 volts.

Fig. 9, which illustrates more fully the complete time-base arrangements of a television receiver, comprises a time-base oscillator, amplifier, and associated circuits. V_1 is again the gas-filled triode or thyratron oscillator, which derives its grid bias *via* the cathode from a tapping on the cathode resistance R_4 of one of the amplifying valves, V_3. This arrangement saves a separate biasing source for V_1, and is permissible because V_3 draws a moderately large and steady anode current, which sets up a definite potential across R_4, whereas V_1 draws no current except during the brief fly-back periods. At such moments distortion of waveform is immaterial, whilst during the scanning periods, V_1 is non-conducting and draws no cathode current. C_1 and R_1 determine the approximate scanning frequency, whilst the amplitude of this, and hence the duration of each line or frame, is determined by the setting of R_4. Synchronising impulses are applied through a simple filter to the grid of V_1 as shown. These are in a positive sense, to reduce the grid-bias momentarily, and thus initiate discharge.

Saw-toothed oscillations occurring across C_1 at the correct intervals are now transferred by the condenser C_2 and leak R_2 to the grid of the first amplifier, V_2. After amplification the potentials are in reversed phase at the anode of V_2, and are applied directly to one deflector plate. A portion of this potential is tapped off by R_6, which in conjunction with R_5 forms a potential divider. If

$$\frac{R_6}{R_5 + R_6} = \frac{1}{\mu} \text{ for } V_2,$$

then the potential transferred through C_3 and R_3 to the grid of the second amplifier V_3 will be equal in amplitude but in opposite phase to that at the grid of V_2. Across the anode resistance R_7 therefore (R_7 approximately equals $R_5 + R_6$, and V_2 and V_3 are similar) will appear an equal potential to that across $R_5 + R_6$, but in reversed phase. This is applied to the second deflector plate.

Means are required for adjusting the mean D.C. potential of the plates with respect to cathode, so that the scanning beam can be centralised and the image placed centrally on the screen. These are termed *framing controls*. In Fig. 9 the desired effect could be obtained within limits by adjusting R_7, R_5 and R_6, or the two anode resistances together. Alternatively the bias on V_2 or V_3 might be controlled. In the case of simpler scanning circuits which employ no amplifier, the earthed deflector plate may be taken to the arm of a potentiometer

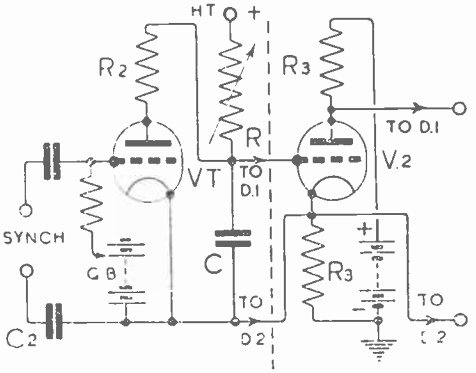


Fig. 8.
A time-base circuit employing a gas-filled triode, which can be used either for television or in an amateur laboratory.

by which an adjustable D.C. potential is applied for the same purpose.

The circuit of Fig. 9 only provides line or frame scanning potentials, and must be duplicated to provide both. There are thus a line time-base and amplifier, and a frame time-base and amplifier, making a total of six valves in all. The two units are often combined on one chassis, and differ mainly in the values of the components, and in particular of C_1 as already explained. Each will be synchronised *via* independent filters, which in commercial equipment are often elaborate devices employing combinations of valve limiters; but reasonable results are possible from very simple arrangements such as the pentode limiter already mentioned. The higher line synchronising frequency may be isolated by passage through a small condenser (shown at C_4 in Fig. 9), with perhaps an adjustable resistance R_8 to regulate the strength of the impulses. The low frame frequency may be taken through a large condenser, also in series with a resistance and perhaps a choke to reject traces of the much higher line or image frequencies. Further isolation might be obtained by a fairly large condenser across the grid of the frame scanning triode V_1, giving that circuit a long time constant. It can then respond to the slow frame impulses, but not to the faster line impulses. Very fair synchronising is possible if each gas-filled triode be fed through resistance-capacity filters of high and low time constant respectively, a common limiter being used for both, or even dispensed with. More elaborate arrangements only become essential when the vision signals are weak, at great distances, or subject to serious interference which tends to upset synchronisation.

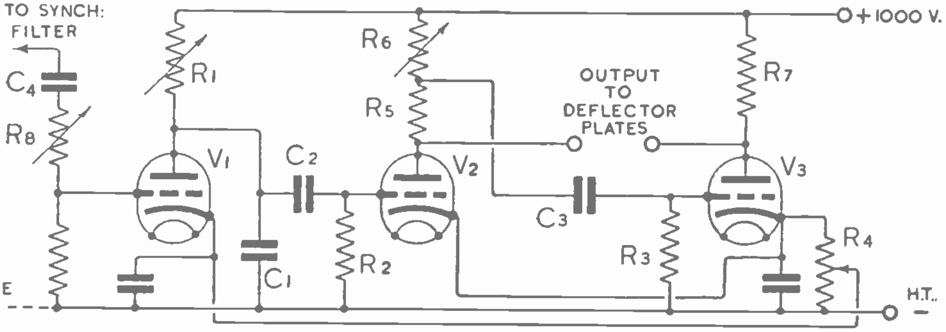


Fig. 9.
Circuit of a complete time-base oscillator and amplifier, employing a gas-filled triode.

At very high scanning speeds there is a tendency for the action of gas-filled valves to become irregular, and numerous circuits have been evolved in which "hard" valves only are used. A further object of such circuits is to attain a large oscillatory voltage without the use of an amplifier, or to reach more readily the high frequencies that may be needed in R.F. measurement. Triodes filled with rare gases such as argon, helium or neon have been found more reliable at high scanning frequencies. The *Osram* GT1B is a recently introduced valve of this type, having an improved electrode construction.

An example of hard-valve time-base due to Puckle is shown in Fig. 10. Here C_1 and R_1 are the main condenser and charging resistance as before. R_1 may be replaced by a pentode when more linear charging is desired, or when the oscillatory potential is to exceed about one-tenth of the H.T. voltage. The two valves V_1 and V_2 together replace the valve V_1 of Fig. 8 or 9. They will be seen to be connected in an unstable manner not unlike a multivibrator oscillator, but the action is somewhat involved. Briefly, when C_1 is discharged there will be no anode voltage on V_1, since its cathode will be at H.T. potential, also the grid will be very negative with respect to cathode owing to the voltage drop along R_3, due to the steady anode current of V_2. This state of affairs persists during the charging period of C_1, V_1 remaining non-conductive until a time when the falling cathode potential approaches that of the grid. The valve then suddenly commences to take anode current, and a potential impulse is transferred *via* C_2 to the grid of V_2, driving it negative and decreasing the anode current of V_2. As a result the grid bias of V_1 quickly falls, and since the whole cycle is cumulative, the anode current of V_1 rushes up to saturation, discharging the main condenser C_1. The process may be likened to a single cycle of an oscillation by the pair of coupled valves, which are prevented from oscillating continuously at a frequency of their own because directly C_1 is discharged the H.T. voltage on V_1 vanishes.

There are also a variety of single valve time-base oscillators in which anode and grid are coupled magnetically. In one class the saw-toothed waveform is obtained by a *squegging* effect similar to that of a self-quenched detector, the valve also oscillating at some much higher frequency which plays no part in scanning. In another type the valve does not oscillate at a high frequency, but anode and grid are tightly coupled through a transformer. H.T. is fed to the valve through the charging resistance R, and the main condenser C occupies the position of an anode decoupling condenser. An unstable condition resulting in saw-toothed oscillation occurs because changes of anode potential are thrown back on to the grid by coupling through the transformer, in such a phase as to augment the original variations of anode potential and to distort the normal sinusoidal oscillations into the desired waveform. Yet another time-base oscillator employs an iron-cored transformer, in which the core is near to magnetic saturation. As a result of this saturation the normal oscillation which would occur is distorted until it approaches the desired waveform. There is ample room for simplification and improvement in time-base generators, which form an ideal field of experiment for the ingenious amateur.

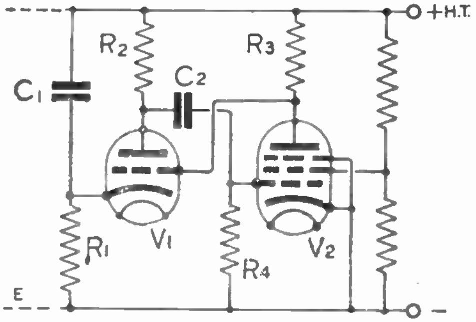


Fig. 10.
Hard valve time-base circuit, described in text.

Power Supply Circuits

At least three types of eliminators are necessary to supply a television receiver, for it is generally thought uneconomic to employ a battery supply except perhaps in the laboratory, whilst D.C. mains would not offer sufficiently high voltages. For the radio receivers the power supply units would differ in no respect from those described in Chapter 9, whilst for the time-bases a unit providing probably about 50 mA at 1,000 volts would be required. This could be of similar construction to that used to supply a medium-powered transmitter. It is usual to provide thermal delay switches, so that the high voltages are not applied until the valves and cathode ray tube are hot.

For the cathode ray tube itself a somewhat different unit is necessary, since only a very small current is required at a high voltage. A typical modern 10" tube may need 3,000 volts at from 1 to 2 mA only, most of which current is dissipated in the resistance network from which the other electrodes derive their potential. A typical eliminator is illustrated in Fig. 11. The total resistance of R_2 to R_6 might be 5 megohms, but the individual resistance values will depend entirely upon the system of electron focusing adopted by the tube manufacturers. The grid biasing resistance R_2 is variable to control the mean brightness of the screen, whilst R_4 may vary the first anode potential for purposes of focusing. Notice that in cathode ray equipment it is usual to earth the anode of the tube, or the *positive* side of the H.T. supply. This is the reverse of usual practice, and if overlooked may lead to unpleasant shocks. Also on account of the small current involved it is satisfactory to replace the conventional smoothing choke by a resistance R_1, which has the added advantage of limiting current in case of an accidental short circuit at some later point in the equipment.

High insulation of the power transformer, filament winding and general wiring cannot be overstressed, since peak voltages of from 3,000 to 6,000 lead very readily to breakdown. It is usual to supply all filaments, etc., from entirely separate transformers, and to treat the cathode ray tube eliminator as an isolated unit. In fact, unit construction is ideal for all television apparatus.

Radio Receivers

As television is now only available abroad, it is desirable to confine these remarks to the pre-war London service, in which the vision carrier was at 45 Mc and that for sound at 41·5 Mc, and to discuss current types of receiver and details of design.

The sound receiver can follow standard practice, and may be a simple superheterodyne, a straight receiver or even a super-regenerative type preceded

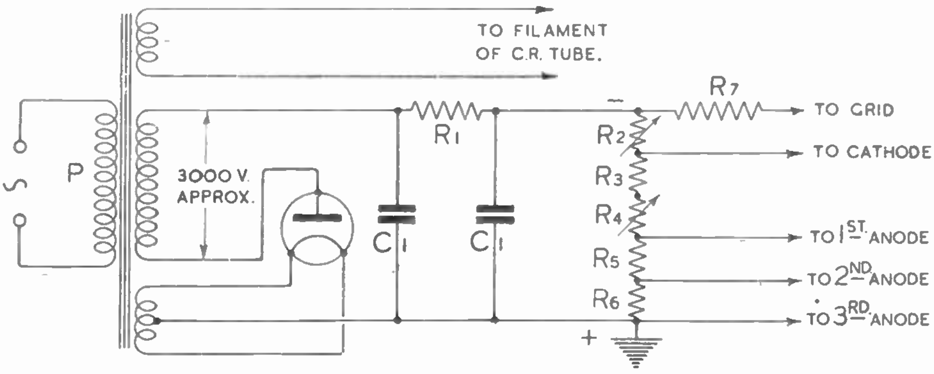


Fig. 11.
Power supply circuit for electrostatically focused cathode ray tube.

World Radio History

by an R.F. stage to reduce radiation. It may be quite independent of the vision receiver, or it may share the R.F. portion of the vision receiver. In one commercial model both receivers are superhets, employing a common R.F. and frequency changer section, but two separate I.F. channels. In another the sound signals pass through the first two R.F. stages of a straight vision receiver before being taken to a separate simple superheterodyne.

Both straight and superheterodyne vision receivers are used. The *Marconiphone* and *H.M.V.* receivers are examples of the former, five flatly tuned R.F. stages being used at 45 Mc followed by a diode detector which directly feeds the cathode ray tube. The coupling coils are resonated by the eddy-current method, being fitted with movable brass plungers. The stage gain is necessarily low, as a band width of 4 Mc must be amplified with only little loss, but the overall amplification is found to be sufficient at any distance from the transmitter at which local background noise permits reception.

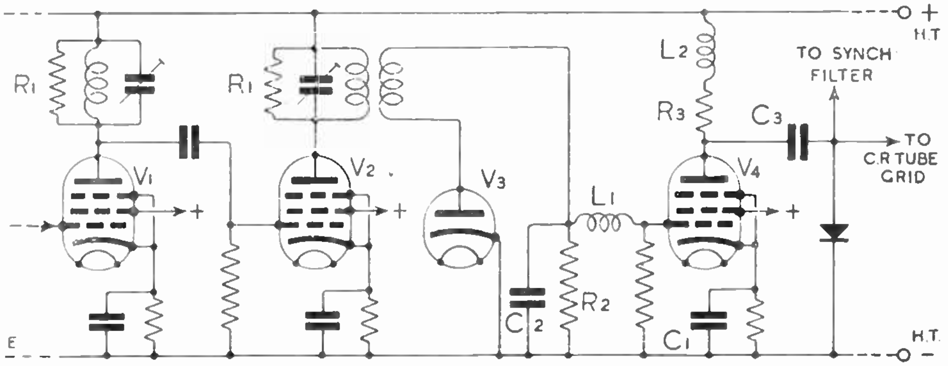


Fig. 12.
The last two I.F. stages, detector, and video amplifier of a vision receiver showing D.C. restoration rectifier.

In most other designs the vision receiver is a superheterodyne, following conventional practice in respect of the frequency changer, which may be a triode-hexode preceded by a single flat R.F. stage. An intermediate frequency between the limits of 5 and 10 Mc is chosen, being high enough to pass the necessary band-width, and low enough to retain as much stage gain as possible. Single sideband amplification is used in certain designs, with a small gain in efficiency, but the amplification per stage using the most suitable R.F. pentodes cannot exceed about 16, and is generally much less owing to the heavy damping of the couplings by resistance, found essential to provide a 2 or 4 Mc bandpass characteristic. As a result, three I.F. stages seem to be a minimum for local reception, and most receivers intended for use at greater distances employ 4, 5 or even more stages.

A second factor enters into the choice of the number of stages to be used, for each additional stage will cause a reversal of phase of the vision signals. It is essential for these to reach the tube in the phase taken as positive, *i.e.* such that an increase in modulation causes an increased brightness of the beam. If an incorrect number of stages be used the image will be negative, and will resemble a photographic negative in appearance. The system of second-detection used also affects phase, a power-grid detector giving the reversed phase from the more usual diode. When the latter is used to feed the cathode ray tube grid directly, phase will be correct when the whole receiver contains an even number of stages.

In Fig. 12 are illustrated the last two I.F. stages, diode detector and following circuits of a typical vision receiver. It will be noticed that the I.F. stages are of the tuned-anode coupled type to prevent excessive selectivity, and that damping resistances R_1 of from 3,000 to 5,000 ohms are joined across the circuit. A transformer coupling is used into the diode, which should be of the low impedance and low capacity type specially available for the work, such as the *Mazda* D1 Acorn diode. The load resistance R_2 must also be low, an average value being 5,000 ohms, the reason for such precautions being found in the very high modulation frequencies that must be retained. It is therefore shunted by a condenser C_2 of the minimum capacity possible to give reasonably efficient rectification, perhaps some 50 μμf.

Should there be sufficient signal output for direct application to the cathode ray tube grid, then the circuit remains very simple. It is a decided advantage to employ one of the recently designed tubes, which require a grid swing of only 9 volts for full modulation. There are several R.F. pentodes able to deliver this swing to the diode, including the types TSP4, SP41, Z62 or MSP41. In Fig. 12 it has been assumed that this is not the case, perhaps because the number of I.F. stages has been kept down for reasons of economy or stability. The amplification of two I.F. stages can be dispensed with if a *video-frequency* amplifier (corresponding to an A.F. stage) be introduced between the diode and tube as illustrated by V_4. A filter now becomes advisable to prevent excessive I.F. from reaching the grid of V_4, and in its simplest form might consist of an R.F. choke L_1, which forms a low pass filter in conjunction with the grid-cathode capacity of the valve. Preferably this choke should be of such an inductance as to resonate at the I.F. with this grid capacity.

World Radio History

The valve V_4 should be of the power pentode class, and the fact that it introduces a phase reversal must not be overlooked when designing the remainder of the receiver. The anode circuit is resistance coupled by R_3 and C_3 to the cathode ray tube grid, and as a result of so doing the D.C. component of the vision signals will be lost, being stopped by C_3. This is the chief objection to the use of a video stage, another being the possibility of distortion and frequency loss. Both the highest and lowest components of the vision signals are more likely to suffer after detection than in the I.F. stages, the latter through loss in the coupling condenser C_3, and the former through the well known effect of stray capacities. To reduce this defect an inductance L_2 is added in series with R_3. Since an inductive reactance rises with frequency there is a tendency for the total anode coupling impedance $R_3 + L_3$ to do so also, thus imparting a rising amplification with frequency characteristic which largely offsets the loss due to stray capacities.

It is possible to replace the lost D.C. component by means of a diode or metal rectifier connected across the input to the cathode ray tube grid as shown. This component rectifies the mean vision modulation to produce a bias equal to the mean carrier amplitude, thus effecting *D.C. restoration* and controlling the mean brightness of the image to correspond with the transmission. In order for any such scheme to be effective and to ensure an image of good quality it is important not to weaken the extremely low frequencies between zero and the frame frequency of perhaps 50 c.p.s. Such a requirement is difficult to meet in the video stage V_4, and demands a very large cathode by-pass condenser C_1 of not less than 50 µF. An alternative method of design is to omit this condenser altogether, when the biasing resistance will introduce a degree of negative regeneration which is independent of frequency and helps to provide an even characteristic. Effective decoupling is also difficult in television circuits, and may be omitted in favour of several independent H.T. supply units of good regulation. Fortunately from this point of view the gain of any individual stage is generally so low that stability is not difficult to achieve.

Vision Aerials

Owing to the necessity of providing as much signal input relative to local noise and the interference due to passing cars as possible, a special aerial is almost essential for vision reception. The array used at the transmitter is designed to provide omnidirectional vertically polarised radiation in the horizontal plane. It consists of a ring of 8 vertical half-wave radiators, each centre-fed, and each with a centre-fed reflector behind it.

A similar receiving aerial is naturally to be preferred, simplified to a single vertical halfwave as shown in Fig. 13, the length L being of the order of 10′ 5″. It will be best proportioned to resonate at a frequency between the vision and sound carrier frequencies which will give a similar signal amplitude to each, assuming of course that the usual method of feeding both receivers from a common aerial is employed.

When signal strength is poor, a reflector may be added on the side remote from the transmitter, and this has been found very well worth while in many cases. A reflector may also assist in keeping out car ignition noise from the rear of the aerial. The reflector consists of an insulated wire 2 or 3 per cent. longer than the radiator, mounted parallel to it and a quarter-wavelength away. This dimension is not very critical, 5′ having been found effective. It must be remembered, however, that in the interest of even response over a two megacycle sideband, the aerial system must not be too selective, and the use of more complex arrays than the simple reflector is not advised, and should not be undertaken without experiment. The use of either large diameter tube for the dipole or several wires in parallel has been found to result in a more uniform impedance with frequency, thus reducing the inherent selectivity of the aerial.

Matched low impedance lines are generally preferred to couple the aerial to the receiver, concentric feeder and the 80 ohms parallel or twisted forms being used. The latter is probably the simplest to install, and may be taken directly to the centre of a split half-wave as illustrated. When end feeding is more convenient, the aerial may be terminated by a quarter-wave matching section spaced at 2″, bridged at the lower end as in the second sketch. The feeder is now tapped on at the optimum point, which is likely to lie between 4″ and 6″ from the bottom end, and is best determined by experiment with the help of some kind of output meter attached to the receiver.

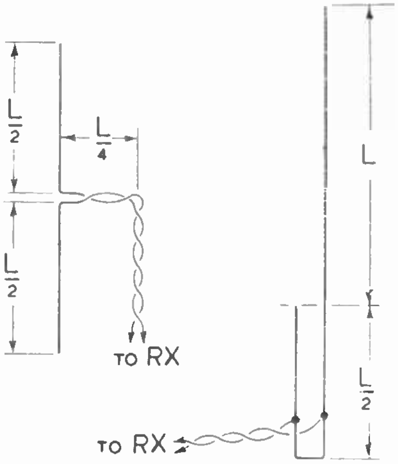


Fig. 13

Aerials suitable for television reception. On the left is shown a single vertical half-wave. For reception of 45 Mc. signals the overall length should be about 10′ 5″. Matched low impedance lines should be used to couple the aerial to the receiver. On the right is shown an end fed arrangement with quarter-wave matching section.

It must be emphasised that a very complete description of television practice cannot be provided in a publication of this type. The amateur studying this intensely interesting field is strongly advised to supplement these notes by reading the appropriate textbooks listed in Chapter 22.

Chapter Twenty

THE NEWCOMER TO AMATEUR RADIO

Use of Codes—" Q " Code, Report Codes, Prefixes, Abbreviations —Learning Morse

THE purpose of this Chapter is to provide the newcomer to Amateur Radio with some general information on procedure and Morse code tuition. Although the operation of amateur stations is suspended for the duration of the war considerable interest is being shown in the plans under discussion for a restoration of licencing facilities after the war, especially by those who are at present engaged in radio work in the Services or in industry.

Use of Codes

In commercial concerns the use of Code Groups has been standard practice for many years. These codes, besides saving time in conveying information, have the very much greater virtue of reducing interference, which has been an outstanding problem facing the amateur movement for some time.

Certain practices which are to-day accepted as normal methods of operation have developed from the over-crowded state of the amateur bands, a condition brought about by the continuous pressure, from other users of radio frequencies, for more and more space in the spectrum. Other amateur operating practices have grown out of the various official codes adopted internationally. An outstanding example being the Q code.

The Codes used by amateurs can be classified into the following groups :

1. International Q Code.
2. Signal Report Codes.
3. Phonetic Codes.
4. Abbreviations.
5. International Prefixes.

The International Q Code

This is the code adopted by International Conferences for maritime and general commercial use. Only a small number of the actual Q signals are used by amateurs, and even in those cases some have been slightly modified to fit their requirements. An example is found in the QSL signal. This, strictly speaking, means, " Can you give me acknowledgment of receipt ? " In amateur parlance it is used to ask for a report or confirmation of a contact.

Q signals consist of groups of three letters each beginning with the letter Q. The most commonly used signals are given in the list which accompanies this Chapter, but the reader who desires a complete list should consult the " Handbook to Wireless Operators " (price 9d., post extra, from His Majesty's Stationery Office).

Readability

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

Signal Strength

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

Tone

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

(If the note appears to be crystal-controlled add an x after the appropriate number.)

The RST Code in general use by amateurs. This code was devised by W2BSR and gives in a series of three numerals a complete report covering " Readability," " Signal Strength " and " Tone." It is usual to preface the numeral group with the letters RST but many amateurs omit them and give the report by means of the numerical group only, as for example, " ur sigs. 569x."

World Radio History

INTERNATIONAL Q CODE

Abbreviation	*Question*	*Answer for Advice*
QRA	What is the name of your station?	The name of my station is . . .
QRB	How far approximately are you from my station?	The approximate distance is . . . miles.
QRD	Where are you bound and where are you from?	I am bound for . . . from . . .
QRG	Will you tell me my exact frequency in kilocycles?	Your exact frequency is . . . kc.
QRH	Does my frequency vary?	Your frequency varies.
QRI	Is my note good?	Your note varies.
QRJ	Do you receive me badly? Are my signals weak?	I cannot receive you. Your signals are too weak.
QRK	What is the readability of my signals?	The readability of your signals is R . . .
QRL	Are you busy?	I am busy. Please do not interfere.
QRM	Are you being interfered with?	I am being interfered with.
QRN	Are you troubled by atmospherics?	I am troubled by atmospherics.
QRO	Shall I increase power?	Increase power.
QRP	Shall I decrease power?	Decrease power.
QRQ	Shall I send faster?	Send faster (. . . words per minute).
QRS	Shall I send more slowly?	Send more slowly (. . . words per minute).
QRT	Shall I stop sending?	Stop sending.
QRU	Have you anything for me?	I have nothing for you.
QRV	Are you ready?	I am ready.
QRW	Shall I tell . . . that you are calling him on . . . kc?	Please tell . . . that I am calling him on . . . kc.
QRX	Shall I wait? When will you call me again?	Wait (or wait until I have finished communicating with . . .). I will call you at . . . GMT.
QRZ	Who is calling me?	You are being called by . . .
QSA	What is the strength of my signals? (1 to 5)	The strength of your signals is . . . (1 to 5).
QSB	Does the strength of my signals vary?	The strength of your signals varies.
QSD	Is my keying correct; are my signals distinct?	Your keying is incorrect; your signals are bad.
QSL	Can you give me acknowledgment of receipt?	I give you acknowledgment of receipt.
QSM	Shall I repeat the last telegram (message) I sent you?	Repeat the last telegram (message) you have sent me.
QSO	Can you communicate with . . . direct (or through the medium of . . .)?	I can communicate with . . . direct (or through the medium of . . .).
QSP	Will you retransmit to . . . ?	I will retransmit to . . .
QSV	Shall I send a series of V's?	Send a series of V's.
QSX	Will you listen for . . . (call sign) on . . . kc?	I am listening for . . . (call sign) on . . . kc.
QSZ	Shall I send each word or group twice?	Send each word or group twice.
QTH	What is your position in latitude and longitude?	My position is . . . latitude . . . longitude.
QTR	What is the exact time?	The exact time is . . .

MISCELLANEOUS INTERNATIONAL ABBREVIATIONS

Abbreviation	*Meaning*
AA	All after . .
AB	All before . . .
AL	All that has just been sent.
BN	All between . . .
C	Yes.
CL	I am closing my station.
CS	Call sign.
GA	Resume sending.
MN	Minute/minutes.

Abbreviation	*Meaning*
N	No.
NW	I resume transmission.
OK	Agreed.
TXT	Text.
UA	Are we agreed?
W	Word.
WA	Word after . . .
WB	Word before . . .
XS	Atmospherics.

World Radio History

Report Codes

In the official list of Q signals, there appear two code groups, QRK, QSA. These are used for reporting upon the readability and strength of signals. Amateurs are especially interested in signal reports, consequently it is not surprising that efforts have been made to improve the official method of giving this important information. In the tables which appear in this Chapter, are given the official QSA—QRK code (adopted at the Cairo Conference in 1938), together with a tone code, and also an amateur code known as the RST Code. The latter is now in general use by telegraphy operators, but for telephony work the QSA—QRK code still finds favour.

QSA Code (Signal Strength)

QSA 1	Hardly perceptible ; unreadable.
QSA 2	Weak, readable now and then.
QSA 3	Fairly good ; readable but with difficulty.
QSA 4	Good ; readable.
QSA 5	Very good ; perfectly readable.

QRK Code (Readability)

R1	Unreadable.
R2	Occasional words distinguishable.
R3	Readable with difficulty.
R4	Readable with practically no difficulty.
R5	Perfectly readable.

Tone Code (Earlier method)

T1	Poor 25, 50 or 60-cycle A.C. tone.
T2	Rough A.C. tone.
T3	Poor rectified A.C. tone. (No filter.)
T4	Fair rectified A.C. tone. (Small filter.)
T5	Nearly D.C. tone. (Good filter but key thumps or back wave noticeable.)
T6	Nearly D.C. (Very good filter.)
T7	Pure D.C. but key thumps and back wave noticeable.
T8	Pure D.C. tone.
T9	Pure crystal-controlled D.C. tone.

The International QSA and QRK Signal Codes with a Tone Code devised by amateurs. When using this system it is usual to give a report in the following manner " ur sigs. QSA5 R5 T9."

Phonetic Code

All users of the ordinary telephone are aware of the difficulty which is likely to arise in interpreting correctly letters which have a similar sound. The letter B for example, can be confused with the letter P. When using telephony transmissions, care is essential in order to avoid mistakes in Call Sign. To overcome this possibility of confusion, amateurs frequently use place names instead of the letters of their call, as for example, the British station G6CL would pronounce his call as Gee Six Canada London, instead of G6CL, which could be mistaken for G6PL or G6BL.

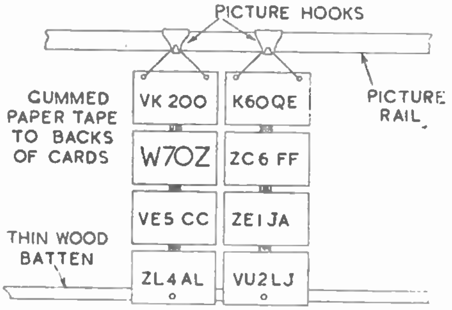
A list of the phonetic words generally used by amateurs appear in the following list :

A	America.	J	Japan.	S	Santiago.
B	Boston.	K	Kentucky.	T	Turkey.
C	Canada.	L	London.	U	University.
D	Denmark.	M	Mexico.	V	Victoria.
E	England.	N	Norway.	W	Washington.
F	France.	O	Ontario.	X	X-Ray.
G	Germany.	P	Portugal.	Y	Yokohama.
H	Holland.	Q	Quebec.	Z	Zanzibar.
I	Italy.	R	Radio.		

Abbreviations

In all forms of telegraphic communication abbreviations are used. In commercial practice the larger telegraph companies employ special code books which are issued to their customers. Telegrams conveying perhaps 200 letters of information can, by the use of codes, be transmitted by sending only 30 or 40 letters.

Radio amateurs use abbreviations mainly for the purpose of " saying a lot " in a few morse characters. Further, by the universal adoption of such abbreviations, it is comparatively simple to carry on a " morse conversation " with amateurs living in foreign countries, who do not know a word of *spoken* English. For example, the contraction GE, which means " good evening," would convey the sense of that greeting to any other amateur, wherever he may be living. It frequently happens that two European amateurs located in different countries are heard " working " one another in abbreviated morse which is based almost entirely on the English language.



A neat and effective method of displaying QSL's without piercing the walls with drawing pins. The thin batten at the bottom can be placed just above the wainscot and held secure by carpenter's pins.

International Prefixes

The last type of code to be mentioned is that which is universally adopted to describe the location and identity of a transmitting station.

Sometimes the first two letters represent the prefix, as for example, HA (Hungary), whilst many of the British Colonies use the same initial letters, but vary the number following, as for example : VP5 (Jamaica) and VP6 (British Honduras).

Readers who possess a list of International Prefixes which were in current use until September 1939, will notice that the British Colonial areas are grouped in such a manner that all amateur stations located on islands adjacent to a specific continent, use the same initial prefix letters. For example, all

World Radio History

British Colonial possessions in America use VP, followed by the appropriate figure to define the colony. An interesting example of further subdivision is to be observed in the case of the Windward and Leeward Isles. Here the prefix is VP2. The first letter following the numeral identifies the particular island in the group, as for example, VP2A (Antigua), VP2M (Montserrat).

The Amateur Bands

The bands of frequency allotted to British amateurs and used by them up to the commencement of the war in September 1939, are given in Table 1.

Band	Began at	Finished at	Width
1·7 Mc	1,720 kc	1,995 kc	275 kc
3·5 Mc	3,505 kc	3,730 kc	225 kc
7·0 Mc	7,005 kc	7,295 kc	290 kc
14·0 Mc	14,005 kc	14,395 kc	390 kc
28·0 Mc	28,010 kc	29,990 kc	1,980 kc
56·0 Mc	56,020 kc	59,980 kc	3,960 kc

Table 1.
The British Amateur Bands, 1939.

It is important to note that frequencies near to the low frequency edge of each band are harmonically related.

The full amateur bands as laid down at the Madrid and Cairo International Conferences of 1932 and 1938 are given in Table 2, from which it will be seen that the British allocations commenced a few kilocycles inside the International bands.

These small buffer widths were designed to prevent British amateur transmissions from falling *outside* the International bands, an eventuality which would have caused severe interference with services working close to the amateur allocations.

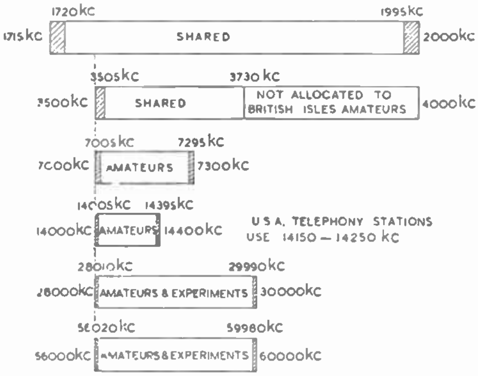
Band	Begins at	Finishes at	Width
1·7 Mc	1,715 kc	2,000 kc	285 kc
3·5 Mc	3,500 kc	4,000 kc	500 kc
7·0 Mc	7,000 kc	7,300 kc	300 kc
14·0 Mc	14,000 kc	14,400 kc	400 kc
28·0 Mc	28,000 kc	30,000 kc	2,000 kc
56·0 Mc	56,000 kc	60,000 kc	4,000 kc

Table 2.
The International Amateur Bands, 1940.

Harmonic Relationship

The importance of the harmonic relationship which exists between the six generally used amateur bands will be clear from a consideration of the Chapters dealing with crystal control and frequency measuring. In the former case it is possible, by the selection of one suitable crystal to operate an amateur transmitter on a spot frequency in each of the bands by means of frequency multipliers. In the second case frequency meters can be calibrated accurately by means of harmonics.

The sketch below illustrates in diagrammatic form the six normal amateur frequency allocations showing how they are related in an harmonic sense.



The Amateur Frequency Bands.
The shaded portions at each end indicate the tolerances specified by the British Post Office to allow for possible crystal variations.

Attaining Morse Speed

Opinions differ widely as to the best method of attaining morse speed. For the man or woman who is unable to obtain the services of a qualified instructor several methods are available. First the well-known Candler System of tuition, second, the method which depends upon the direct reception of commercial signals, and third a home memorising method.

Details of the Candler System can be obtained on application to the Candler Co., Craven House, Kingsway, London, W.C.2. Suffice it is to say that this system which has been in operation for over 27

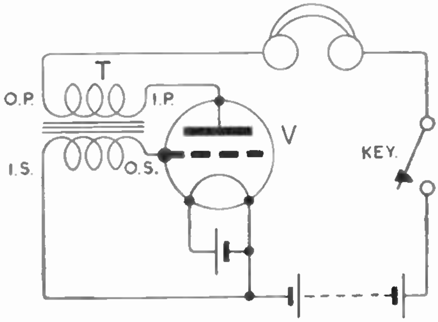
STATION LOG

Date.	G.M.T.	Station heard.	Station being called.	C.W. Phone.	Frequency.	R.	S.	T.	Weather.	Details of Transmission.	Recr. dial setting.	QSL	
												Out.	In.

A suitable ruling for a receiving station log book.

years has probably produced more successful students than any other correspondence course of its type.

Those who adopt the other methods of self-tuition must remember that no progress can be made until the Morse Code has been thoroughly memorised, and sound formations instantly recognised. The absolute beginner will only retard his progress by learning to send before he has learnt to receive correctly-spaced sound equivalents.



A simple Morse practice circuit.
The valve which can be of any 2-volt receiving type, functions as an oscillator. The transformer can be of the A.F. step-up type.

When the code has been mastered a morse practice set can be employed for sending. It is at this stage in particular that the assistance of a qualified instructor becomes of great importance as it is essential to learn how to send properly spaced letters, words and groups.

By using this device no audible signals are heard in the room, while a further advantage is the fact that the person being trained receives a similar type of signal in the headphones to that encountered in practice.

Morse practice can also be obtained by the use of specially prepared gramophone records, the speed of which can be controlled by means of the turntable motor.

The recently introduced *McElroy* tape morse practice equipment is the nearest approach to the ideal as the tapes are especially cut and are as a consequence capable of giving perfect spacing. The speed of sending can be accurately controlled and a special arrangement enables the student to key a reproduction of the letter or figure immediately it has been heard on the attendant loud speaker or telephone head set.

After a reasonably good speed has been attained the student would be advised to attempt the task of copying through interference. Concentration alone is necessary to read a wanted signal through the background of an interfering signal. When using a modern superheterodyne receiver it will frequently be found that by careful manipulation of the beat control, a wanted signal can be brought up to a pitch which will make its reception clear above a background of interference.

LEARNING THE CODE

Committing the Morse Code to memory is not a difficult task providing the beginner adopts a systematic method. Possibly the oldest method is that of learning the letters and figures in groups which are similar or opposite in character. The generally recognised groups are as follows:

The Dots (pronounced " De "—very short " e ").

E	●
I	● ●
S	● ● ●
H	● ● ● ●
5	● ● ● ● ●

The Dashes (pronounced " Dah " to rhyme with far ").

T	▬
M	▬ ▬
O	▬ ▬ ▬

The Opposites

A	● ▬	N	▬ ●
B	▬ ● ● ●	V	● ● ● ▬
C	▬ ● ▬ ●	Ä	● ▬ ● ▬
D	▬ ● ●	U	● ● ▬
F	● ● ▬ ●	L	● ▬ ● ●
G	▬ ▬ ●	W	● ▬ ▬
J	● ▬ ▬ ▬	Ö	▬ ▬ ▬ ●
Q	▬ ▬ ● ▬	Y	▬ ● ▬ ▬

The Inversions

K	▬ ● ▬	R	● ▬ ●
P	● ▬ ▬ ●	X	▬ ● ● ▬
Z	▬ ▬ ● ●	Ü	● ● ▬ ▬

The numerals can be memorised by remembering that those from 1 to 5 have a dot-dash sequence and those from 6 to 0 have a dash-dot sequence.

World Radio History

INTERNATIONAL MORSE CODE

LETTERS

A	de dah	● ▬	N	dah de	▬ ●
Ä	de dah de dah	● ▬ ● ▬	Ñ	dah dah dit dah dah	▬ ▬ ● ▬ ▬
B	dah de de de	▬ ● ● ●	O	dah dah dah	▬ ▬ ▬
C	dah de dah de	▬ ● ▬ ●	Ö	dah dah dah de	▬ ▬ ▬ ●
CH	dah dah dah dah	▬ ▬ ▬ ▬	P	de dah dah de	● ▬ ▬ ●
D	dah de de	▬ ● ●	Q	dah dah de dah	▬ ▬ ● ▬
E	de	●	R	de dah de	● ▬ ●
É	de de dah de de	● ● ▬ ● ●	S	de de de	● ● ●
F	de de dah de	● ● ▬ ●	T	dah	▬
G	dah dah de	▬ ▬ ●	U	de de dah	● ● ▬
H	de de de de	● ● ● ●	Ü	de de dah dah	● ● ▬ ▬
I	de de	● ●	V	de de de dah	● ● ● ▬
J	de dah dah dah	● ▬ ▬ ▬	W	de dah dah	● ▬ ▬
K	dah de dah	▬ ● ▬	X	dah de de dah	▬ ● ● ▬
L	de dah de de	● ▬ ● ●	Y	dah de dah dah	▬ ● ▬ ▬
M	dah dah	▬ ▬	Z	dah dah de de	▬ ▬ ● ●

NUMERALS

1	de dah dah dah dah	● ▬ ▬ ▬ ▬	6	dah de de de de	▬ ● ● ● ●
2	de de dah dah dah	● ● ▬ ▬ ▬	7	dah dah de de de	▬ ▬ ● ● ●
3	de de de dah dah	● ● ● ▬ ▬	8	dah dah dah de de	▬ ▬ ▬ ● ●
4	de de de de dah	● ● ● ● ▬	9	dah dah dah dah de	▬ ▬ ▬ ▬ ●
5	de de de de de	● ● ● ● ●	0	dah dah dah dah dah	▬ ▬ ▬ ▬ ▬

PUNCTUATION SIGNALS

Apostrophe	de dah dah dah dah de	● ▬ ▬ ▬ ▬ ●
Brackets	dah de dah dah de dah	▬ ● ▬ ▬ ● ▬
Comma	dah dah de de dah dah	▬ ▬ ● ● ▬ ▬
Fractional Bar	dah de de dah de	▬ ● ● ▬ ●
Full Stop	de dah de dah de dah	● ▬ ● ▬ ● ▬
Hyphen	dah de de de de dah	▬ ● ● ● ● ▬
Inverted Commas	de dah de de dah de	● ▬ ● ● ▬ ●
Note of Interrogation	de de dah dah de de	● ● ▬ ▬ ● ●
Separation (used between whole number and fraction)	de dah de de dah	● ▬ ● ● ▬
Underline	de de dah dah de dah	● ● ▬ ▬ ● ▬

PROCEDURE SIGNALS

Acknowledgement of Receipt	de dah de	● ▬ ●
Break Sign	dah de de de dah	▬ ● ● ● ▬
End of Message	de dah de dah de	● ▬ ● ▬ ●
End of Work	de de de dah de dah	● ● ● ▬ ● ▬
Error	de de de de de de de de	● ● ● ● ● ● ● ●
Invitation to Transmit	dah de dah	▬ ● ▬
Preliminary Call	dah de dah de dah	▬ ● ▬ ● ▬
Understood	de de de dah de	● ● ● ▬ ●
Wait	de dah de de de	● ▬ ● ● ●

World Radio History

Chapter Twenty-one

THE R.S.G.B. AND THE RADIO AMATEUR

History — Membership — Organisation — Privileges

History

THE Radio Society of Great Britain commenced its activities in July, 1913, under the title of The London Wireless Club. Later its name was changed to the Wireless Society of London, under which title it operated for nearly 10 years. With an increase in interest in experimental work throughout the British Isles a more national title was chosen, since when the Society has become recognised as the national organisation responsible for the furtherance of experimental amateur radio throughout Great Britain.

The Society was granted a certificate of incorporation during 1927.

Membership

Membership is granted to those expressing a genuine interest in the science of radio. An applicant must be proposed by a Corporate member, or he may submit two references from householders who can testify that he has been interested in radio for a period of not less than one year. All applications are dealt with monthly by the Council.

On election each member receives a certificate of distinctive design and the Society's official lapel badge.

Members may also use special headed notepaper, which is available at popular prices.

Grades of Membership

There are three grades of membership, viz.:

Home Corporate Members,
Overseas Corporate Members,
Associates.

Members elected to the *Corporate Grade* receive the full privileges of membership, and are entitled to use the letters " M.R.S.G.B."

The *Associate Grade* is designed to cater for non-technical persons resident within the British Isles. Members in this grade have no voting powers, but they receive a copy of the Society's Journal, and may attend Society meetings. They are not granted a B.R.S. number. Persons holding pre-war Post Office experimental licences are normally debarred from applying for admission to the Associate Grade.

Articles of Association

A copy of the Articles of Association, governing the operation and conduct of the Society's affairs, is sent to each member on election. The Society is incorporated under the Companies Act.

Subscriptions

The scale of war-time annual subscriptions is as listed :

	s.	d.
Home Corporate Members	15	0
Overseas Corporate Members	12	6
*Service Corporate Members**	10	0
Associates (*Non-Corporate Members*) ..	10	0
Junior Associates (*under* 17 *years of age*)	10	0

Subscriptions date from the first day of the month in which a member is elected, and are renewable annually upon that date.

* *This reduced subscription is intended to apply only to those whose financial position has been adversely affected by the war.*

Organisation

The affairs of the Society are controlled by a Council of radio amateurs who are elected annually by the membership. The Council meets at least once a month. The general organisation of the Society's work is in the hands of a permanent Secretary who is also Editor of all Society publications. The General Secretary is himself a well-known amateur, who for several years prior to his appointment in 1932 held the position of Honorary Secretary.

The R.S.G.B. Bulletin

The R.S.G.B. Bulletin, formerly *The T. & R. Bulletin,* is the official journal of the Society and a

The Incorporated
Radio Society of Great Britain
W.B.E.

An illustration of the W.B.E. Certificate issued by the Society for outstanding transmitting work on the 28 Megacycle (10 Metres Band).

copy is sent post free each month to members. First published in 1926, it continues to provide members with up-to-date information on all aspects of amateur radio. *The R.S.G.B. Bulletin* is published on or about the 15th of each month.

War-time issues contain technical articles, topical news from members in H.M. Forces, District notes and news, book reviews, etc.

The R.S.G.B. Bulletin is unique, inasmuch as it is written by and for radio amateurs. A specimen copy will be sent to any address on receipt of a P.O. for 1s.

Experimental Section

This Section operates through a Manager and Group Managers, the latter being responsible for organising specific lines of experimental work. Groups function in connection with propagation and receiver problems. In peace-time aerial and transmitter groups also operate.

Meetings

Meetings are arranged at the Institution of Electrical Engineers, London, at which important technical papers are read by prominent members or distinguished visitors.

Every endeavour is also made to hold regular informal meetings in R.S.G.B. Districts, to which members are warmly welcomed.

The name of the Society's local representative will be forwarded on request. The importance of continuing local meetings during war-time is appreciated by the Council, who request their representatives to furnish prior advice of all such functions in order that publicity may be given through the medium of *The R.S.G.B. Bulletin*.

B.R.S. Numbers

A B.R.S. (British Receiving Station) number is issued for identification purposes to all Corporate members who did not hold a pre-war experimental transmitting licence.

Certificates of Achievement

Members may qualify for any of the special certificates issued by the Society, including the W.B.E. (Worked British Empire), H.B.E. (Heard British Empire) and B.E.R.T.A. (the British Empire Radio Transmission Award).

By virtue of the Society's status as the representative amateur radio society in Great Britain, Home members may qualify and apply through the Society for the special W.A.C. (Worked all Continents) certificate issued by the International Amateur Radio Union.

The Incorporated

RADIO SOCIETY OF GREAT BRITAIN.

THE BRITISH EMPIRE RADIO TRANSMISSION AWARD

This is to Certify That

The British Empire Radio Transmission Award.

The rules governing the award of certificates are available on receipt of a stamped and addressed envelope.

Headquarters

The Headquarters of the Society are at New Ruskin House 28/30, Little Russell Street, W.C.1 (Telephone: Holborn 7373), to which address all correspondence must be sent. Office hours: Mondays to Fridays 9.30 a.m. to 12.30 p.m., 2 p.m. to 5 p.m.

World Radio History

Chapter Twenty-two

REFERENCE BOOKS

DUE to prevailing conditions certain of the books listed in this chapter may now be out of print or reprinting. The prices quoted (which do not include postage) are subject to alteration without notice. For these reasons readers are advised to communicate with the publishers before placing an order.

COMMERCIAL BOOKS (RADIO)

(*a*) Elementary

Air Cadets Manual on Radio. By I. R. Vesselo and R. D. Morrison. (Allen and Unwin, 2s.)

Elementary Handbook for Wireless Operators. By W. T. Crook. (Pitman, 4s.)

First Course in Wireless. By "Decibel." (Pitman, 5s.)

Foundations of Wireless. By A. L. M. Sowerby. (Iliffe, 7s. 6d.)

Mathematics of Wireless. By R. Stranger. (Newnes, 6s.)

Outline of Wireless. By R. Stranger. (Newnes, 15s.)

Radio Simplified. By John Clarricoats. (Pitman, 4s. 6d.)

Radio Simply Explained. By John Clarricoats. (Pitman, 9d.)

Radio Questions and Answers, Vol. 1., "Basic Radio." By E. M. Squire. (Pitman, 5s.)

(*b*) General Treatises

Admiralty Handbook of Wireless Telegraphy. 1940. (H.M.S.O., Part 1, 4s.; Part 2, 6s.)

Amplification and Distribution of Sound. By A. E. Greenlees. (Chapman and Hall, 12s.)

Electric Circuits and Wave Filters. By A. T. Starr. (Pitman, 25s.)

Elements of Radio. By A. and W. Marcus. (Allen and Unwin, 27s. 6d.)

Elements of Radio Communication. By O. F. Brown and E. L. Gardiner. (Oxford University Press, 16s.)

Experimental Radio Engineering. By E. T. A. Rapson. (Pitman, 8s. 6d.)

Fundaments of Radio. By F. E. Terman. (McGraw-Hill, 26s.)

Handbook for Wireless Operators. (H.M.S.O., 9d.)

Handbook of Technical Instruction for Wireless Telegraphists. By H. M. Dowsett and L. E. Q. Walker. (Iliffe, 30s.)

High Frequency Measurements. By A. Hund. (McGraw-Hill, 35s.)

Measurements in Radio Engineering. By F. E. Terman. (McGraw-Hill, 28s.)

Modern Radio Communication. By J. H. Reyner. (Pitman, Vol. I, 7s. 6d.; Vol. II, 7s. 6d.)

Principles of Radio. By Keith Henney. (Chapman and Hall, 21s.)

Principles of Radio Communication. By J. H. Morecroft. (Chapman and Hall, 45s.)

Principles of Radio Engineering. By R. S. Glasgow. (McGraw-Hill, 28s.)

Problems in Radio Engineering. By E. T. A. Rapson. (Pitman, 5s.)

Radio and Telecommunication Engineer's Design Manual. By R. E. Blakey. (Pitman, 15s.)

Radio Circuits. By W. E. Miller. (Iliffe, 3s. 6d.)

Radio Engineering. By F. E. Terman. (McGraw-Hill, 35s.)

Radio Frequency Electrical Measurements. By H. A. Brown. (McGraw-Hill, 28s.)

Radio Frequency Measurements by Bridge and Resonance Methods. By L. Hartshorn. (Chapman and Hall, 21s.)

Radio Handbook Supplement. (R.S.G.B. Paper Cover, 2s. 6d., Cloth Cover, 5s.)

Radio Interference Suppression. By G. W. Ingram. (Iliffe, 5s.)

Radio Technology. By B. F. Weller. (Chapman and Hall, 21s.)

Radio Training Manual. By F. J. Camm. (Newnes, 6s.)

Short-Wave Radio. By J. H. Reyner. (Pitman, 10s. 6d.)

Short-Wave Wireless Communication, including Ultra Short Waves. By A. W. Ladner and C. R. Stoner. (Chapman and Hall, 35s.)

Superheterodyne Manual. Edited by F. J. Camm. (Newnes, 6s.)

Superheterodyne Receiver. By A. T. Witts. (Pitman, 5s.)

Theory and Practice of Radio Frequency Measurement. By E. B. Moulin. (C. Griffin, 34s.)

Wireless. By L. B. Turner. (Cambridge University Press, 25s.)

Wireless Telegraphy. Notes for students. By W. E. Crook. (Pitman, 7s. 6d.)

(*c*) Servicing, Maintenance and Design

Classified Radio Receiver Diagrams. By E. M. Squire. (Pitman, 10s. 6d.)

Introducing Radio Receiver Servicing. By E. M. Squire. (Pitman, 6s.)

Practical Wireless Service Manual. By F. J. Camm. (Newnes, 8s. 6d.)

Radio Designers Handbook. Edited by F. Langford Smith. (Iliffe, 10s. 6d.)

Radio Laboratory Handbook. By M. G. Scroggie. (Iliffe, 12s. 6d.)

Radio Receiver Circuits Handbook. By E. M. Squire. (Pitman, 5s.)

Radio Receiver Servicing and Maintenance. By E. J. G. Lewis. (Pitman, 8s. 6d.)

Radio Servicing Simplified. (Automatic Coil Winder & Electrical Equipment Co., 2s. 6d.)

Radio Upkeep and Repairs. By A. T. Witts. (Pitman, 7s. 6d.)

World Radio History

Testing Radio Sets. By J. H. Reyner. (Chapman and Hall, 15s.)

Wireless Servicing Manual. By W. T. Cocking. (Iliffe, 7s. 6d.)

(*d*) Thermionic Valves and Cathode Ray Tubes

Cathode Ray Tube and its Application. By G. Parr. Chapman and Hall, 13s. 6d.)

Cathode Ray Oscillograph in Industry. By W. Wilson. (Chapman and Hall, 12s. 6d.)

Cathode Ray Oscillographs. By J. H. Reyner. (Pitman, 8s. 6d.)

Cathode Ray Oscillography. By T. McGregor-Morris and J. A. Henley. (Chapman and Hall, 24s.)

Electron Tubes and Their Applications. By J. H. Morecroft. (Chapman and Hall, 27s.)

Electron Tubes in Industry. By K. Henney. (McGraw-Hill, 35s.)

Introduction to Valves, including reference to Cathode Ray Tubes. By F. E. Henderson. (Iliffe, 4s. 6d.)

Theory and Design of Valve Oscillators. By H. A. Thomas. (Chapman and Hall, 21s.)

The Cathode Ray Oscilloscope. By W. E. Miller. (Iliffe, 2s. 6d.)

Thermionic Valves in Modern Radio Receivers. By A. T. Witts. Pitman, 10s. 6d.)

Time Bases. By O. S. Puckle. (Chapman and Hall, 16s.)

(e) Reference and Data Books

Definitions and Formulae for Students. By A. T. Starr. (Pitman, 6d.)

Radio Data Charts. By R. T. Beatty. (Iliffe, 7s. 6d.)

Radio Engineer's Vest Pocket Book. By F. J. Camm. (Newnes, 3s. 6d.)

(*f*) Miscellaneous

Accumulator Charging, Maintenance and Repair. By W. S. Ibbetson. (Pitman, 6s.)

Aircraft Radio. By D. Hay Sturgeaner. (Pitman, 15s.)

Basic (Radio and Electrical) Calculations for R.A.F. Ground Duties. By A. E. Druett. (Pitman, 3s. 6d.)

D/F Handbook for Wireless Operators. By W. T. Crook. (Pitman, 3s. 6d.)

Electrolytic Condensers. By P. R. Coursey. (Chapman and Hall, 12s.)

Elements of Loudspeaker Practice. By N. W. McLachlan. (Oxford University Press, 5s.)

General Radio Communication Regulations annexed to International Telecommunications Convention. (Cairo.) (H.M.S.O., 7s.)

Learning Morse. (Iliffe, 6d.)

Morse in 7 Days Without an Instructor. By H. O. Lewis. (E.U.P., 1s. 3d.)

Practical Morse. By John Clarricoats. (Pitman, 1s. 3d.)

Quartz Oscillators and their Applications. By P. Vigoureux. (H.M.S.O., 4s. 6d.)

Radio-Frequency Measurements by Bridge and Resonance Methods. By L. Hartshorn. (Chapman and Hall, 21s.)

Radio Interference and its Suppression. By J. H. Reyner. (Chapman and Hall, 10s. 6d.)

Radio Receiver Design. (*Part I, R.F. Amplification and Detection.*) By K. R. Sturley. (Chapman and Hall, 28s.)

Radio Waves and the Ionosphere. By T. W. Bennington. (Iliffe, 6s.)

Short Course in Elementary Meteorology. By W. H. Pick. (H.M.S.O., 2s. 6d.)

Theory and Design of Valve Oscillators for Radio and other Frequencies. By H. A. Thomas. (Chapman and Hall, 21s.)

Through the Weather House. By R. A. Watson-Watt. (Peter Davies, 7s. 6d.)

Valve Oscillators of Stable Frequency. By F. M. Colebrook. (H.M.S.O., 1s.)

Wireless Direction Finding. By R. Keen. (Iliffe, 30s.)

Wireless Terms Explained. By "Decibel." (Pitman, 3s.)

Worked Radio Calculations. By A. T. Witts. (Pitman, 6s. 6d.)

COMMERCIAL BOOKS (TELEVISION)

Electron Optics. By L. M. Myers. (Chapman and Hall, 47s.)

Photo-Electric and Selenium Cells. By T. J. Fielding. (Chapman and Hall, 7s. 6d.)

Principles of Television Engineering. By Donald G. Fink. (McGraw-Hill, 35s.)

Television Cyclopædia. By A. T. Witts. (Chapman and Hall, 8s. 6d.)

Television Optics. By L. M. Myers. (Pitman, 30s.)

Television Receiving Equipment. By W. T. Cocking. (Iliffe, 10s. 6d.)

Television Reception. By M. Von Ardenne. (Chapman and Hall, 12s.)

Television Reception Technique. By Paul D. Tyers. (Pitman, 12s. 6d.)

Television, Theory and Practice. By J. H. Reyner. (Chapman and Hall, 14s.)

Testing Television Sets. By J. H. Reyner. (Chapman and Hall, 10s. 6d.)

AMATEUR RADIO PERIODICALS

QST. Monthly Journal of the American Radio Relay League. (Annual subscription payable through Radio Society of Great Britain.)

The R.S.G.B. Bulletin. Monthly Journal of the R.S.G.B. (1s. 6d. Free to members.)

AMATEUR RADIO HANDBOOKS

A.R.R.L. Antenna Handbook. (A.R.R.L., through R.S.G.B.)

Radio Amateurs' Handbook. (A.R.R.L., through R.S.G.B.)

"Radio" Handbook. (Editors and Engineers, Ltd., through R.S.G.B.)

COMMERCIAL AND PROFESSIONAL PERIODICALS

Electronic Engineering, Incorporating Electronics, Television and Short-Wave World. Monthly. (Hulton Press, 2s.)

Institution of Electrical Engineers, Proceedings of the Wireless Section. (Two or three times a year, 5s.)

Practical Wireless. (Newnes, 9d.)

Wireless Engineer. Monthly. (Iliffe, 2s. 6d.)

Wireless World. (Iliffe, 1s. 6d.)

World Radio History

Chapter Twenty-three

DATA AND FORMULAE

Electrical Formulae—Standard Symbols—Copper Wire Tables—
Drill Sizes—Screw Threads—Metric Prefixes

ELECTRICAL FORMULAE

A.C. CIRCUITS

Current in circuit containing Inductance (L) only,

$$I = \frac{E}{\omega L} \text{ where } \omega = 2\pi f = 6{\cdot}28f$$

Current in circuit containing Capacity (C) only

$$I = \omega CE$$

Current in circuit containing Inductance Capacity and Resistance (R) in series,

$$I = \frac{E}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}$$

AUTOMATIC BIAS RESISTANCE

The value is given by the expression,

$$R = \frac{E_B}{I_A}$$

where E_B = Bias volts required.
I_A = Anode current (amps)
R = Resistance (ohms).

ATTENUATION

Weakening of electrical waves. Reduction of voltage, current or power in an electric circuit. (See *Decibel.*)

CAPACITANCE

(1) The charge in coulombs, Q, retained by a condenser = F (farads) multiplied by E (volts).

(2) Condensers in parallel.

$C_T = C_1 + C_2 + C_3 +$ etc.
C_T = total capacitance.

Condensers in parallel share their charges according to their capacitance.

(3) Condensers in series all retain equal charges

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \text{etc.}$$

(4) Simple parallel plate condenser.

$$C = \frac{1{\cdot}11kA}{4\pi d} = \frac{kA}{11{\cdot}3d}\ \mu\mu F$$

where A = area of each plate in sq. cm.
d = distance apart in cm.
k = permittivity, or dielectric constant.

Note.—Some Continental condensers have the capacity expressed in centimetres (1 cm = $1{\cdot}11\ \mu\mu F$).

CURRENT

(See *Ohm's Law*).

DECIBEL

The decibel is one-tenth of the Bel, and is the unit of power-level difference, *i.e.*, a measure of gain or loss (attenuation). The number of decibels corresponding to a given power-ratio is 10 times the common logarithm of that ratio.

$$N\ (\text{dB}) = 10 \log_{10} \frac{P_2}{P_1}$$

where P_1 = input power
P_2 = output power
$\frac{P_2}{P_1}$ = power ratio.

If the ratio is greater than 1 (unity) there is a power gain ; if the ratio is less than unity there is a power loss. In the latter case it is usual to invert the fraction and express the positive answer so obtained as a power loss.

The decibel can also be used to express the ratio between voltages and currents, but in such calculations it is implied that the impedances and power factors of the circuits, with which the respective voltages and currents are associated, are identical :

$$N = 20 \log_{10} \frac{E_2}{E_1} \qquad N = 20 \log_{10} \frac{I_2}{I_1}$$

Power-levels may also be expressed as the number of decibels by which they differ from an arbitrary reference known as zero power-level, which, in America, is usually 0·006 watts, or 6 milliwatts, and in Europe is 0·001 watts, or 1 milliwatt. Thus, a gain is stated as " up " or " plus dB," and a loss as " down " or " minus dB."

The decibel is also used to express difference in level in acoustics. In this case the arbitrary zero acoustic pressure level is generally taken as 1 dyne/cm², and velocity level as 1 cm/sec.

The *phon* is the measure of acoustic loudness level and is expressed in the same way as the decibel.

The zero level of loudness, *i.e.*, 0 phons, corresponds to a pressure of ·0007 dynes/cm² at 400 c.p.s.

D.C. CIRCUITS

Power (watts) = E.M.F. (volts) × current (amperes).

World Radio History

EFFECTIVE RESISTANCE

Effective resistance of a tuned circuit at resonant frequency :

$$R = \frac{L}{C \times r}$$

where r = equivalent series resistance.

FREQUENCY

The number of complete cycles per second.

If f is frequency in kilocycles and λ is the wavelength in metres of a radio wave, then

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

To change wavelength to frequency divide 300,000 by wavelength in metres.

IMPEDANCE

In a circuit with Resistance, Inductance and Capacity in series,

$$Z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2} = \sqrt{R^2 + X^2}$$

INDUCTANCE

Where there is no mutual inductance,
Inductances in parallel :—

$$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \text{etc.}$$

Inductances in series :—

$$L_T = L_1 + L_2 + L_3 + \text{etc.}$$

NEPER

A unit of power-level given by $0{\cdot}5 \log_E P_1/P_2$ neper. One neper = 8·68 dB (cf. *Decibel*).

OHM'S LAW

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

E = Electro-motive Force (volts).
I = Current (amps).
R = Resistance (ohms).

Simplified rearrangement :

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

Cover up the unknown quantity and perform the remaining operations indicated.

OSCILLATORY CIRCUITS

Wavelength of a tuned circuit LC is given by,

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

λ = wavelength in metres.
L = inductance in μH (microhenrys).
C = capacity in μF (microfarads).

Resonant frequency of a tuned circuit is given by,

$$f = \frac{10^6}{2\pi\sqrt{LC}}$$

L = inductance in μH (microhenrys).
C = capacity in μF (microfarads).

PHON

(See *Decibel*).

POWER

$$W \text{ (watts)} = I^2R = E \times I = \frac{E^2}{R}$$

POWER FACTOR

$$\text{Power factor} = \frac{\text{True Power}}{\text{Apparent Power}} = \frac{EI \cos \phi}{EI} = \cos \phi$$

" Q "

A measure of coil efficiency and hence tuned circuit selectivity. " Q " is the ratio of the reactance of a coil to its effective resistance.

$$Q = \frac{2\pi f L}{R}$$

Where R = Total D.C. and R.F. Resistances.

REACTANCE

Of an inductance :

$$X = \omega L = 6{\cdot}28\, fL$$

Of a condenser

$$X = \frac{1}{\omega C}$$

Of a tuned circuit (series) :

$$X = \left(\omega L - \frac{1}{\omega C}\right)$$

RESISTANCE

Resistances in parallel :

$$\frac{1}{R_T} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \text{etc.}$$

Two values only :

$$R_t = \frac{r_1 \times r_2}{r_1 + r_2}$$

(*Note.*—This formula, when the appropriate changes have been made, applies also to condensers in series and inductances in parallel.)

Resistances in series :

$$R_T = r_1 + r_2 + r_3 + \text{etc.}$$

Resistance of Meter Shunts :

$$\text{Shunt} = \frac{\text{Meter resistance}}{(N - 1)}$$

where N = Number of times full scale current is to be increased.

SPEAKER OUTPUT TRANSFORMER RATIO

$$N = \sqrt{\frac{R_L}{Z}}$$

where N = Transformer turns-ratio.
R_L = Valve optimum load resistance.
Z = Loudspeaker impedance.

TIME CONSTANT

For a condenser in series with a resistance :—
Let E = proportion of total voltage developed across condenser in
t = seconds.
C = capacity in farads and
R = resistance in ohms.

World Radio History

During the charging of the condenser, imagine an infinitesimal increment of time = dt seconds.

Then in this time dt seconds, the voltage on the condenser will rise by dE and the charge will increase by dEC coulombs.

The voltage across the resistance during the time dt will average :—

$$\left(1 - E - \frac{dE}{2}\right)$$

so that the current will be

$$\frac{1 - E - \frac{dE}{2}}{R}$$

and the increment of charge is :—

$$\left(\frac{1 - E - \frac{dE}{2}}{R}\right) dt.$$

The product of dt and $\frac{dE}{2}$ is so small that it can be neglected, so that the charge is :—

$$\left(\frac{1 - E}{R}\right) dt.$$

$$\text{Hence } \left(\frac{1 - E}{R}\right) dt = dEC$$

$$\text{or} \quad dt = CR\frac{dE}{1 - E}$$

and integrating by calculus :—

$$t = -CR \log_e (1 - E)$$
$$\text{or } t = -2{\cdot}3\, CR \log_{10} (1 - E)$$

The negative sign appears in the process of integration and must be considered, since (1 − E) is less than unity and its logarithm is therefore negative.

Simplifying,

$$t = CR$$

where t is the time required to charge the condenser to 63·21 per cent. of its final voltage. The theoretical time to charge to the full voltage is, of course, infinity.

For an inductance in series with a resistance a similar expression holds :

$$t = -2{\cdot}3 \frac{L}{R} \log_{10} (1 - I)$$

where I = the proportion of the final current through the system. Here again, when $t = \frac{L}{R}$ t is the time required for the current to reach 63·21 per cent. of its final value.

WAVELENGTH

Approximate velocity of light and wireless waves = 3×10^8 metres per sec.

$$\therefore \text{Wavelength (metres)} = \frac{300{,}000 \text{ (Velocity)}}{\text{kc (Frequency)}}$$

$$\text{Frequency (kilocycles)} = \frac{300{,}000 \text{ (Velocity)}}{\lambda \text{ (Wavelength)}}$$

STANDARD SYMBOLS

REPRESENTING UNITS OF MEASUREMENT

Ampere	A
Amperehour	Ah
Coulomb	C
Decibel	db, or dB
Farad	F
Henry	H
Joule	J
Kilowatthour	KWh
Megohm	MΩ
Metre	m
Milliampere	mA
Ohm	ω or Ω
Volt	V
Voltampere	VA
Watt	W
Watthour	Wh

REPRESENTING QUANTITIES AND CONSTANTS

Admittance	G + jB = Y
Angular Velocity	2π × f = ω
Capacitance	C
Conductance	G
Current	I ; (Instantaneous)
Dielectric Constant	k
Efficiency	η
Electric Force	e
Electro-motive Force	E
Electrostatic Flux	Ψ
Electrostatic Flux Density	D
Energy	W
Frequency	f
Impedance	R + jX = Z
Length	l
Magnetic Fieldstrength	H
Magnetic Flux	Φ
Magnetic Flux Density	B
Magnetic Force	F
Mass	m
Mutual Inductance	M
Period	T
Permeability	μ
Phase Angle	ø
Phase Displacement	ø
Potential Difference	V
Power	P
Quantity of Electricity	Q
Reactance	X
Reluctance	S
Resistance	R
Self-inductance	L
Susceptance	b or B
Time	t
Velocity	v
Voltage	E ; e (Instantaneous)
Wavelength	λ

COPPER WIRE (S.W.G.)

S.W.G.	Diam. in Inches.	Yards per Pound (Bare).	Ohms per Yard.	Max. Current (Amps)* at 1000 A. per Sq. Inch.	Turns per inch.				S.W.G.
					D.S.C.	D.C.C.	Enam.	E. and S.S.C.	
10	·128	6·67	·00186	—	7·55	7·04	—	—	10
12	·104	10·15	·00283	8·495	9·22	8·47	9·26	—	12
14	·080	17·21	·00478	5·027	11·8	10·6	11·9	—	14
16	·064	26·90	·00746	3·217	14·7	13·15	14·8	14·2	16
18	·048	47·80	·01327	1·8096	19·6	16·9	19·7	19·0	18
20	·036	73·40	·02359	1·0179	25·6	21·3	26·0	24·7	20
22	·028	140·5	·03899	·6158	32·2	25·6	33·3	31·2	22
24	·022	227·2	·06316	·3801	40·0	31·2	42·3	39·5	24
26	·018	340·0	·09435	·2545	48·8	35·7	51·5	48·1	26
28	·0148	502·8	·1395	·1720	57·8	40·3	62·5	57·8	28
30	·0124	716·5	·1988	·1208	67·1	44·6	74·6	67·0	30
32	·0108	945·0	·2621	·0916	75·2	48·1	85·5	76·3	32
34	·0092	1300	·3612	·0665	85·5	52·0	100	87·7	34
36	·0076	1905	·5292	·0454	99·0	60·2	120	102	36
38	·0060	3058	·8491	·0283	117	66·6	151	125	38
40	·0048	4780	1·327	·0181	137	72·5	188	151	40

* In amateur transformers, the figures for maximum current may be doubled.

SINGLE CIRCULAR COPPER CONDUCTORS

Gauge	S.W.G.			B. & S.	
	Diameter.		Ohms.	Diameter.	
	Inch.	mm.	per 100 yds.	Inch.	mm.
10	·128	3·25	0·186	·1019	2·588
12	·104	2·64	0·283	·0808	2·052
14	·080	2·03	0·478	·0641	1·628
16	·064	1·63	0·747	·0508	1·290
18	·048	1·22	1·329	·0403	1·024
20	·036	·914	2·362	·0320	·813
22	·028	·711	3·904	·0253	·643
24	·022	·559	6·324	·0201	·511
26	·018	·457	9·447	·0159	·404
28	·0148	·376	13·97	·0126	·320
30	·0124	·315	19·91	·0100	·254
32	·0108	·274	26·24	·0079	·203
34	·0092	·234	36·16	·0063	·160
36	·0076	·193	52·99	·0050	·127
38	·0060	·152	85·03	·0040	·102
40	·0048	·122	132·90	·0031	·079
42	·0040	·102	191·30	·0025	·063
44	·0032	·081	298·90	·0020	·051
46	·0024	·061	531·40	·0018	·046

EUREKA AND MANGANIN CONDUCTORS

S.W.G.	Eureka.		Manganin.	
	Ohms per pound.	Ohms per 100 yds.	Ohms per pound.	Ohms per 100 yds.
10	0·352	5·23	0·313	4·67
12	0·807	7·93	0·72	7·07
14	2·304	13·39	2·50	11·96
16	5·62	20·94	5·05	18·62
18	17·80	37·18	15·65	33·20
20	56·17	66·13	50·15	59·05
22	153·6	109·3	137·10	97·62
24	403·0	177·0	359·75	158·1
26	900·0	264·5	802·75	236·2
28	1970·0	391·4	1753·25	349·5
30	4000·0	557·5	3560·25	497·7
32	6950·0	725·0	6197·25	656·2
34	13174·0	1012·8	11760·00	904·2
36	28308·0	1484·0	25275·00	1325·0
38	72856·0	2380·8	65050·00	2126·0
40	177744·0	3718·4	158700·00	3320·0
42	—	—	—	4882·5
44	—	—	—	7470·0
46	—	—	—	13282

World Radio History

TWIST DRILL SIZES FOR WOOD SCREWS.

Screw Size	Shank Dia.	Twist Drill Dia.	Twist Drill Sizes Number	Letter	Fractional
1	·066	·067	51	—	—
2	·080	·081	46	—	—
3	·094	·096	41	—	—
4	·108	·110	35	—	—
5	·122	·128	30	—	—
6	·136	·140	28	—	—
7	·150	·154	23	—	—
8	·164	·169	18	—	—
9	·178	·182	14	—	—
10	·192	·196	9	—	—
11	·206	·209	4	—	—
12	·220	·228	1	—	—
13	·234	·238	—	B	—
14	·248	·250	—	E	—
15	·262	·266	—	H	—
16	·276	·281	—	K	—
17	·290	·295	—	M	—
18	·304	·316	—	O	—
19	·318	·323	—	P	—
20	·332	·339	—	R	—
21	·346	·348	—	S	—
22	·360	·368	—	U	—
23	·374	·377	—	V	—
24	·388	·397	—	X	—
25	·402	·413	—	Z	—
26	·416	·421	—	—	$\frac{27}{64}''$
27	·430	·437	—	—	$\frac{7}{16}''$
28	·444	·453	—	—	$\frac{29}{64}''$
29	·458	·468	—	—	$\frac{15}{32}''$
30	·472	·484	—	—	$\frac{31}{64}''$
31	·486	·500	—	—	$\frac{1}{2}''$
32	·500	·515	—	—	$\frac{33}{64}''$

METRIC PREFIXES

In this system all multiples and submultiples are decimal; multiples are expressed by Greek and submultiples by Latin prefixes.

Symbol.	Value.	Name.	Prefix.
μμ	10^{-12}	billionth	micro-micro-
mμ	10^{-9}	thousand-millionth	milli-micro-
μ	10^{-6}	millionth	micro-
m	10^{-3}	thousandth	milli-
c	10^{-2}	hundredth	centi-
d	10^{-1}	tenth	deci-
	1	one	uni-
dk	10^{1}	ten	deca-
h	10^{2}	hundred	hecto-
k	10^{3}	thousand	kilo-
	10^{4}	ten thousand	myria-
M	10^{6}	million	mega-

BRITISH ASSOCIATION (B.A.) SCREW THREADS

Number.	Full diameter. bolt and nut. mm.	inches.	Approx. No. of threads per inch.
0	6·0	·236	25·4
1	5·3	·209	28·2
2	4·7	·185	31·3
3	4·1	·161	34·8
4	3·6	·142	38·5
5	3·2	·126	43·1
6	2·8	·110	47·9
7	2·5	·098	52·9
8	2·2	·087	59·1
9	1·9	·075	65·1
10	1·7	·067	72·6
11	1·5	·059	81·9
12	1·3	·051	90·7
13	1·2	·047	102·0
14	1·0	·039	110·0
15	0·90	·035	121·0
16	0·79	·031	—
17	0·70	·028	—
18	0·62	·024	—
19	0·54	·021	—
20	0·48	·019	—

WAVELENGTH CLASSIFICATION

Designation of radio waves according to wavelength.	Wavelength in metres.
Myriametric	Above 10,000
Kilometric	10,000 to 1,000
Hectometric	1,000 to 100
Decametric	100 to 10
Metric	10 to 1
Decimetric	1 to 0·1
Centimetric	0·1 to 0·01

LINEAR MEASURES

Unit.	Equals.	Equals.
1 inch	2·54 cm.	25·4 mm.
1 foot	30·48 cm.	304·8 mm.
1 yard	0·9144 m.	—
1 mile	1·6093 km.	5,280 ft.
1 millimetre	0·03937 in.	—
1 centimetre	0·3937 in.	—
1 metre	39·37 in.	3·281 ft.
1 kilometre	0·6214 mile	—
1 decimetre	3·937 in.	—
1 decametre	10·936 yds.	—

World Radio History

Chapter Twenty-four

CHARTS AND ABACS

1. Inductance Chart
2. Abac Relating Inductance, Capacity, Frequency and Wavelength
3. Abac Relating Voltage, Resistance and Current (Ohm's law)
4. Abac Relating Volts, Amperes and Watts
5. Inversion Chart for Resistances in Parallel, Condensers in Series, etc.

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CHART No. 1.

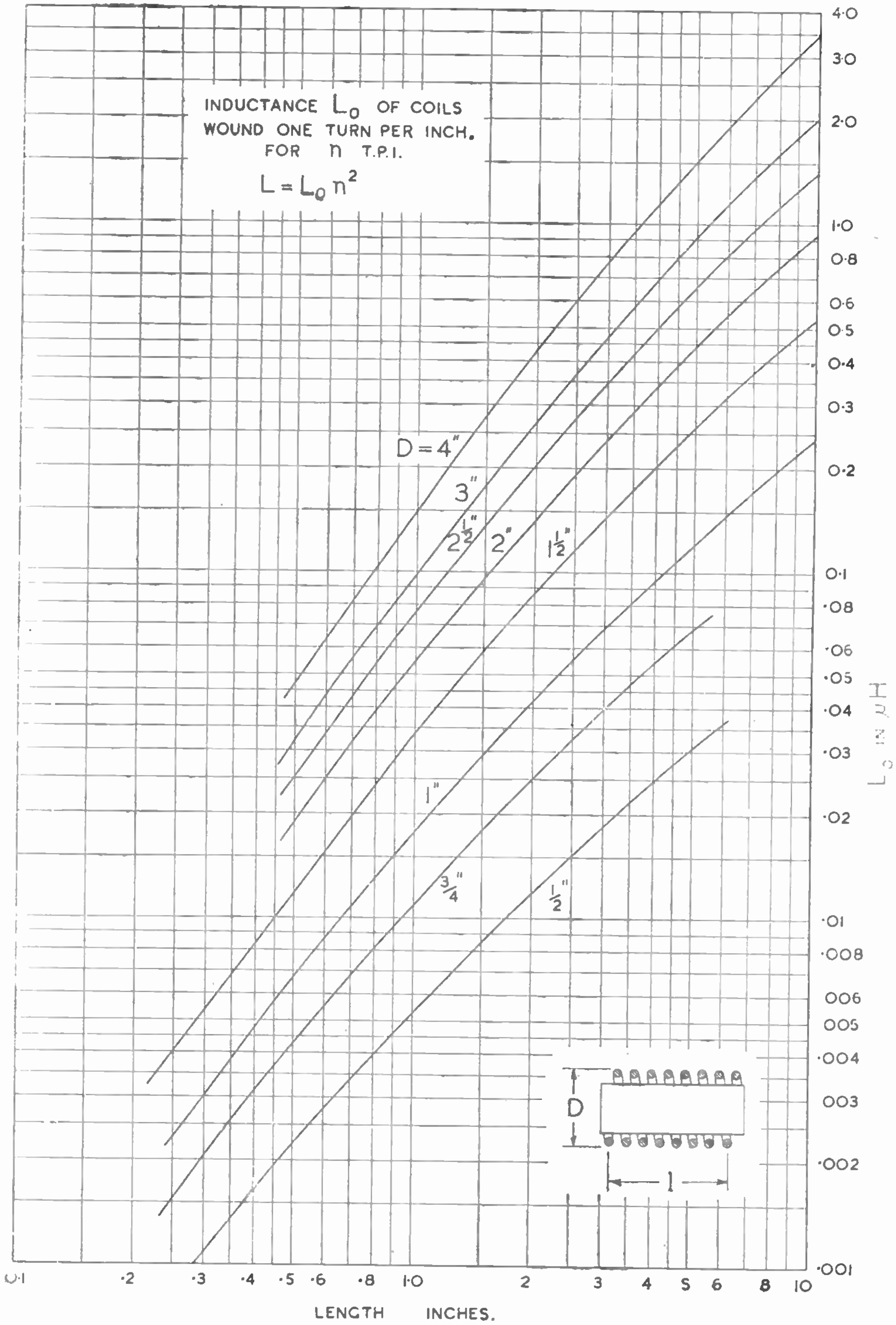

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CHART No. I.

INDUCTANCES.

Practical examples showing the use of the Chart which appears on the opposite page.

THE inductance of a coil is proportional to diameter × F × square of the number of turns, F being a function of the *shape*. If F is plotted against shape it is then possible to find the inductance of any given coil. F would then represent the inductance of a coil of unity diameter if all its turns were connected in parallel to make one turn.

In the inverse process of finding the turns for a required value of inductance the shape is not fixed till the turns are known, and the " one turn coil " conception is useful, but it is better to work in terms of one turn per inch and plot a new curve, the points of which can be multiplied by n^2 (n turns per inch) to give the true inductance.

The chart opposite gives in this way the inductance L_0 of coils of various shapes wound one turn per inch, and may be used for finding either inductance or turns required. The chart is for circular section one layer coils.

Examples

(*a*) Required a coil of 15μH inductance for a 7 Mc P.A. tank circuit, which it is proposed to wind on a 2¾″ *inside* diameter, ⅛″ copper tube with a pitch of four turns per inch. First divide 15μH by 4^2 in order to find L_0, which is 0·94. On the curve for $D = 3''$ (outside diam.) it will be seen that L_0 0·94 occurs when the length is 5″. The number of turns is therefore 20.

(*b*) A plug-in coil former of diam. 1½″ is threaded 16 turns per inch, and wound with 24 turns. What is the inductance? The length is 24/16 which equals 1½″, and the chart gives L_0 as 0·060. n is equal to 16, therefore $L = 0{\cdot}060 \times 16^2 = 15{\cdot}3\mu H$.

Alternatively, if it is desired to fill a given winding space and produce a certain inductance, then this inductance is divided by the L_0 value given on the chart to find n^2, the square root of which is the turns per inch. The coil may then be wound to this pitch, or a suitable type of wire selected to fit this pitch.

Note.—In coils of heavy conductor such as those made from tubing, R.F. currents flow on the outside. For that reason, therefore, it is the overall diameter which must be taken If the former is of hexagonal section, the *effective* diameter is only 90 per cent. of the diameter across opposite corners.

World Radio History

CHART No. 2.

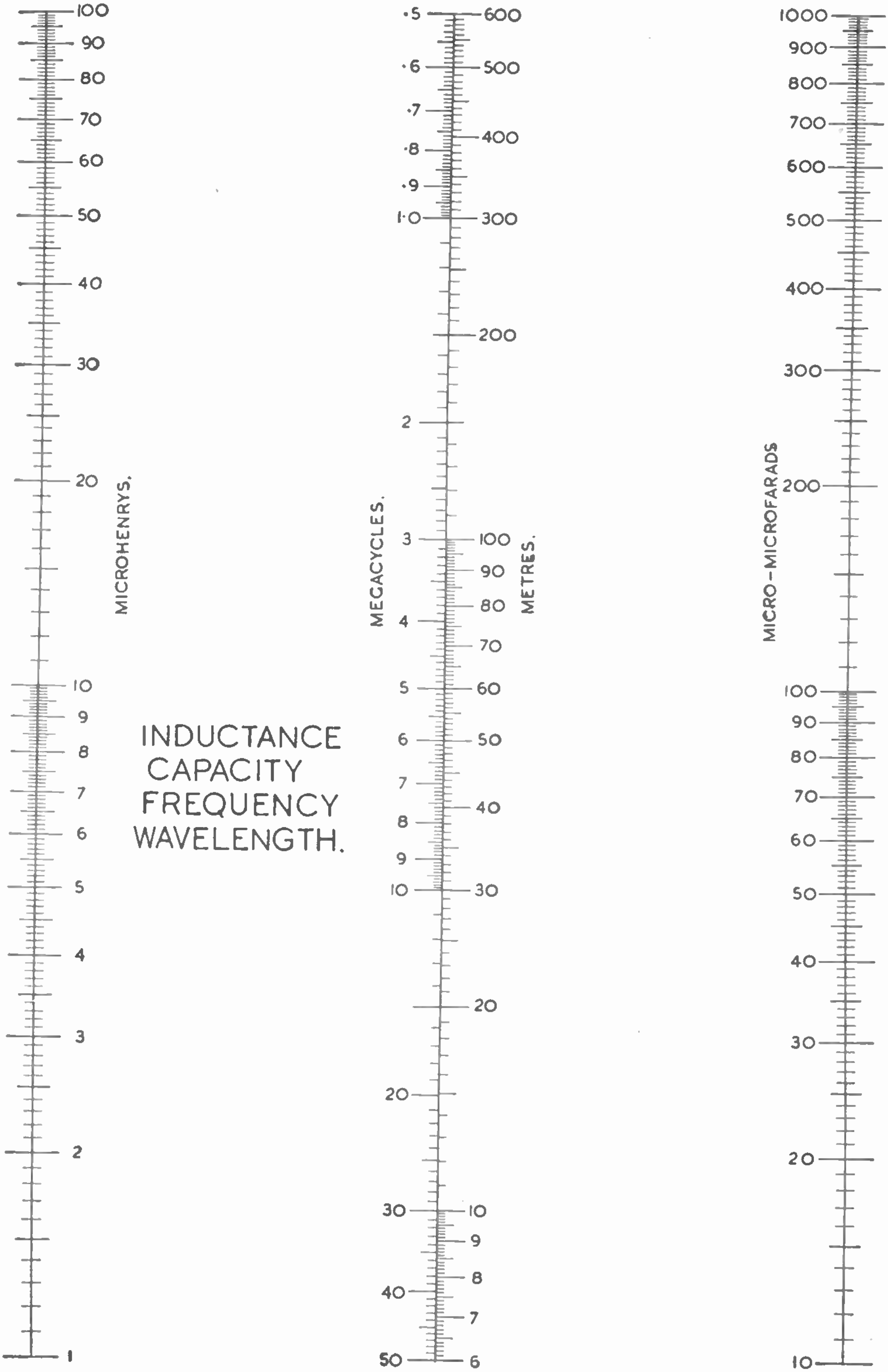

INDUCTANCE
CAPACITY
FREQUENCY
WAVELENGTH.
MICROHENRYS.
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
MEGACYCLES.
·5
·6
·7
·8
·9
1·0
2
3
4
5
6
7
8
9
10
20
30
40
50
METRES.
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
MICRO-MICROFARADS
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10

CHART No. 2.

Abac relating Inductance, Capacity, Frequency and Wavelength.

THIS chart is of the type known as an *Abac, i.e.,* a device in which multiplication, division, etc., is carried out by laying a ruler (or transparent straight-edge) through the appropriate points on two scales and reading the answer at the place where it intersects the third scale.

The usual formula relating Wavelength to Inductance and Capacity is $\lambda = 1885\sqrt{LC}$ (the units being metres, microhenrys and microfarads). This formula is useful for finding the wavelength to which a given capacity and inductance will tune. When C and λ are known it is necessary to re-arrange the equation to the form $L = \text{Constant} \times \lambda^2/C$.

An abac for these equations consists of three equal logarithmic scales, correctly placed. In the abac opposite, suitable units have been chosen for the short and medium wave ranges. The range of the scales may be extended by multiplying inductance, capacity, and wavelength *simultaneously* by the same factor, 10 or 100, or dividing the frequency by the same factor.

It should be noted, when reading the scales, that the frequency scale reads *downwards.*

Frequency—Wavelength Conversion.

The centre scale is calibrated in both frequency and wavelength, and may therefore be used as a conversion chart, reading one side of the scale against the other. If great accuracy is required, it is necessary to calculate from the formulæ

$$\lambda\,(\text{metres}) = 300 \div f\,(\text{Mc}) \quad \text{or } f = 300 \div \lambda\,;$$

the scale may then be used to check the position of the decimal point.

Examples

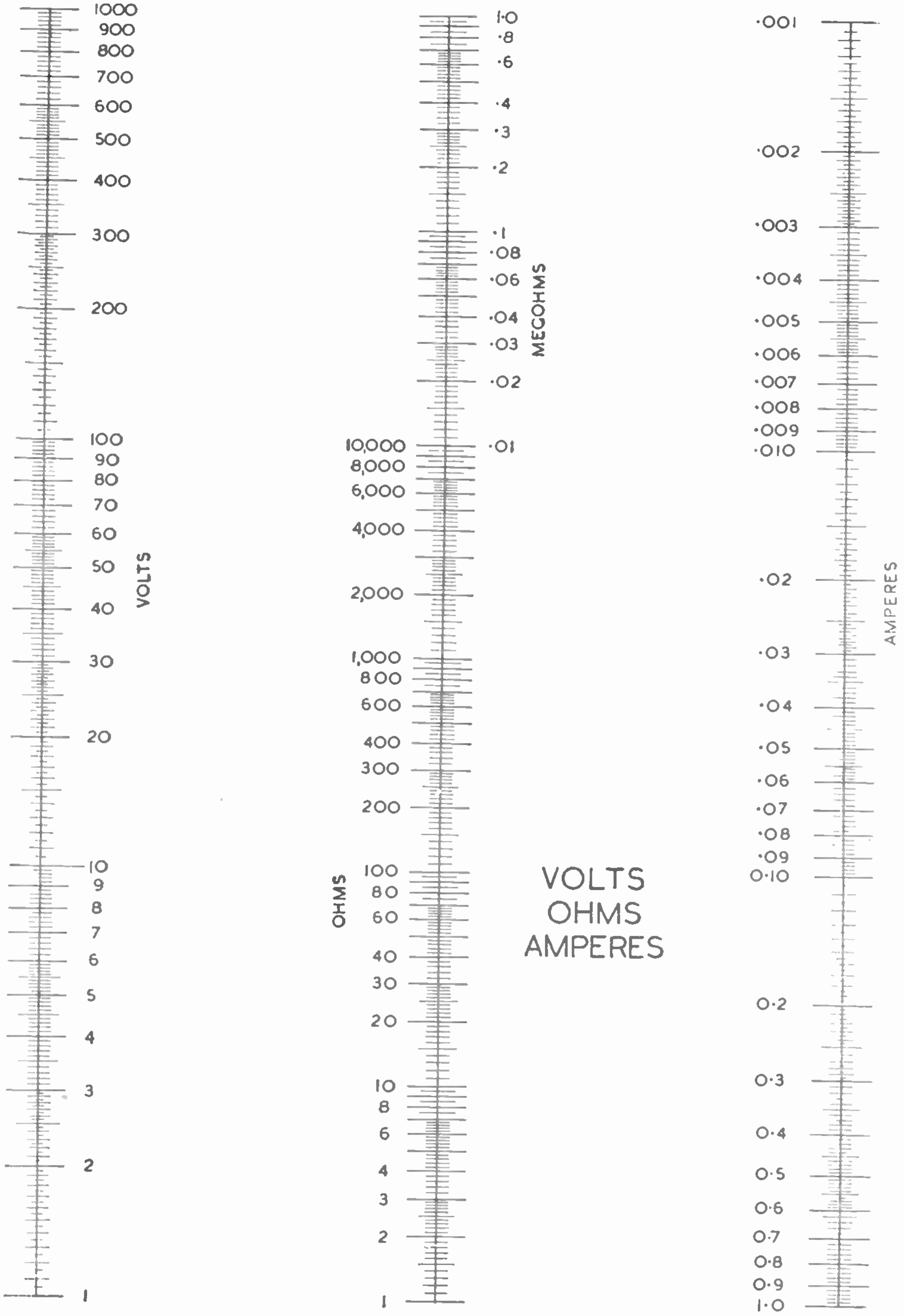
(*a*) A capacity of 50 micro-microfarads tunes a coil of 10 microhenrys inductance to a wavelength of 42 metres, or to a frequency of 7·15 megacycles.

(*b*) With a capacity of 20 micro-microfarads, a coil of 1·6 microhenrys inductance resonates at 28 Mc (10·7 metres).

(*c*) Multiplying L, C, and λ by 10 and dividing f by 10, it can be found that 500 micro-microfarads tunes 1,000 microhenrys to 1,330 metres wavelength, or 0·225 Mc. (225 kc).

World Radio History

CHART No. 3.



World Radio History

CHART No. 3.

Abac relating Voltage, Resistance and Current—Ohm's Law.

OHM'S law states that the current flowing through a conductor is proportional to the voltage applied between the ends of the conductor. This may be stated as voltage = constant × current. The constant is the resistance of the circuit in question, and depends on the shape and material of the conductors. The common units of voltage, resistance, and current are the volt, the ohm and the ampere respectively, the milliampere being a convenient subdivision of the ampere (1/1,000 ampere).

The abac (Chart 3) has been constructed to suit the values of those quantities commonly encountered in amateur radio, and is used in the same way as the wavelength abac, a straight-edge being placed across points corresponding to the two known quantities, to read the unknown where it intersects the third scale. In reading the scales, note that the ohms scale reads *downwards*.

The abac may also be used where the circuit is *reactive* but can only deal with the total *impedance* of the circuit.

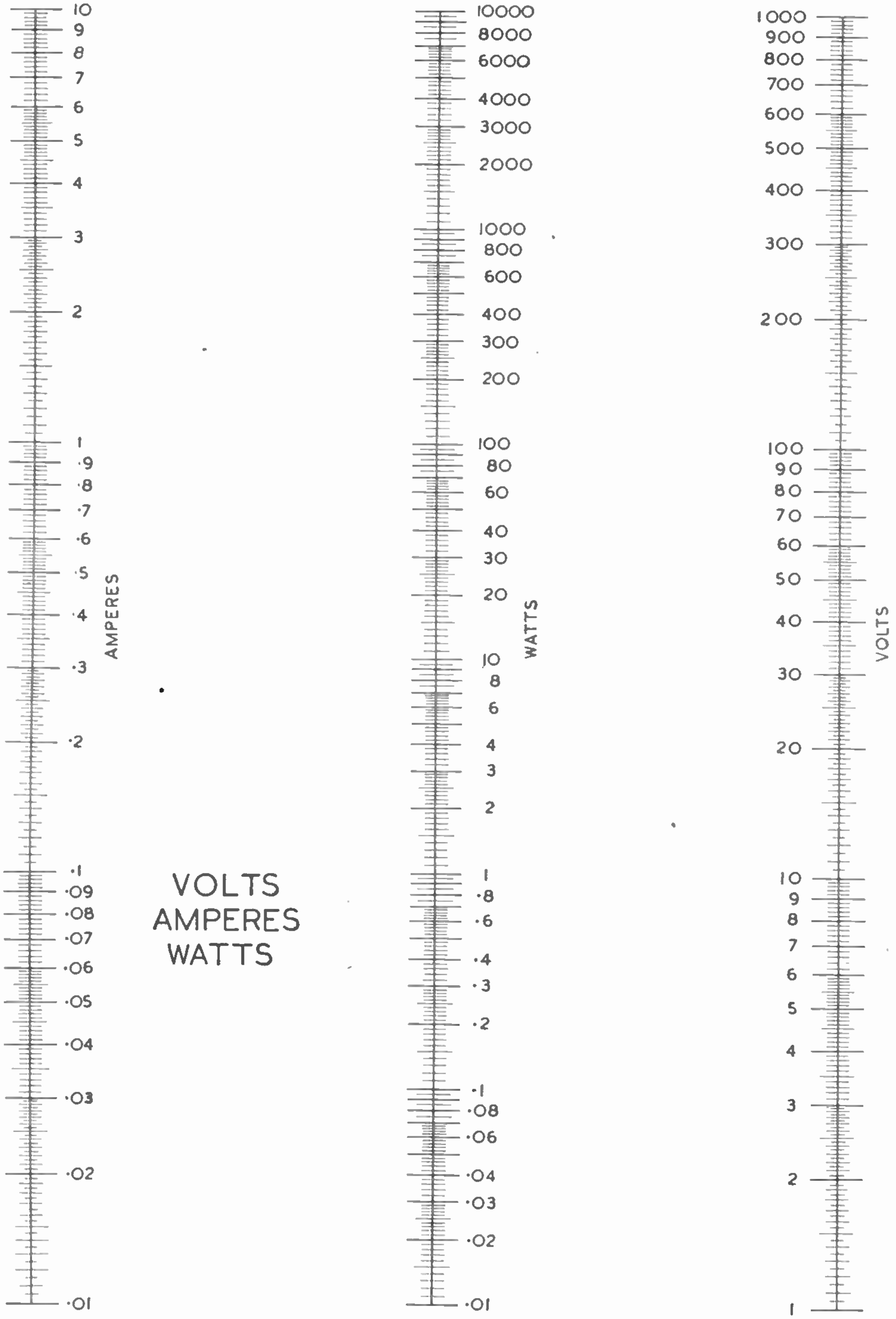
Examples

(*a*) A pentode valve has a resistance in series with its cathode for provision of bias voltage. The total anode, screen, and suppressor current is 35 milliamps (·035 amp). What is the value of the resistor required to produce a bias voltage across it equal to 5 volts? Answer: 140 ohms.

(*b*) Suppose now, that the H.T. supply available is 300 volts, and it is required to drop the screen to 200 volts, at which potential it passes 7 milliamps. The required drop in voltage is 100 volts, and the chart shows that a resistor of value 14,000 ohms will be required.

World Radio History

CHART No. 4.



World Radio History

CHART No. 4.

Abac relating Volts, Amperes and Watts.

WHEN a current flows through a resistor heat is generated, and the rate of power consumption is expressed electrically in watts. The relations are quite simple, the power in watts being equal to the product of the current flowing through, and the voltage drop across, the resistor. The voltage or current may be found from Chart 3, and the chart opposite can then be used to determine the watts. When the circuit also contains reactance, power is not consumed in the reactance but only *stored*, and it is necessary to determine the current and voltage pertaining to the resistive part of the impedance (see *Chapter* 1).

Examples

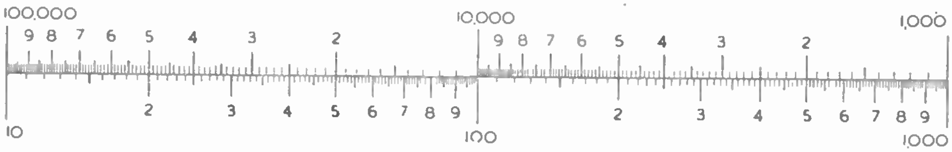
(*a*) The cathode bias resistance used as an example for Chart 3 had a voltage drop of 5 volts at a current of 35 milliamperes. Chart 4 shows that power is dissipated at the rate of 0·17 watts. Thus a resistance rated at ½ watt would be adequate for the purpose.

(*b*) The ballast resistor of a stabilised power supply consumes 15 mA at 550 volts. The chart shows that this is equivalent to 8 watts, and a 10 watt type of resistor would be suitable. The value as found from Chart 3 is 37,000 ohms. If the resistor were wire-wound on a card, it would be necessary to choose the wire so that the winding exposed a surface of 8 square inches. At this rating of one watt per square inch of surface, the resistance would not heat sufficiently to damage the insulation of the wire.

World Radio History

CHART No. 5.

Inversion chart for Resistances in parallel, Condensers in series, etc.



THIS chart is arranged to give reciprocals by reading from one side of the scale to the other. It is therefore suitable for calculating expressions such as :—

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \text{ or } \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$

The inverse of resistance is conductance, and the unit of conductance is called the *mho.* One mho conductance corresponds to one ohm resistance, and 1/10 mho to 10 ohms, 1/100 mho to 100 ohms, etc. A unit which is often convenient is the *micro-mho* and this is the inverse of a megohm. The scale is marked so that if the figure for a resistance is taken on one side, the corresponding figure on the other side is the conductance in micro-mhos.

To find the resultant of a number of resistances in parallel, convert them to micro-mhos, add, and then convert back to ohms. The scale may be used either way round. For example, resistances of 10,000, 5,000, and 2,000 ohms give conductances of 100, 200, and 500 micro-mhos. The sum of these is 800 micro-mhos, and the corresponding resistance 1,250 ohms.

The formula for capacities in series is of the same type, and the scale may be used in a similar way although there is no name for the inverse of a capacity. For example, two capacities of 1,000 and 500 μμF invert on the scale to 1,000 and 2,000 units. These add to give 3,000 units, which, when inverted on the scale, gives 333 μμF, the resultant of the two capacities in series.

World Radio History

INDEX

World Radio History

World Radio History

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Signature

Surname (Block Capitals)

Christian Names (Block Capitals)

*Address (For all communications)

*Applicants on Active Service must give a Home Address.

Nationality Age (if under 21)

Licenced Call Sign at outbreak of War (if any)

Proposed by .... Pre-War Call Sign or B.R.S. No.

(Personal Signature of Corporate Member necessary).

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This Undertaking must be signed.

I, the undersigned, agree that in the event of my election to membership of The INCORPORATED RADIO SOCIETY OF GREAT BRITAIN, I will abide by and observe the Rules, Regulations and Articles of Association of the Society, and that in the event of my resignation from the Society given under my hand in writing, I shall, after the payment of all arrears which may be due by me at that period, be free from this obligation. I further agree to observe strictly the terms of any licence issued to me by the responsible authorities to operate transmitting or receiving apparatus.

Witness my hand this..........day of..................19..... (*signed*)..................................

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