DAVIDSON

RECEIVING AERIAL SYSTEMS

Receiving Aerial Systems

For Broadcast and Television

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Preface

In this book the design of aerials for the reception of broadcasting and television signals is discussed, together with some practical aspects related to their construction and installation. Other books have been written on this subject, but these generally consider aerials as part of a communication system where transmitting aerials are equally important. In this book, however, the emphasis is on receiving aerials, and the additional problems that are encountered when these are part of a domestic installation.

Some of the mathematical formulae relating to the performance of aerials have been given. This is intended as a guide for calculating certain specific problems, such as the magnitude of the signal received by an aerial. Detailed derivation of the formulae is not given in order to keep the mathematical analysis to a minimum. For the same reason, other theoretical analysis of aerial performance, such as the calculation of directional characteristics, has been omitted. The chapter on aerial measurements has been included to give an indication of some of the methods used. These are not the only methods that are possible, but they give some indication of the care and forethought needed in these measurements if reliable results are to be obtained.

Wherever possible the practical features of the various types of aerials have been given, but this is often closely linked to a product of a particular manufacturer. Detailed information on specific aerials has therefore been avoided, but it is hoped that this book will put in perspective some of the technical statements made by aerial manufacturers.

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Introduction

The need for an aerial – Frequency allocations – Impedance – Directional properties – Other electrical properties – Electrical requirements – Bandwidth requirements – Directional properties and gain – Mechanical requirements – Summary

SOUND broadcasting in some form or other is now established in nearly every country in the world, while television is available in over thirty countries. This book will describe and discuss some of the technical problems associated with receiving aerials both for sound radio and television.

THE NEED FOR AN AERIAL

A question that is often asked is 'Why is an aerial needed?' The answer is simple. The radio or television signal is carried from the transmitter to the receiving site by waves, and it is the purpose of the receiving aerial to convert the energy in these waves into electric currents so that they can be interpreted by the receiver.

The first subject to discuss, therefore, is that dealing with the waves which carry the signals. These are called electromagnetic waves, although this name also covers other radiation such as light. Radio waves are characterized by their wavelength, which ranges from a few centimetres for some television signals to hundreds of metres for the 'long wave' broadcast signals. The wavelength is important as it affects the size and shape of receiving aerials, and it also influences the coverage that can be obtained from a given transmitter. Aerials must have the property of being able to intercept these waves, and absorb a small amount of energy from them. This concept of energy may be misleading, but it is worth while to get the magnitude of the quantities involved in their right perspective. A transmitter may be radiating many kilowatts of energy. At the receiving site where the signal is very spread out, the power absorbed will be measured in fractions of a microwatt, i.e. less than a millionth part of a watt, while the current flowing to the input circuit of the receiver will be measured in microamps. Even though it is so small, the idea of 'received power' still has a meaning. Another concept, power flux, is also used to describe the energy carried by the wave.

An aerial must also be able to supply electric current to the input circuit of the receiver, often through a length of cable. The electrical design of aerials must therefore be closely linked with the electrical properties of receiver input circuits and RF cable. This is one of the many electrical factors which have to be considered in the design of aerials, all of which have varying degrees of importance depending on the application.

It will be seen later that there is a very wide range of aerials, and it will be impossible to describe all types. Only the more characteristic ones will be discussed in detail, but by doing so it is hoped that it will be possible to see an over-all picture of the subject.

FREQUENCY ALLOCATIONS

The wavelength or frequency of the incoming signal is such an important factor that it will be considered in more

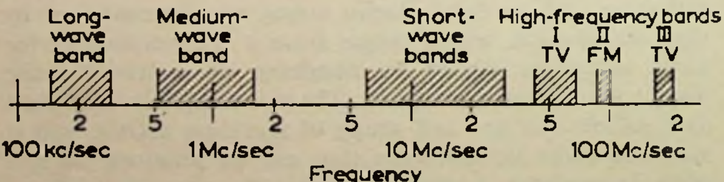


Fig. 1. The radio spectrum

detail. The radio spectrum (Fig. 1) has been divided up into frequency bands, which have been allocated to a wide variety of users, such as radio-telephone services, shipping, amateur use and, of course, sound broadcasting and television. The bands set aside for these last two services are those which will be considered here. The details of these broadcast bands vary throughout the world, so that only brief details will be given in Table 1 to indicate their position in the radio spectrum.

Table 1*

	Use	*Approximate frequency range*	*Wavelengths*
Long-wave band ..	Radio	150–300 kc/sec	2,000–1,000 m
Medium-wave band	Radio	520–1,600 kc/sec	567–187 m
Short-wave bands	Radio	6–30 Mc/sec Divided into a number of individual bands	50–10 m
Band I or low-band TV	Television	42–68 Mc/sec	—
Band II or FM broadcasting ..	Radio	88–100 Mc/sec	—
Band III or high-band TV ..	Television	174–216 Mc/sec	—

* For a more complete list see *Guide to Broadcasting Stations*, Iliffe, 1956

Each frequency range or band contains a number of transmitters, each one allocated a small range of frequencies, called a channel. The choice of a particular band for a transmitter depends on a number of factors, such as the type of transmission and the area to be covered. For instance, the long- and medium-wave bands are used exclusively for sound broadcasting, and in these bands the service area for a given transmitter will stretch for a few hundred miles. The short-wave bands are also used for sound broadcasting, and in this case, by a suitable choice of frequency, world-wide coverage can be obtained. Above 30 Mc/sec television transmission is possible, as this requires the greater bandwidth that can only be obtained at the higher frequencies. With the increase of frequency, however, the service area of a given transmitter decreases, and on average terrain a high-power station will have a service area up to about fifty miles.

Bands above 200 Mc/sec have also been allocated for television, but so far the use of these UHF channels for this purpose has been limited to the U.S.A.

The frequency has a marked effect on the design of aerials, the most distinct dividing line occurring at 30 Mc/sec. Below this frequency, in the long-, medium- and short-wave bands, aerials usually consist of a non-resonant wire or rod, or else of a loop or a coil on a ferrite rod. Above 30 Mc/sec, however, resonant rods are the more usual practice, together with a transmission line between the aerial and the receiver. Whatever form the aerial may take, and irrespective of the frequency band in which it operates, there are certain basic concepts which help to describe its ability to convert the incoming electromagnetic waves into electric currents. These will be considered quite generally here, and in more detail on a quantitative basis in a later chapter.

IMPEDANCE OF AERIALS

One important electrical factor which is of interest at all frequencies is the impedance of the aerial. For a short wire aerial, i.e. one that is shorter than a quarter wavelength, it will be capacitative, while for a loop it will be inductive. For a correctly designed, resonant-type aerial it will be resistive. Why is the impedance so important? The aerial behaves as a source of voltage causing a current to flow in the input circuit of the receiver. The magnitude of the current will depend on both the impedance of the input circuit and also on the internal impedance of the aerial, as illustrated in Fig. 2. The impedances have to be matched to each other for the maximum energy flow between the aerial and the receiver ; e.g. in the case of the short wire aerial mentioned above, the input impedance of the receiver should be inductive. Another factor becomes important with the resonant type aerials, which have a resistive impedance. This type of aerial can be mounted away from the receiver, and it is often advantageous to do so. Now, at high frequencies the cable has a resistance associated with it, known as its characteristic impedance. The meaning of this resistance will not be discussed here, but some typical values are 50 and 75 Ω for coaxial cable, and 150 and 300 Ω for a balanced or twin cable. The significance of this is that the impedance of both the aerial and the input circuit of the receiver should have the same value as the cable.

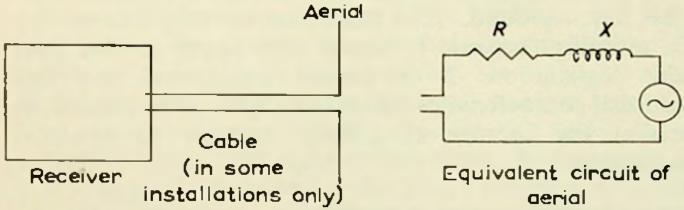


Fig. 2. The equivalent circuit of an aerial

When the system is correctly matched there will be the maximum transfer of power from the aerial to the receiver, and the most efficient use will be made of the aerial. It has been seen that the correct impedance for an aerial is associated with both the design of the input circuit of the receiver as well as the type of cable, if any, between the aerial and the receiver.

DIRECTIONAL PROPERTIES OF AERIALS

The directional properties of aerials are important, especially at the higher frequencies. Aerials have the property of being able to have a sensitivity that depends on the direction of arrival of the incoming signal. This enables it to differentiate, to a certain extent, between the wanted and any unwanted signals. The directional characteristics of individual types of aerials will be given later.

It will be seen that these characteristics refer to the aerial by itself, mounted away from buildings, telephone wires and many other objects that can cause reflection of the signal. It might be thought, therefore, that directional characteristics have very little meaning, as in practice aerials are seldom mounted completely on their own, but it does give a useful method of comparing two different types of aerial and also of showing the approximate performance of the aerial when installed on a building. It would be possible to measure the directional pattern of an aerial on a house, but only if the house were completely surrounded by flat, open ground. The measurement would have very little meaning, because it would only apply to that particular installation. It is usually considered that the directional characteristics measured under ideal conditions represent the average of a large number of practical installations.

OTHER ELECTRICAL PROPERTIES

The other electrical properties of importance are the gain and the polarization of the aerial. The gain is a measure of the sensitivity of the aerial, i.e. its ability to intercept the wave falling on it. The idea of gain only has a practical significance for the resonant type aerials. Gain can only be expressed as the ratio of the signal received to that received by some standard aerial, the standard usually chosen being a half-wave dipole.

Electromagnetic waves have a direction of polarization associated with them, which is either vertical or horizontal, and this has an influence on the design of the aerials, as it will determine the orientation of the rods of a resonant aerial. Polarization is a factor which becomes more important as the frequency is increased. At low frequencies, although the vertical polarization should predominate, there is usually sufficient scattering from local objects to produce a strong horizontal component, making the apparent polarization indeterminate.

ELECTRICAL REQUIREMENTS OF AERIALS

The facts so far can be correlated as follows. There are four important electrical characteristics associated with an aerial, (a) impedance, (b) directional characteristics, (c) forward gain and (d) polarization. Although all these properties are present, they have differing relative importance depending on the frequency and the application of the aerial. What, therefore, are the requirements for a receiving aerial? Here again a subdivision can be made at a frequency of 30 Mc/sec.

Below 30 Mc/sec, i.e. in the long-, medium- and short-wave bands, the requirements are that the impedance of the aerial should match, as far as possible, the input impedance of the receiver. The other requirements are less important. In some cases the directional properties are useful for the removal of unwanted signals; sometimes, however, the signals to be received may originate from a variety of directions, in which case an omnidirectional pattern is desirable. As the aerials are usually non-resonant, the concept of gain has very little meaning and, as has been seen, polarization is also unimportant.

Above 30 Mc/sec the factors given above show a very clear description of the electrical performance of an aerial, so much so that given this information it is usually possible to determine the performance of an aerial if the conditions at the receiving site are known. Moreover, they can be used for comparing the behaviour of two dissimilar aerials, such as a loop and a dipole. What, therefore, are the qualities required for an aerial for use in bands I, II or III?

It has been seen that the impedance of an aerial determines its ability to transfer energy to the receiver, usually through a length of cable. Furthermore, the input impedance of the receiver is ideally chosen to be the same as the characteristic impedance of the cable, although in practice this is not always strictly true. The aerial should have an impedance that matches the cable that is used with it. In

Great Britain 75 Ω coaxial cable has been generally adopted, so that the ideal impedance for an aerial for these conditions is 75 Ω. In the U.S.A., however, 300 Ω balanced feeder is usually used, so that the aerial has to feed into that impedance. All other countries have adopted one of these impedances for use with television receiving systems, so that it can be generally assumed that all aerials have to be designed to work with a resistive load of either 75 or 300 Ω, depending on the system used.

It is possible for an aerial to work satisfactorily even if a moderate mismatch occurs between the aerial and the feeder, and in fact a small mismatch has often got to be tolerated. Aerials for television reception have to work over a range of frequencies, and this is referred to as the bandwidth of the aerial. This question of bandwidth is so important that it will be considered in more detail, but first a short description must be given of the nature of a television signal, as it is this that determines the required bandwidth.

BANDWIDTH REQUIREMENTS OF AERIALS

A television picture is constructed by a process of scanning the scene being televised. The whole scene is covered in exactly the same way as printing covers a page of a book. It is scanned a large number of times per second, so that the resultant picture is seen with no flicker. If a very high definition picture is required, then the lines have to be close together, and the rate of scanning along the lines has to be fast. It has been found that the faster the lines are scanned, the greater the bandwidth required to transmit the picture information. The bandwidth requirement of the aerial is therefore closely related to the system adopted. For the system used in France, which consists of 819 lines, an over-all bandwidth of 12 Mc/sec is required, while in Great Britain where a 405-line system is used, the bandwidth is only 3½ Mc/sec. The bandwidth requirement of the aerial is therefore a function of the system being employed.

There is another reason for designing aerials to cover a wide range of frequencies. In certain areas there is more than one television transmitter, and it is often desirable to have a single aerial capable of receiving all the stations. This may mean that the aerial has to cover all of band I or all of band III, or even all of both bands simultaneously. In other instances the aerial has to receive a selected channel in one band, and a selected channel in the other band. There are many combinations, but in general this broad band, or multichannel operation is often in direct conflict with the requirement of a good match to the cable, as it must be remembered that the impedance match should be satisfied at all the frequencies at which the aerial will be used.

It has been seen that the bandwidth that an aerial has to be able to accept is a function of the system being employed, and that the impedance is related to the type of cable that is used. The polarization of the aerial is also determined by the signal that it is receiving, but this is of minor importance, as in most cases the same aerial can be used for either polarization by rotating it through a right angle. Of course the mast will prevent this in many cases, in fact the mast will influence the performance of any aerial when used with vertically polarized signals. This is really a mechanical problem, because it is usually possible to place it in such a position, or else crank it, so that it is clear of any of the active elements of the aerial. The other important factors, the directional characteristics and gain are both functions of the aerial, and are in no way connected with the characteristics of the received signal.

DIRECTIONAL PROPERTIES AND GAIN

The directional properties of aerials enable them to differentiate between the main signal and any other on the same frequency but arriving from another direction. This second signal may be some form of interference signal which would cause crackling on sound, or white or black splashes on a television screen. It may be the television signal itself arriving late at the receiving site, after having been reflected from some other object. This late arrival will cause a second image to be formed on the screen, and this is usually referred to as a ghost image. Fortunately, however, this reflected signal usually arrives at the receiving site in a direction different from the main signal, so that the aerial can distinguish between them.

The gain of an aerial is a measure of its ability to convert the incoming signal into electric currents. It is very closely connected with its directional properties, and an aerial with one narrow lobe in its directional pattern will usually have a high gain in this direction. When measuring or quoting gain, reference is made to a half-wave dipole, the gain of that being assumed to be unity. An ideal aerial will have a high gain and a directional pattern consisting of one, and only one, narrow lobe. If the aerial is required to cover more than one channel, these conditions have to be maintained throughout its frequency range.

MECHANICAL REQUIREMENTS FOR AERIALS

Up to now only the electrical properties of aerials have been discussed, but their mechanical construction also has to be considered. All aerials, whether they are for radio or television, are usually mounted in one of four places, in the receiver itself, in the same room as the receiver, in the attic or outside the building. In the first case, i.e. those inside the receiver, there is no need to consider the mechanical aspect as this will be closely associated with the design of the receiver chassis. For those mounted in the same room as the receiver, or for that matter in any room in the house, mechanical rigidity is not all that important as long as they are sufficiently robust to withstand the normal wear and tear of handling. In this case, however, their design should be such that they will blend with ordinary furniture or be made in such a way that they can be mounted in an obscure corner of the room. Very little need be said about attic aerials as these fall in a class between indoor aerials and those for outdoor mounting.

Outdoor aerials, on the other hand, should have sufficient rigidity and robustness to withstand all types of weather for a period of many years. This means that there must be very little risk of the elements bending or breaking or coming dislodged under conditions of wind, rain, snow, etc. Furthermore, their electrical performance must not suffer under these conditions, so that care has to be taken in the design of the insulators and in the method of making connections to the downlead.

There is another requirement that has developed in recent years. It must be possible to erect the aerial in the shortest possible time and, as will be seen later, this has led to the development of preassembled aerials which only require their elements to be hinged into position. There has also been a tendency for certain shapes or special features to be popular, and this 'fashion' aspect plays an important part in the over-all design of commercial aerials.

SUMMARY

The basic factors which go together to produce an ideal aerial have been mentioned, and it has been shown that most of these are dependent on the frequency of the signal being received. Comparisons between aerials, or the assessment of an individual type, can only be made by a critical investigation of all the various factors, and the lack of one of them, such as poor mechanical rigidity, can produce a poor aerial.

This then gives an over-all picture of the design of receiving aerials. The individual items will be considered in more detail in the following chapters, as they apply to systems for both radio and television.

2

Fundamental Concepts

Electromagnetic waves – Formulae for isotropic aerials – Formulae for aerials with directional properties – Connection of aerial to an electrical circuit – Relation between transmitting and receiving aerials – Reception with a reactive load – Gain of aerials – Summary

THE over-all requirements of aerials have already been outlined and in this chapter the electrical features will be considered in more detail. Individual aerials will not be described, but the basic concepts behind them will be given and this will mean introducing certain formulae that are essential in describing their quantitative performance. Aerials will be considered as a device for converting electromagnetic energy into electric currents. Properties of impedance, gain and directivity will be associated with them and their performance described by these abstractions.

ELECTROMAGNETIC WAVES

First of all a few facts will be given about electromagnetic waves, but in doing so all the mathematical analysis will be omitted. The various facts will therefore seem to be unrelated to each other, but they can all be derived from a few fundamental concepts, illustrated by Maxwell's equations. A wide variety of radiation is covered by electromagnetic radiation, other examples being light and X-rays. All of these follow the same fundamental laws, although it is only with radio waves that it is possible to have 'aerials' as a transformer between the radiation and an electric circuit.

In free space electromagnetic waves travel with a velocity of 3×10^8 m/sec, and if there are no objects to cause reflections or diffraction of the waves, they will travel along straight lines. For most purposes the atmosphere can be considered as being free space, the main exception being the upper ionized layers known as the Ionosphere. The conditions there are far from those of free space, but this will only be of concern when long distance propagation is considered. At the earth's surface, therefore, the waves will travel in straight lines until they encounter a solid object, and will travel with a velocity of 3×10^8 m/sec.

An electromagnetic wave (Fig. 3) has two components : an electric field, and a magnetic field. The expression

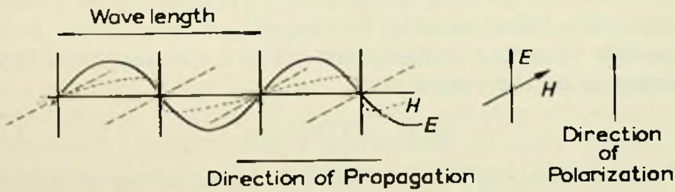


Fig. 3. *An electromagnetic wave*
E—Electric field
H—Magnetic field

'electric field' is only a way of describing the conditions existing between the plates of a condenser, while 'magnetic field' describes the conditions near to an inductance. In an electromagnetic wave, however, these 'fields' exist on their own, i.e. quite separate from any condenser or inductance. These fields have directions associated with them, the direction of the two fields in the wave being at right angles to each other, and at right angles to the direction of propagation. A wave is said to be polarized in the direction of the electric vector, i.e. a vertically polarized wave has its electric vector vertical, and can be received by a vertically mounted dipole. It is possible to have waves that are not plane polarized, that is they have not got a unique direction defining the direction of the electric vector. This circular, or elliptical polarization as it is called, is not important in the reception of radio or television. This type of wave can in fact be shown to be equivalent to two plane polarized signals, with their planes of polarization at right angles to each other, and with a suitable phase angle between them.

The amplitudes of the electric and magnetic vectors can be measured, and the ratio between them will be constant for a given medium. Now the electric field strength, E, will have the units of Volts per metre (V/m), while the magnetic field, H, will have units of Amperes per metre (A/m). The ratio between them will have the units of Volts per Ampere (V/A), or in more familiar units, ohms (Ω). The value of this constant for free space is 377 Ω, and this is usually called the Characteristic Impedance of free space. It is possible therefore to relate the electric and magnetic field strengths by the equation :

$$E/H = 377 \text{ ohms} \qquad . \ . \ . \ (1)$$

Energy is carried by the wave in the direction of propagation. The energy flux, i.e. the rate of flow of energy through a surface of unit area, is given by the product of the electric and magnetic field strengths, which is the product of E and H. This only applies when these two quantities are in phase, but this is always so for a plane wave in free space. The energy flowing through an area A square metres is given by w, where

$$w = A \times E \times H = A\,\frac{E^2}{377} \text{ watts} \qquad . \ . \ . \ (2)$$

FORMULAE FOR ISOTROPIC AERIALS

The basic formula for any receiving aerial is the relation between the voltage developed by the aerial and the strength of the signal falling on it. The signal strength is defined as the strength of the electric vector, and is measured in volts per metre, or in practical cases, in milli- or microvolts per metre. The derivation of the formula relating field strength to the developed signal can be made by a series of logical steps, and in doing so certain abstractions, for example an isotropic radiator, which is often used in describing aerials, will be illustrated. The first step will be to deduce the field strength a certain distance away from an aerial which is radiating a signal, and then comparing this field strength with that from a plane wave which has had to pass through an aperture in a screen. The next step will be to reverse the process and assume that power is being absorbed instead of radiated from the aerial, and by doing so the aperture of a receiving aerial will be defined. Then finally the concepts of gain and impedance will be introduced, so that the formula will apply to practical aerials.

It is possible to calculate the field strength at a distance from an aerial that is radiating electromagnetic waves. This has very little practical value, because it is assumed, first that the space is free, thereby ignoring the ground effect, and secondly that the transmitting aerial radiates uniformly in all directions. This type of aerial, known as an isotropic radiator, is a mathematical abstraction, and it is impossible in practice to construct such a device. Even a simple dipole, for example, will radiate more in the direction at right angles to the elements than in line with them. The idea of an isotropic radiator is useful as it is a simple theoretical aerial with which more practical aerials can be compared.

If a power W is being radiated from an isotropic radiator, then at a certain distance from it, say r metres, this power will be flowing through the surface of a sphere of radius r. The power flux at any point on this sphere will therefore be given by $W/4\pi r^2$. The field strength will then be obtained by relating this to equation (2), from which the field strength at distance r from an isotropic radiator, radiating a power W will be given by :

$$E = \sqrt{\left(\frac{377}{4\pi}\right)} \frac{\sqrt{W}}{r} \text{ volts/metre} \quad . \; . \; . \quad (3)$$

It is now necessary to investigate the reverse of this, the absorption of energy by an isotropic aerial when illuminated by an electromagnetic wave. To do this it will first be shown that a large screen in which a small rectangular aperture is cut and then illuminated by a plane wave, will be equivalent, at least in the direction normal to the aperture, to an isotropic aerial. Consider therefore such a screen, in which the size of the rectangular hole is $a \times b$, as shown in Fig. 4. The calculation of the field strength along a line perpendicular to the aperture is a problem in optics, and a simple

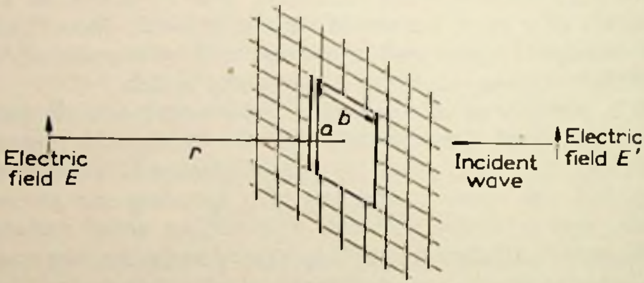


Fig. 4. Electromagnetic wave passing through a screen with a rectangular aperture

analysis shows that if the signal falling on the screen has a field strength E' volts/metre then the field E at a distance r from the centre of the aperture will be given by :

$$E = \frac{a \times b}{\lambda \times r} E' \quad \text{volts/metre} \quad . \; . \; . \; (4)$$

where λ is the wavelength of the signal. But the power flux through the aperture is given by equation (2) as

$$a \times b \, (E'^2/377)$$

and therefore the field strength from an aperture through which a power W is flowing can be rewritten as :

$$E = \frac{\sqrt{(a \times b)}\sqrt{(377)}}{\lambda} \frac{\sqrt{W}}{r} \text{ volts/metre} \quad . \; (5)$$

This is the field strength from a power W flowing through an aperture, and a direct comparison between equations (3) and (5) shows that these are identical if the area of the aperture, or $a \times b$, is given by :

$$\text{Area of aperture} = a \times b = \frac{\lambda^2}{4\pi} \quad . \quad . \quad . \quad (6)$$

It has been seen that an isotropic radiator, radiating a signal with a wavelength of λ, behaves in the same way as if the signal were flowing out through an area of $\lambda^2/4\pi$. In the case of reception the same identity between the two aerials will hold. If either the isotropic aerial or its equivalent aperture is illuminated by a signal which has a field strength of E, then the power flux through the aperture will be

$$\frac{E^2}{377}\,\frac{\lambda^2}{4\pi}$$

This will be the same as the power absorbed by the isotropic aerial, and hence the power absorbed by such an aerial when in a field strength E is given by :

$$W = \frac{\lambda^2}{4\pi\,377} E^2 \text{ watts} \quad . \quad . \quad . \quad (7)$$

Equations (3) and (7) describe the behaviour of an isotropic aerial ; equation (3) gives the field strength which will be established at a certain distance from it when radiating power, while equation (7) gives the power that will be absorbed by it when placed in a given field. Two factors are missing when these formulae are applied to practical aerials. First of all a practical aerial will not radiate or absorb energy uniformly in all directions as it will have directional characteristics. It will either radiate a greater signal, or absorb more power than an isotropic aerial, and this increase is described as its gain. Also, no account has been taken of the electrical circuit connected to it. It will be necessary to consider in greater detail the voltage developed by an aerial at its terminals when connected to a circuit or transmission line. These two factors will now be considered separately.

FORMULAE FOR AERIALS WITH DIRECTIONAL PROPERTIES

When discussing the gain of a practical aerial there is a risk of confusion, as on a theoretical basis it is convenient to compare it with an isotropic aerial, but from a practical viewpoint a half-wave dipole is a more useful reference aerial. Throughout this book the power gain G will always be related to a half-wave dipole, and this has a gain of 1·635 or 2·13 dB relative to an isotropic source. This factor will be denoted by G_d. Furthermore, the gain will be taken in the direction of the maximum of the directional characteristics. It is now possible to rewrite equation (7) to include the concept of gain. If an aerial is placed in a field of strength E, the power absorbed by it will be

$$W = \frac{\lambda^2}{4\pi\,377}\,GG_dE^2 \text{ watts} \qquad . \; . \; . \; (8)$$

There is one other factor to consider which is closely related to the gain, and that is the effective aperture of the aerial. This is the area over which all the energy of the wave is absorbed, and by comparison with equation (6), it is given by :

$$\text{Effective aperture, } A = \frac{\lambda^2 GG_d}{4\pi} \qquad . \; . \; . \; (9)$$

This does not usually correspond to a physical area except in the case of a broadside array consisting of a large number of dipoles, parabolic and similar aerials and horn or lens aerials. These types of arrays have their greatest application at higher frequencies than those at present used for radio or television, and these will not be discussed in any detail.

CONNECTION OF THE AERIAL TO AN ELECTRIC CIRCUIT

Up to now aerials have only been considered in relation to the electromagnetic wave that they are transmitting or receiving, but as an aerial is a device for linking these waves with an electric circuit, it must always include two terminals, which will be referred to as the feed-point. In the case of a receiving aerial the maximum power will be delivered to the associated circuit when this circuit is matched to the aerial. This means that the resistive component of the impedance of the aerial and the load should be equal, while the reactive components should have equal values but of opposite sign. The importance of this will be explained later. For the present it will be assumed that these conditions are satisfied by making the impedance of the load and the aerial both resistive with a value of R_a ohms. If V_0 is the voltage appearing across the terminals of the aerial, then the power developed in the load will be V_0^2/R_a watts. Combining this with equation (8), the voltage developed across the terminals of an aerial when connected to a matched load and radiated by a wave having a field strength of E volts/metre, is given by

$$V_0 = \sqrt{\left(\frac{R_a G G_d}{4\pi\, 377}\right)}\; \lambda E \text{ volts} \qquad . \quad . \quad . \quad (10)$$

This equation gives the voltage developed by a practical aerial, and in fact relates the field strength in volts/metre with the terminal voltage in volts. The ratio of these, which will have the dimensions of a length, is defined as the effective height of the aerial. This is a confusing expression, as it is a constant for a given aerial and bears no relation with the actual height of the aerial above the ground. The effective height h of an aerial is therefore given by :

$$h = \sqrt{\left(\frac{R_a G G_d}{4\pi\, 377}\right)}\, \lambda \text{ metres} \qquad . \quad . \quad . \quad (11)$$

One special case of effective height needs consideration, that is for a half-wave dipole. Practical aspects of this aerial will be given in later chapters, but it can be shown that it will have a radiation resistance of 73·1 Ω, and hence be matched when connected to a resistive load having this value. As this aerial is used as a reference for the definition of gain, the value of G will be unity, while G_d has a value of 1·635. Substituting these values in equation (11), the effective height of a half-wave dipole becomes :

$$h_d = \sqrt{\left(\frac{73{\cdot}1 \times 1{\cdot}635}{4\pi\, 377}\right)}\lambda = \frac{\lambda}{2\pi} \text{ metres} \quad . \quad . \quad . \quad (12)$$

This can also be derived from consideration of the current induced in the elements of such an aerial when placed in an electric field, but the discussion given above is a logical development from the fundamental equations and the formula is not restricted to a half-wave dipole, but can be applied to any aerial for which R_a and G are known.

RELATION BETWEEN TRANSMITTING AND RECEIVING AERIALS

Up to now aerials for transmitting and receiving have been considered separately, but it will now be shown that their characteristics are the same in both cases. This applies to their gain, directional characteristics and impedance, but of course there are some concepts, such as effective height, which only apply in the receiving case. Moreover, the design of transmission and receiving aerials is quite different both for mechanical reasons and because of the vast difference of power that is handled.

An aerial has two terminals, so from the electrical point of view it can be considered as a two-terminal network, and the theorems applying to networks can be applied. In particular Thévenin's theorem can be applied. An aerial when receiving a signal is a two-terminal network containing an internal source of e.m.f. This theorem states that in a case like this it behaves as a generator with an internal impedance equal to the impedance measured between the terminals in the absence of the internal e.m.f. It also states that the open-circuit voltage gives the value of the internal e.m.f. This means that the equivalent circuit shown in Fig. 2 is valid for a receiving aerial. Now when the impedance is being measured, in order to carry out the measurement a voltage has to be applied to the two terminals. The aerial will then behave as a transmitting aerial. In other words it follows directly from Thévenin's theorem that the impedance of an aerial when used for transmission is the same as its internal or generator impedance when used for reception.

Further application can be made of the network theorems, namely the reciprocity theorem. Consider two aerials,

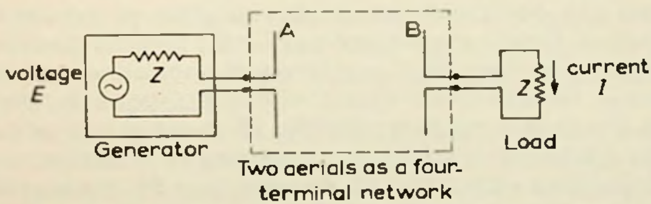


Fig. 5. Network equivalent of two aerials

which, although they may be many miles apart, constitute a four-terminal network, as shown in Fig. 5. Assume that one of them, aerial A, is connected to a generator having an e.m.f. of V and an internal impedance of Z, while the other aerial, B, is connected to a load of impedance Z. If the current flowing in this load is I, then it follows from the reciprocity theorem that if the e.m.f. is now placed in the circuit associated with aerial B, then a current I will flow in aerial A. In the first case aerial A was transmitting and aerial B receiving, and in the second case aerial B transmitting and aerial A receiving. This means in practice that whenever aerial measurements are made, the aerial under test can be used for transmitting or receiving without affecting the final result.

A more important aspect of this, however, is that it is possible to show that the gain of an aerial is the same when transmitting or receiving. If, in the example given above, aerial B is replaced by a half-wave dipole, then the current flowing in the load will be changed to a value kI which will be independent of whether the dipole is transmitting or receiving. Now this change in the current in the load given by the factor k is related to the gain of aerial B, as by changing it by a dipole a direct comparison has been made between it and the dipole. Now k is the same in both the transmitting and receiving cases, so that the gain of an aerial will be independent of whether it is receiving or transmitting a signal. The directional characteristics of an aerial can be thought of as the variation of gain with direction. Gain is usually reserved for the forward direction only, and the expression 'gain function' is sometimes used to describe the directional characteristics. It follows therefore that the directional characteristics of an aerial will be the same whether it is used for transmission or reception.

It has been shown that all the important RF characteristics of aerials are the same, irrespective of whether they are transmitting or receiving a signal. It is for this reason that in many places the characteristics of receiving aerials will be considered in terms of radiation and not reception of waves. This will often give a clearer picture of their method of operation, especially when the directional characteristics are being considered.

RECEPTION WITH A REACTIVE LOAD

It is now possible to generalize the formula for the signal received by an aerial to cover a practical installation. It will be assumed to be erected in a field strength of E volts/metre, and to be connected to a load whose impedance is Z_L. Z_L in practice is often resistive, but the formula is also valid for a reactive load. Z_a is assumed to be the impedance of the aerial, and it is also assumed that the resistive component of this is the radiation resistance of the aerial R_a. The terminal voltage V is then given by:

$$V = \sqrt{\left(\frac{R_a\, G\, G_d}{120}\right)} \frac{\lambda}{\pi} \cdot \frac{Z_L}{Z_a + Z_L} E \text{ volts} \quad . . . (13)$$

where G is its gain relative to a half-wave dipole, and G_d the gain of a half-wave dipole relative to an isotropic radiator, i.e. has the value of 1·635. This formula is important as it shows the voltage developed by a practical aerial when connected to a load, assuming that the parameters of the aerial and load are known.

GAIN OF AERIALS

The concept of gain needs further explanation, as there are two ways of looking at it, (i) by comparison with a half-wave dipole and (ii) from investigation of the directional characteristics.

The gain of an aerial can be derived from its directional characteristics. If a sphere is drawn round the aerial, then the power flux through any part of the sphere will be given by the directional characteristics of the aerial, but the total power radiated must be equal to the power supplied to the aerial, that is if there are no losses of power in the aerial itself. The relation between the field strength and the power for an isotropic radiator has been given in equation (3). From these the relative field strengths produced by an isotropic radiator and the aerial can be deduced, assuming that both are radiating the same total power, and from this the gain of the aerial can be found. This value of the gain is dependent only on the directional characteristics of the aerial, and does not take into account any losses, such as ohmic losses, in the elements.

The second method of defining gain is by comparison of the signal received by the aerial to that from a half-wave dipole. This is a much more practical definition, and takes into account the losses in the aerial itself. Unfortunately, it suffers from the disadvantage that the impedance of the aerial will differ from that of the half-wave dipole, that is the values of Z_a and R_a will not usually be the same in both cases. Unless special precautions are taken with the matching, and this is one of the numerous experimental difficulties that occur, the measured value of the gain will not be a true parameter of the aerial, but will also be a function of the aerial impedance. In most cases the ohmic losses in the elements etc. will be small and the difference between the two definitions of gain will be negligible.

SUMMARY

The relation between the signal developed by an aerial and the field strength of the wave falling on it has been given as:

$$V = \sqrt{\left(\frac{R_a\, G\, G_d}{120}\right)} \frac{\lambda}{\pi} \frac{Z_L}{Z_a + Z_L} E$$

where V is the voltage developed across the load

- E is the field strength of the wave
- λ is the wavelength
- Z_a is the impedance of the aerial
- R_a is the radiation resistance of the aerial, or in a lossless aerial the resistive part of the impedance
- Z_L is the impedance of the load
- G is the gain of the aerial relative to a half-wave dipole
- G_d is a constant, equal to 1·635.

Certain abstractions, such as an isotropic radiator, aerial aperture and effective height have been introduced, as well as the more practical factors of gain and impedance.

It has also been shown that the same laws hold for transmitting and receiving aerials, although the design problems are different in the two cases.

3

Aerials for Broadcast Reception

Aerials depending on the electric field – Interference-rejection properties of aerials – Aerials depending on the magnetic field – Ferrite rod aerials – Aerials for use below 30 *Mc/sec – Aerials for use above* 30 *Mc/sec*

THE frequencies that are used for sound broadcasting are either below 30 Mc/sec or in the VHF range. The techniques in the two cases are quite different and the two types of aerials will be considered separately. Those for frequencies below 30 Mc/sec can be subdivided into two further groups depending on whether they respond to the electric or magnetic component of the incident wave.

AERIALS DEPENDING ON THE ELECTRIC FIELD

A simple rod can be used for receiving radio signals, but such a device for all frequencies below 30 Mc/sec, and especially in the long- and medium-wave bands, will be shorter than a quarter wavelength. This assumption will in fact be made, and by doing so all resonances in the aerial itself can be ignored, with a corresponding simplification of the analysis. It is possible to build up a physical picture of the method of operation of this type of aerial. The incident wave will induce voltage differences in the rod which will cause a current to flow in it as shown in Fig. 6. The magnitude of this current will depend on both the capacity between the aerial and the ground, and also on the impedance of the load that is connected to the base of the rod. It can be seen that adding further capacity at the top of the

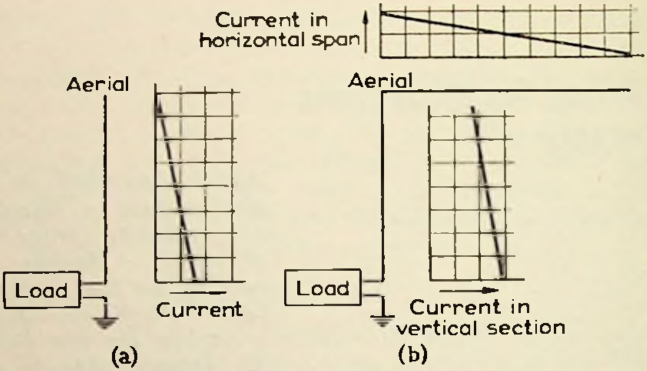


Fig. 6. Current distribution in short non-resonant aerials
(a) A short vertical rod
(b) A vertical rod connected to a horizontal span

rod by some form of 'top loading' such as a horizontal span of wire, will increase the flow of current and hence improve the efficiency of the system. Some typical values of the base impedance of this type of aerial are given in Table 2. These figures are based on theoretical calculations, so that on a practical installation the measured values might depart

Table 2

Type of aerial	*Impedance Z_a ohms*		
	200 kc/sec	1 Mc/sec	10 Mc/sec
4 ft vertical rod	$5{\cdot}2\times10^{-4}$ $-j\,5{\cdot}3\times10^{4}$	$1{\cdot}3\times10^{-2}$ $-j\,1{\cdot}1\times10^{4}$	$1{\cdot}3-j\,1{,}100$
15 ft vertical rod	$7{\cdot}3\times10^{-3}$ $-j\,1{\cdot}4\times10^{3}$	$1{\cdot}8\times10^{-1}$ $-j\,2{\cdot}9\times10^{3}$	$18-j\,290$
30 ft vertical wire with 60 ft span	$0{\cdot}12-j\,4{,}900$	$2{\cdot}9-j\,980$	Aerial beyond resonance

quite considerably from them. They illustrate, however, the order of magnitude of the aerial impedance that is encountered. The frequencies that have been chosen in this table correspond to values in the long-, medium- and short-wave bands, while the three types of aerial correspond approximately to a short rod or length of wire, a simple outdoor aerial and an ambitious installation with a horizontal span respectively.

The actual amplitude of the signal received by any of these aerials will depend very greatly on the load connected to its terminals. This, of course, is determined by the input circuits of the receiver, so that it is quite impossible to predict the signal that will be given by a given installation even if the electrical characteristics of the aerial are known in detail. This can be illustrated by considering the reception of a 1 Mc/sec signal by a 15 ft vertical rod. Three loads will be connected to this; (i) an inductance of approximately 0·47 mH, (ii) an open circuit and (iii) a resistive load having a value of 75 Ω. The formula for the terminal voltage V of such an aerial when in a field strength E has been derived in the previous chapter, and is given by:

$$V = \sqrt{\left(\frac{R_a G\ G_d}{120}\right)}\ \frac{\lambda}{\pi}\ \frac{Z_L}{Z_a + Z_L} \cdot E$$

where $G\ G_d$ is the gain of the aerial relative to an isotropic radiator, and in this case has a value of 3/2.

λ is the wavelength, and at 1 Mc/sec this is 300 m.

Z_a from the table given above has a reactive component of $-$j 2,900 Ω and a radiation resistance, R_a, of 0·18 Ω.

The resulting voltage can be calculated from these figures if the field strength is known; a value of 1 μV/m will be assumed for this so that the relative performance of the aerial in the different cases can be compared. In case (i) an inductive load of 0·47 mH has been chosen, because this value will resonate with the capacity of the aerial. The value of V, terminal voltage on the load, will depend on the losses in the system, but assuming reasonable values for these, the output voltage will be approximately 1 mV. In case (ii) when there is an open circuit at the base of the aerial, no assumptions need be made of the aerial losses, and the value of V will be 4·8 μV. In case (iii) which corresponds to a correctly terminated coaxial cable connected to the base of the aerial, the value of V will only be 0·12 μV. This arrangement would never be used in practice because it is inefficient, instead the cable would not be terminated by a resistive load, its capacity being included as part of the input circuit of the receiver. This case would

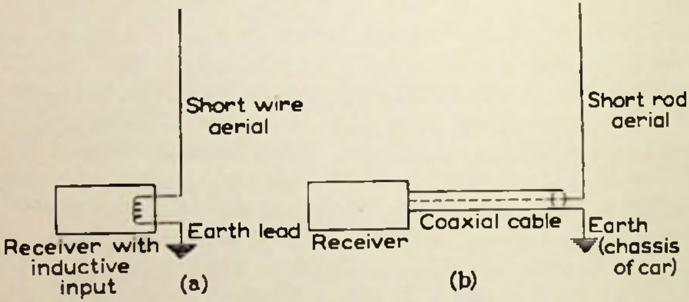


Fig. 7. Broadcast receiving arrangements
(a) Vertical wire with correctly matched receiver
(b) Car radio installation

then correspond very closely to a car radio installation, as shown in Fig. 7.

It has been seen that there are large differences in the terminal voltages, and that the maximum signal is obtained when the aerial impedance is resonated by an inductive input circuit in the receiver. This corresponds to the maximum voltage at the input of the receiver, but not necessarily the maximum power transfer between the aerial and the receiver. The voltage has been considered to be the most important factor in determining efficiency and not, as in the case of television or VHF broadcasting, the power delivered to the load. The reason for this is that below

30 Mc/sec the noise generated by the first valve of the receiver is of less importance than the noise received by the aerial from external sources, such as atmospheric static or man-made noise.

The radiation resistance R_a should be as high as possible. Even if the reactive component of the impedance is completely cancelled out, there will be ohmic losses in both the aerial and the load which are comparable with, or even much greater than the value of R_a. The radiation resistance determines the amount of signal that the aerial can receive, so that for an efficient system the physical size must be as large as possible.

INTERFERENCE-REJECTION PROPERTIES OF AERIALS

The existence of locally generated interference has a direct bearing on the siting of this type of aerial. Interference signals from an electric motor, for example, will be conducted by the wiring in the building and will be radiated from it. Examples of installations are the horizontal span, the vertical rod at chimney, gutter or window-sill level. These vertical aerials have been classified by the Radio and Electronic Component Manufacturers' Federation as class A, B or C aerials, as shown in Fig. 8. In all these, however, there is a risk of interference signals being picked up on the lead between the aerial and the receiver, as this may have to run quite close to the mains wiring in the house. This interference can be reduced if the lead is a balanced, screened cable. With this type of cable there is rejection of the unwanted signals both because it is of balanced construction, and hence not relying on the earth as a return lead, and also because of the screening round the conductors. The aerial is connected at the top end of the cable by a screened transformer that converts the cable impedance to a value suitable for connection to the aerial. At the lower end of the cable is a second transformer, so that the impedance is correct for the average commercial receiver. There is also a dual-purpose earth connection on the aerial

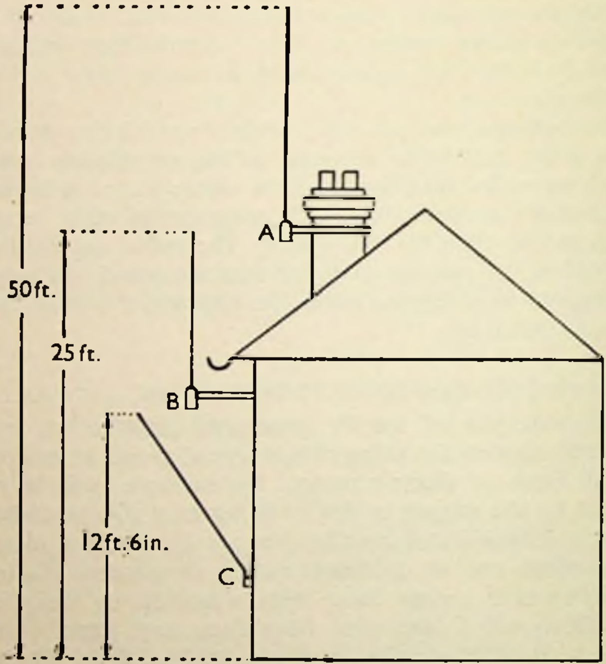


Fig. 8. R.E.C.M.F. classification of vertical rod aerials for broadcast reception

transformer. Its first purpose, illustrated in Fig. 9, is that it completes the aerial circuit as it connects the lower end of the aerial winding of the transformer to earth. Secondly, the earth wire is a safety precaution during thunderstorms, when it acts as a lightning conductor for the aerial. The primary winding of the transformer is protected in this case by a safety gap connected across it. This is an ideal type of installation if there is a high interference level, but as the whole system is liable to introduce a certain loss, the size of the aerial connected to the upper transformer should be as large as possible.

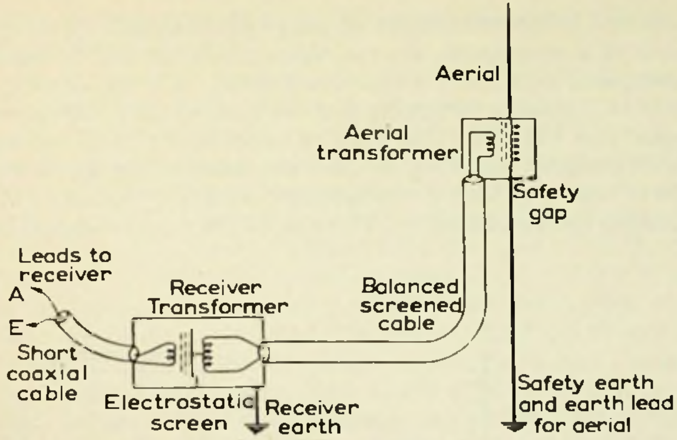


Fig. 9. Receiving aerial arrangement for the reduction of interference at broadcast frequencies

AERIALS DEPENDING ON THE MAGNETIC FIELD

Aerials in the form of a loop have many applications in broadcast reception, but only two aspects of them will be considered here, those used in some portable receivers, and ferrite rod aerials. The most important other application of loop aerials is in radio direction finding, but with this many special precautions have to be taken for accurate results and discussion of them lies outside the scope of this book. First of all, therefore, the simplest type of loop aerial will be discussed.

A loop aerial normally consists of one or more turns of wire, the ends of which are connected to the input circuit of the receiver. The amount of signal that it will receive depends on its radiation resistance and this in turn depends on the area of the loop. The radiation resistance will increase with the number of turns, the formula for the radiation resistance of a small loop of area A, containing n turns will be*:

$$\text{Radiation resistance } 31{,}200 \left(n\frac{A}{\lambda^2}\right)^2 \text{ ohms}$$

* For more detailed information see J. D. Kraus, *Antennas*, chap. 6, McGraw-Hill, 1950.

where λ is the wavelength of the received signal. As in the case of a wire aerial, the radiation resistance will be small compared with the reactive component. A loop, however, will be inductive, requiring a condenser across it for resonance (see Fig. 10). This type of aerial lends itself for use with portable receivers, as the inductance of the aerial can be chosen such that it will resonate with one section of the ganged tuning condenser. The size of the loop is limited by

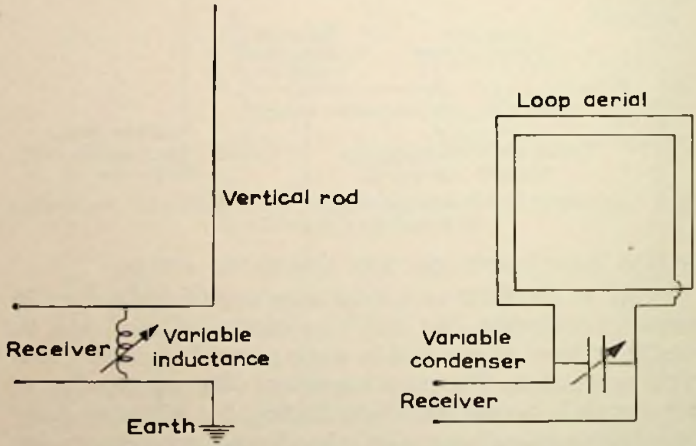


Fig. 10. *Ideal loads for vertical rod and loop aerials*

the size of the cabinet of the receiver, and it usually has a much lower radiation resistance than a vertical wire.

As an example of a loop aerial, a coil of 16 turns wound on a rectangular frame having dimensions of 10 in. × 8 in. will have a radiation resistance of $2{\cdot}6 \times 10^{-14}\ \Omega$ at 1 Mc/sec. It would have an inductance of 0·25 mH approximately, and for resonance at 1 Mc/sec the condenser across it would have to have a value of 100 pF. Under these conditions the terminal voltage on the loop when in a field of 1 μV/m would be $3{\cdot}4 \times 10^{-4}\ \mu$V. This assumes reasonable losses in the loop and condenser as these will have a marked effect on the output voltage, because the radiation resistance of the loop is so small.

On the basis of the simple examples that have been given, the loop seems very inferior to a single vertical wire. Free space conditions have been assumed, and in fact if a single rod and a loop were compared in the open, the wire would probably give the stronger signal. Indoors, however, the situation is quite different, the loop often proving the more satisfactory. There are two reasons for this, both of which are due to the presence of vertical conductors in any building in the form of electric wiring, water pipes, drain pipes etc. Near one of these conductors the electric field will be small, as any such field merely causes a current to flow in the conductor. The magnetic field is not affected in the same way, and can in fact have a greater value near a conductor than it would have in free space. A loop aerial, which depends on the magnetic component of the wave, will give a more reliable signal under these conditions. The second way in which vertical conductors can change the signal to make a loop more efficient than a wire can be illustrated by considering a cage similar to those used for lions at a circus. Inside the cage the electric component would be very small, while the magnetic component would be virtually unaltered. This, of course, is an extreme example, but it illustrates one way in which the performance of a loop aerial is satisfactory when it is used inside a building.

Nothing has been said so far about the directional properties of a loop aerial. Such an aerial, in free space, has a figure-of-eight polar diagram, with a minimum along the axis of the loop. In practice, due to scattering from local objects, as well as stray pick-up of the electric field, the directional characteristics will depart very considerably from the ideal. It will, however, usually have at least one direction of minimum reception, and it is because of this that it is often a very useful aerial for the rejection of signals causing whistling or interference, such as signals from other broadcasting stations.

FERRITE ROD AERIALS

One version of a loop is the ferrite rod aerial. In this a coil is wound on a long ferrite rod and, as before, is resonated with a section of the receiver tuning condenser. The main advantage of this type of aerial is that its physical size is very much smaller than a normal loop, and it can in fact be mounted on the receiver chassis itself. Being smaller it can if necessary be oriented separately from the cabinet of the receiver, in which case the direction of reception is adjusted by a separate control.

Ferrite rod aerials rely on the magnetic field through the coil being concentrated by the permeability of the core. A normal iron core would not be suitable due to eddy currents, and this cannot be overcome by lamination as in an LF transformer as they would have to be extremely thin. Ferrite, however, has the property of having a high permeability at the same time as being a reasonable insulator, so that eddy current losses are small even at radiofrequencies. This simple picture of a ferrite rod aerial being derived from a loop does not take into account the length of the rod. This is an important factor, the longer the rod the more efficient the aerial becomes. Also the directional characteristics of the aerial will be affected in the same way as any indoor aerial by the scattering of the signal by nearby objects.

AERIALS FOR USE BELOW 30 MC/SEC

It is possible to summarize the various aerials for broadcast reception below 30 Mc/sec by considering the applications of three different types. This of course leaves out a very large number of systems that are used in practice, but they represent the three most important groups of aerials.

(a) *Outdoor installation in the form of a single wire.*—This can take many forms, but the most efficient is that in the shape of ˥ or T, with the downlead entering the building at a point near to the receiver. The top section of the aerial should be as far from the ground as possible. This is the most sensitive type of aerial and is ideal when reception of distant stations is required.

(b) *Outdoor vertical rod aerial at chimney, gutter or window-sill level*—This is a simplified version of (a) above, but it lends itself to being transformer-coupled to a screened lead between the aerial and receiver. This type of installation is particularly useful when there are locally-generated noise signals.

(c) *Indoor aerials in the form of a loop or a coil on a ferrite rod*—These are ideal for portable receivers, or for the reception of strong signals. They are particularly useful when it is necessary to have the aerial indoors, and in this application they have many advantages over a single wire aerial.

AERIALS FOR USE ABOVE 30 MC/SEC

The main band above 30 Mc/sec for broadcast use is in the frequency range 88–100 Mc/sec, or band II. Frequency modulation is usually used in this band, although this does not have much influence on the aerial story.

Most of the aerials for use in this band will be described in connection with the reception of television in bands I and III. In general a slightly less ambitious aerial is required for sound broadcasting in band II than for television, assuming that the field strength conditions are the same. In this case the aerials will usually be connected to the receiver through a length of cable, and will have an impedance to suit the cable.

It will be seen that for television reception a good directional pattern is often required for the elimination of ghost signals. These ghost signals also show up in reception with FM systems, but instead of the second image in a television picture, they produce distortion of the audio sound.

The explanation is that the ghost signal, arriving late at the receiving aerial, can be out of phase with the main signal and the phase difference will depend on the modulation. This produces an amplitude modulated component, which in certain detector circuits can cause distortion. The cure, as with television reception, is a more directional aerial, but it is not so serious as in television, as the distortion can also be improved in this case by a redesign of the receiver circuits.

Other problems arising from the reception of FM broadcast signals in the UHF band need not be discussed here as they will be adequately covered when other aerials for use above 30 Mc/sec are discussed. There is, however, one type of aerial that is often used with frequency modulation, but which has few applications in television reception. This is

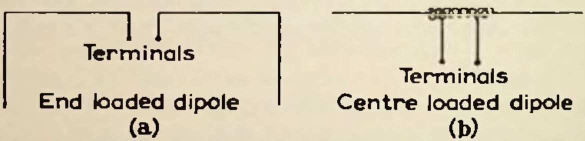


Fig. 11. *Compressed dipoles for band II reception*

the compressed dipole, usually mounted inside the cabinet of the receiver. This aerial is shorter than the resonant half-wave dipole, so that it can be fitted inside a normal sized cabinet. This shortening can be carried out in either of two ways. The first method is by introducing end-loading at the outer ends of the dipole elements as shown in Fig. 11 (a), and the second by introducing inductive loading at the centre of the dipole, at the point where the cable is connected to it, as shown in Fig. 11 (b). Both methods suffer from the disadvantage that the radiation resistance is much less than the 75 Ω required for a good match to the cable, but in areas where there is adequate signal, this provides one method of having a built-in aerial. Most receivers fitted with this type of aerial have an aerial socket, so that if necessary an external aerial can be used.

4

Directional Characteristics of Aerials

Rejection of unwanted signals – Rejection of ghost signals – Aircraft flutter – Forward gain of an aerial – Summary

THE voltage produced by an aerial will depend on the direction of arrival of the signal, and this property is described by its directional characteristics. They are often referred to as the polar diagram of the aerial, corresponding to the case when the directional characteristics are required in one plane only, and are plotted on polar graph paper. This expression can be misleading for two reasons. First of all they are a three-dimensional quantity, and not restricted to a single plane. Secondly they can equally well be represented in Cartesian co-ordinates, and for some applications this method of representation has its advantages. The expression 'polar diagram' will therefore be reserved for the representation of the directional characteristics in a given plane and not used as a means of description of an aerial.

The directional properties become important when television reception is considered. The quality of the picture can be changed by them for several reasons :

(a) the directional properties can be utilized for the rejection of unwanted signals, such as ignition interference ;

(b) they can be used for the rejection of ghost signals ;

(c) they can reduce aircraft flutter ;

(d) the forward gain of a given aerial will be a function of its directional characteristics.

Each of these factors will be considered separately.

REJECTION OF UNWANTED SIGNALS

Signals causing interference on a picture can arise from two types of source, both of which call for different directional characteristics for their removal. If the location of the source of interference is known, then an aerial with a very deep minimum in its response curve, with this minimum directed towards the interference, will give the best result. The width of the minimum in this case need only be small. If, however, the noise originates from an unknown direction or even from a moving object such as a motor vehicle, then a broad minimum in the characteristics will give the best results. In practice, television receiving aerials are designed as a compromise between these two cases, so that it is possible to have one aerial only for the reduction of interference. The performance of an aerial cannot be ascertained from its horizontal polar diagram only. As an example, consider an aerial designed for use with a vertically polarized signal. Three factors will be needed to describe completely the rejection properties of the aerial, namely :

(i) Its response curve in the horizontal plane for vertically polarized signals.

(ii) Its response curve for signals arriving at the aerial from directions other than the horizontal.

(iii) Its directional characteristics for horizontally polarized signals.

Of these (ii) is important when considering ignition interference from motor vehicles, as if the aerial is mounted at chimney level on a house situated quite near to a road, then the direction of arrival of ignition interference signals will be far from horizontal. It will be seen later that another detrimental effect, that of aircraft flutter, depends mainly on the response to signals arriving at angles above the horizontal. (iii) is important as interference signals will not necessarily be polarized in a given plane, and an aerial which has very good characteristics for vertically polarized signals might be very poor when horizontally polarized signals are considered. This does not apply to aerials in which the elements are vertical but it can be important when there are sloping elements, as in the K, X or V type aerials.

REJECTION OF GHOST SIGNALS

The rejection of ghost signals is probably the most important factor when considering the directional characteristics of television receiving aerials. The meaning and significance of ghost signals will be discussed first as this will assist in the explanation of various techniques that are employed for their removal.

Ghost images on a television picture are produced by two or more signals arriving at the receiver, one coming direct from the transmitter while the others arrive after reflection from objects such as large buildings, hills, etc. These secondary signals have travelled farther than the direct signal, and will therefore arrive at the receiver a few microseconds late. Now a television picture is built up by a scanning process, so that the time delay shows itself as a displacement of the picture. If there are several signals arriving by different paths, then a series of 'ghost' images will be seen across the screen. Ghosts can spoil the quality of a picture in several ways :

(i) The existence of double (or more) images on the screen obviously detracts from the quality of the picture.

(ii) Ghost signals can affect the line synchronization of the picture, causing the picture to 'tear'. The television waveform contains pulses at regular intervals that synchronize the line time base in the receiver. In the British system these pulses take the form of a break in the transmission, as shown in Fig. 12. If, however, there is a strong ghost signal, then it is possible for the synchronizing pulse to be partially, or even completely filled by the ghost signal from the previous line. Furthermore, the amount by which the pulse is distorted will be a function of the amplitude of the picture, so that the degree of synchronization will change as the picture changes. In many cases quite strong double images can be tolerated, the picture still having

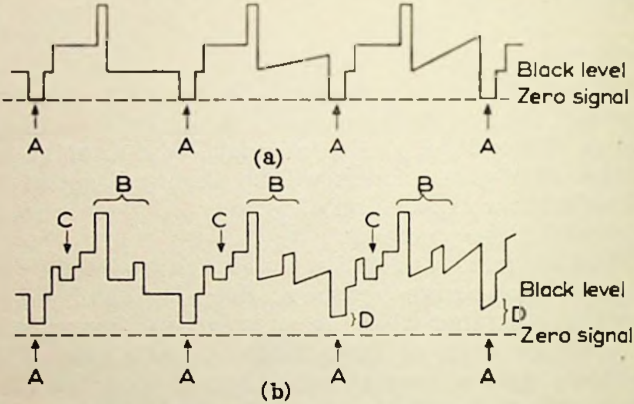


Fig. 12. Waveform of a television signal (British system)

(a) Undistorted waveform (three lines)
(b) Waveform with ghost signal

A. Line synchronizing pulses (negative)
B. Double image
C. Ghost image of synchronizing pulse
D. Variations in synchronizing pulse amplitude caused by video amplitude of previous line

entertainment value, but if tearing is present the picture is usually considered to be not worth viewing.

(iii) A ghost image can be formed from the synchronizing pulse itself, if the displacement is sufficiently large. In this instance it occurs as a steady vertical band on the left-hand side of the picture.

(iv) If the extra path is small, distinct images might not be seen, but they will blur the picture, making it look as if it were out of focus.

This simple explanation of ghost images is not the whole story. The direct and reflected signals are added together at the aerial, i.e. while they are still in the form of a radio-frequency signal. Now when two RF signals are mixed

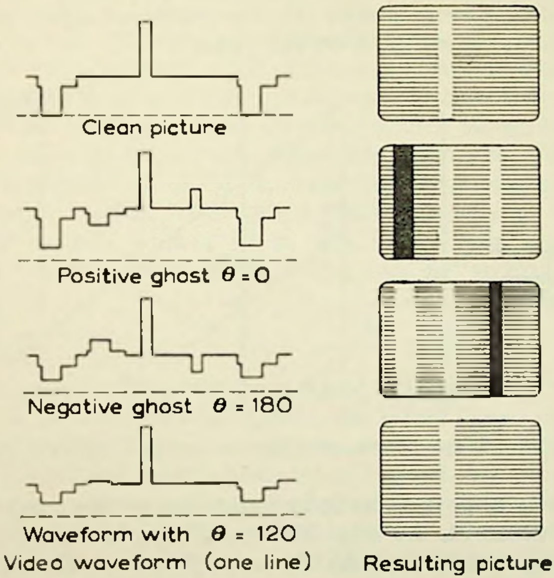


Fig. 13. *Effect of phase changes on a ghost image*

together, the resultant is not necessarily of increased amplitude, in fact the final amplitude can be less than either of the original signals. The actual amplitude will depend on their relative phase. The effect that this will produce can be illustrated by an actual example. Consider a picture consisting of a vertical white bar on a grey background, together with a ghost image of sufficient displacement. Now if the phase is such that the ghost signal adds to the main signal, the ghost will show up as a white bar. If on the other hand the ghost subtracts from the main signal, the ghost will appear black, even though it was produced from a white image, as shown in Fig. 13. It is therefore possible to see both 'positive' and 'negative' ghosts. There is an intermediate version where, in the example above, the ghost would be grey. It would in fact blend with the background, and so that even though there is a delayed signal present, it is not showing itself on the picture.

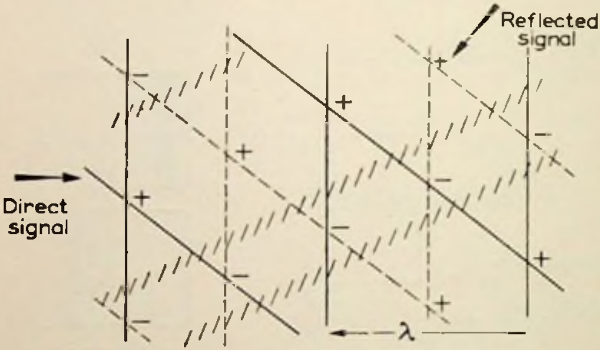


Fig. 14. Wave pattern with direct and one reflected signal

This is important as it explains one of the methods of ghost removal, by the horizontal displacement of the receiving aerial. Consider the wave pattern at the receiving site at any instant of time, as shown in Fig. 14. The wave from the transmitter is shown coming in from the left, while that from the ghost, from the top. Now each wave will consist of positive and negative peaks. At the points where the positive or negative peaks coincide on the two waves, the waves are in phase, and the resultant ghost will be positive. At the points where the positive peaks of one wave-train coincide with the negative peaks of the other wave-train, the resultant ghost will be negative. The points where the ghost will be 'grey' are also shown, but this is only approximate as its exact position will depend on the relative amplitude of the main and reflected signals. It can be seen therefore that it is sometimes possible to remove a ghost image by moving the receiving aerial a small distance horizontally, the amount of the displacement usually being of the order of a quarter wavelength of the signal.

The displacement of a ghost image on the screen will depend on the distance of the reflecting object from the receiving site. There is no straightforward relationship, as it is the extra path travelled by the signal which determines the displacement, and this will depend on the relative direction of the transmitter and the ghost source. As an example of the order of magnitude of this displacement : if there is a hill one mile behind the receiving site, producing an extra path of two miles, then with a 405-line television system, and a receiver with a 17 in. diameter screen, the ghost image will be displaced by a distance of approximately 1½ in.

AIRCRAFT FLUTTER

It is possible for a television signal to be reflected from an aircraft, so that the two signals, the direct signal and that from the aircraft arrive at the receiver together. In some cases the second signal shows up as a ghost, but the phenomenon is more troublesome than this as it gives rise to variations in the brightness of the picture. The reflection is taking place on a moving object so that the reflected wave alternately adds and subtracts from the main signal. The flutter so produced can have a frequency up to several cycles per second depending on the speed and direction of the aircraft. It can have a very detrimental effect on a picture, especially in locations near to airfields. Fortunately it can be reduced both by suitable aerial design and by automatic gain control circuits in the receiver. This latter method is particularly effective if the time constant of the circuit is chosen correctly.

Aircraft flutter is most noticeable when the aircraft is relatively near to the receiving site, as the amplitude of the reflected signal will then have its maximum value. In this case, however, the direction of arrival of the unwanted signal will be farther from the horizontal than that of the main signal. An aerial suitable for the reduction of this form of interference needs to have good directional properties in the vertical plane, i.e. a maximum response in the horizontal direction with reduced sensitivity in directions towards the vertical. It is easier to fulfil these conditions with vertical than with horizontal polarization.

FORWARD GAIN OF AN AERIAL

The forward gain of an aerial is very closely related to its directional characteristics, and as a general rule the more directional an aerial, the greater will be its gain. The value of the gain when calculated from the directional properties will be the maximum value that can be attained from the particular arrangement of conductors, as the method ignores both the resistance losses in the elements and also any mismatch that may occur between the aerial and its feeder. For most practical aerials, however, it gives a value for the gain that is reasonably near to the value obtained by direct measurement, and it can be illustrated by considering a special type of array, consisting of a number of parallel half-wave radiating elements. An example of this type of aerial is the 'Yagi' array, which will be considered later.

The difficulty with this method is that it is necessary to know the complete directional characteristics of the aerial, i.e. its response in all directions. With the example that has been chosen it is possible to calculate this, given the polar diagram in the plane at right angles to the plane of the elements, and also the directional characteristics of the individual elements. The method is then to calculate, from the directional pattern, the field strength and hence the power radiated, in all directions, and integrate this over the whole sphere. It is possible to do this calculation on special graph paper, the vertical scale of which is proportional to the power (i.e. the square of the voltage) radiated by the aerial, and the horizontal scale a function of the direction, the form of this being chosen to allow for the directional pattern of the individual elements. An example of the gain of an aerial calculated by this means is shown in Fig. 15. The gain is given by the reciprocal of the area under the curve, and this can most conveniently be measured by means of a planimeter or similar instrument. An example of this special paper is given in Appendix II, together with the formulae giving the derivation of the horizontal scale.

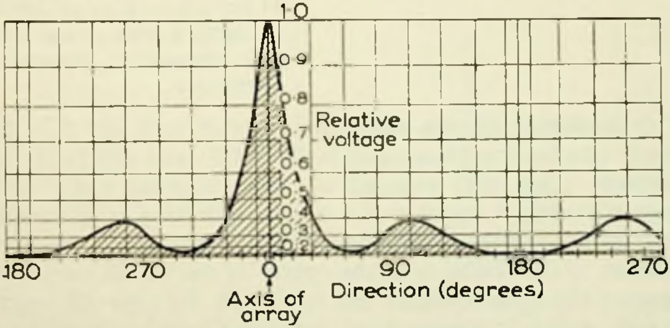


Fig. 15. *Calculation of the gain of an array from its directional characteristics*

$$\textit{Example: Power gain} = \frac{\textit{Total area}}{\textit{Shaded area}} = \frac{100}{14{\cdot}4} = 6{\cdot}96$$

i.e. Gain relative to a half-wave dipole 8·4 *dB*

SUMMARY

Some of the aspects of the directional characteristics of aerials have been given, where it has been shown how these influence the performance of an aerial when used for television reception. The polar diagrams of individual aerials have not been given, as these will be introduced when the various types of aerials are discussed in more detail.

5

The Half-wave Dipole Aerial

Bandwidth of a half-wave dipole – Directional characteristics of a half-wave dipole – Parasitic elements – Examples of H aerials – Folded dipole – Aerials with more than one parasitic element – Summary

THE fundamental type of resonant aerial, and one that has many practical applications, is the half-wave dipole. In its simplest form this consists of two collinear rods, each approximately a quarter of a wavelength long, and usually held mechanically at the centre by an insulator. The connection to the feeder is at the centre of the aerial, to points near to the inner ends of the two rods. Its over-all length would make it impractical for long- or medium-wave reception, but for television and UHF broadcast reception it has many applications. These services use frequencies above about 40 Mc/sec and the over-all length of the dipole is therefore less than 12 ft. It is of interest as a practical form of receiving aerial whose operation can be analysed, and also because it can be used to illustrate the impedance properties of aerials.

An exact mathematical analysis of a half-wave dipole is not possible unless certain approximations are made. One of these is to assume that the aerial consists of two similar, coäxial cones having their apexes close together as shown in Fig. 16. This differs from a normal dipole in that the diameter of the elements varies along their length, but by making these changes it is then possible to derive the expressions for the electric and magnetic fields in the vicinity of the elements. This has been done in great detail by Schulkenoff, who has also calculated the impedance of such a system. A more pictorial representation of a dipole is to consider it consisting of two uniform cylinders, on which there is a sinusoidal distribution of current. The latter of these two methods will be used here to describe most of its characteristics. It will be assumed that the dipole has a voltage generator connected to its terminals so that it will radiate a signal. It has already been shown that its properties under these conditions will be the same as if it were used for reception.

When considering the current flowing in the elements it is assumed that the current at the outer end will be zero, also that the phase of the current will be the same at all points. The voltage has a certain value at the feed-point corresponding to the driving voltage, and this increases down the elements. For a half-wave dipole the voltage reaches its maximum value at the outer ends of the elements. The current and voltage distributions are shown in Fig. 17. Three cases are shown here, namely the dipole at resonance and operating at frequencies above and below this. The importance of these is that they illustrate the feed-point impedance of the aerial. The terminal impedance is given by the ratio of the current and the voltage at this point. For many applications it is also useful to know the admittance, the reciprocal of the impedance, so both these quantities will be considered.

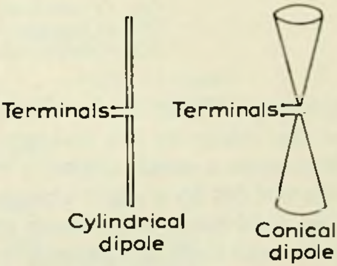


Fig. 16. *Two types of dipole aerial*

For a dipole that is resonant the impedance is the same as that from a resistance of approximately 73 Ω. This means that the current and the voltage will be in phase. This is a

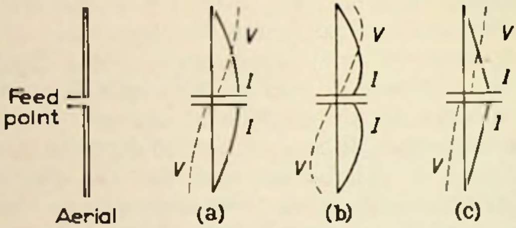


Fig. 17. *Voltage and current distributions on a half-wave dipole aerial*

(*a*) *At resonance*
(*b*) *At frequencies above resonance*
(*c*) *At frequencies below resonance*

theoretical figure and neglects any extra capacity introduced at the centre by the insulator. Any practical insulator will introduce a small capacity at this point, but this can be allowed for by a slight change in the length of the elements. The feed-point impedance can be made resistive, but its value will then be changed from the theoretical value given above. It is for this reason that the measured value of the impedance of a dipole often departs from the expected value.

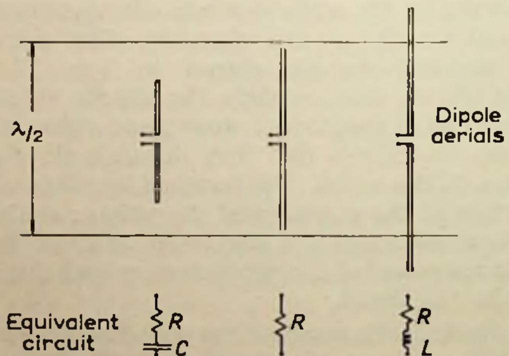


Fig. 18. *Equivalent circuit of a dipole aerial*

Consider now a dipole that is shorter than the resonant length. It will look capacitative and will have a resistive component less than the value at resonance. It will therefore be equivalent to a resistance in series with a condenser, or, as an admittance, as a resistance and condenser in parallel. The other case, a dipole longer than the resonant length, will have the resistive component of the impedance greater than the value at resonance, with the reactive component that of an inductance. These are illustrated in Fig. 18. The quantities

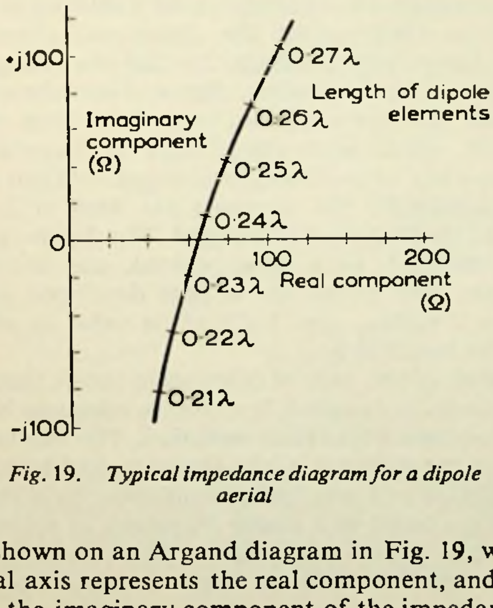


Fig. 19. *Typical impedance diagram for a dipole aerial*

are also shown on an Argand diagram in Fig. 19, where the horizontal axis represents the real component, and the vertical axis the imaginary component of the impedance. The impedance can be shown as a function of the length of the element, and it can be seen that at one particular length the curve crosses the axis. This corresponds to a resistive value for the impedance and hence resonance. This method of representing the impedance of an aerial is useful when illustrating the properties of broadband aerials, and will be shown again covering a wider range of frequencies in a later chapter. The length of a dipole for resonance when a normal type of insulator is used is approximately 95 per cent of the quarter wavelength.

BANDWIDTH OF A HALF-WAVE DIPOLE

One important characteristic of an aerial is its bandwidth, in other words the frequency range that it will accept. In a multi-element aerial both the directional characteristics and the impedance will change as the frequency is changed, but with a dipole aerial the directional characteristics remain substantially constant, so that the change in the impedance is the controlling factor. Now the change of impedance with frequency can be derived from the curve in Fig. 19, which gives the change of impedance at a fixed frequency as its length is changed. When considering the bandwidth the elements are kept at a constant length and the frequency is changed. The dipole is assumed to be connected to a resistive load, and the range of frequencies over which the voltage developed across the resistance if within, say, 3 dB of its value at resonance, defines the bandwidth.

The result of this type of calculation shows that however a dipole aerial is designed, it will have adequate bandwidth for single-channel television reception. The bandwidth will depend on the diameter of the elements, and both theoretical calculation and practical measurement have shown that for elements tuned to a centre frequency of approximately 45 Mc/sec, it will be 7 Mc/sec for $\frac{1}{2}$-in. diameter elements, and 4 Mc/sec if the element diameter is reduced by using 30 gauge wire.

DIRECTIONAL CHARACTERISTICS OF A HALF-WAVE DIPOLE

It is possible to calculate the directional characteristics of a dipole, assuming the sinusoidal distribution of current shown in Fig. 17. The aerial is symmetrical about its axis, so that for a vertically mounted dipole its horizontal polar diagram will be a circle. In the plane containing the elements the polar diagram will be given by the expression

$$\frac{\cos(\pi/2 \cos\theta)}{\sin\theta}$$

This is a figure of eight, and is shown in Fig. 20. Also in this figure is the polar diagram of the Hertzian dipole aerial. This is a theoretical aerial, which has a polar diagram given by $\sin\theta$.

These curves are very close to the measured curves, although in practice it is very difficult to obtain accurate polar diagrams of aerials. The polar diagram of the Hertzian dipole is similar to that of a short wire aerial or a small

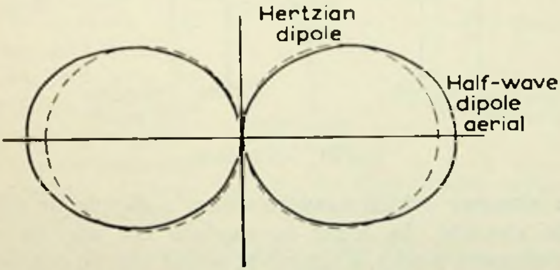


Fig. 20. Polar diagram of dipole aerials

loop. It represents, therefore, the theoretical directional pattern of receiving aerials used for broadcast reception, although it has already been seen that, because of the low frequencies involved, this curve is never borne out in practice.

PARASITIC ELEMENTS

It has already been seen that the directional properties of aerials are often important in the reception of television signals for the removal of interference and ghost signals. It has also been seen that a vertical dipole has a uniform response in the horizontal plane when used with vertically polarized signals. The performance of such an aerial can be very greatly improved by the addition of one or more parasitic elements, in the form of directors or reflectors. Some of the properties of these elements will therefore be considered in more detail.

A parasitic element is usually in the form of a straight rod, held mechanically at the centre, and has electrical continuity throughout its length. It is cut to such a length that it is near to electrical resonance at the frequency of operation. Currents are induced in it by placing it near to

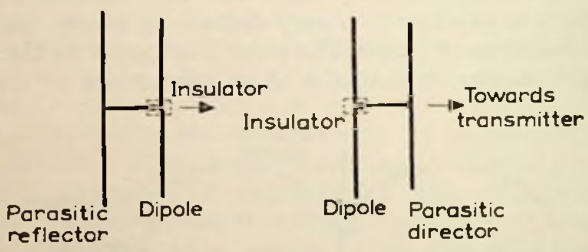


Fig. 21. H *aerials*

another element, which may be either a dipole or another parasitic element. In order to explain the way in which such an element works, a simple H aerial will be considered, i.e. a dipole with one parasitic rod only. With this arrangement it is possible for the aerial to have maximum sensitivity in the direction of the dipole, in which case the parasitic element is a reflector ; while if the maximum is in the direction of the parasitic element, it is then called a director (Fig. 21). These two arrangements have different properties, but as they are both based on the same principle, they will be considered together.

The current flowing in a parasitic element, and the voltage at any point along its length is shown in Fig. 22. It will be seen that these are very similar to the corresponding curves for the dipole element given in Fig. 17, with the exception that the voltage at the centre is zero, i.e. it has not the finite value that is necessary if it is to be connected to a transmission line.

If it is assumed that a generator is connected to the terminals of the dipole element in an H aerial, then the current and voltage distributions in the dipole element will be substantially the same as in the case of the dipole itself. These will produce an electric field in the vicinity of the parasitic element, which in turn will cause electric currents to flow in it. The current in the parasite will radiate in the same way as that in a dipole. The directional properties of the aerial as a whole will be dependent on the radiation from both these elements, and will be changed both by the relative amplitude of the two currents, and by their phase difference. It will also be a function of the mechanical spacing between the two sources of radiation. Consequently there are three variables : the spacing between the elements, the relative magnitude of the currents and their relative phase. These three quantities are interdependent, but they will be considered separately for the sake of simplicity.

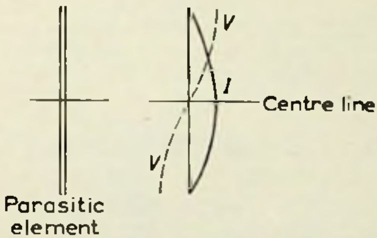


Fig. 22. Current and voltage distribution in a parasitic element

To consider the effect of the separation between the dipole and parasite on the directional pattern, the magnitude of the two currents will be assumed to be equal, while the phase between them will be made to correspond to the physical spacing. The directional patterns produced by this arrangement are illustrated in Fig. 23, where the changes in the pattern produced by a progressive increase of the spacing can be seen. It will be noted that there is always a maximum in line with the elements, and that the number of minima increase as the spacing is increased. In practice, with this

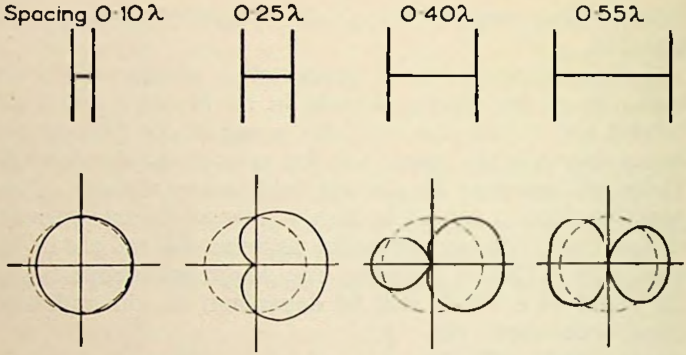


Fig. 23. Directional patterns of two-element aerials. (The currents in the two elements are assumed to be equal, and the phase is chosen for maximum amplitude in the forward direction.) Dipole performance shown dotted

type of aerial the spacing never exceeds a quarter of a wavelength. The magnitude of these curves indicate the gain that it is possible to achieve with this arrangement, and it can be seen that this is also a function of the spacing. In this special case it will also be noted that the minima correspond to a zero signal level, but this can only occur when the two currents are exactly equal.

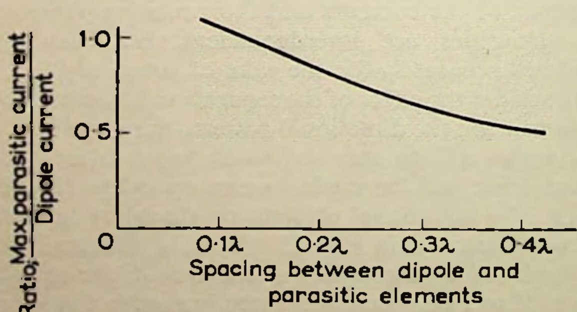


Fig. 24. Example of maximum current in a parasitic element compared with the current in the associated dipole

The relative amplitude of the currents in the dipole and parasitic elements is important when the depth of the minima are considered, and it is their depth that usually determines the quality of the polar diagram. In the direction of a minimum the radiation from the two elements are in opposite phase, so that complete cancellation of the radiation is only possible if the two amplitudes are equal. The magnitude of the radiation from a parasitic element is a function of its length, and also of the spacing. Fig. 24 shows the maximum current that it is possible to have in a parasitic element as a function of its spacing, and

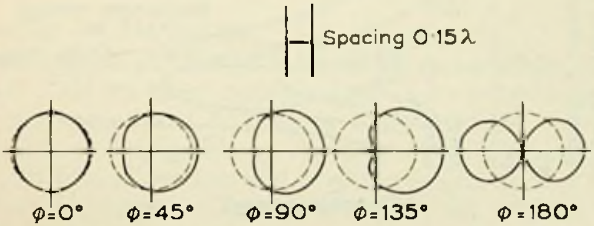


Fig. 25. Directional patterns of two-element aerials. (The currents in the two elements are assumed to be equal, and the relative phase between them is given by the angle φ)

from this it can be seen that for spacings greater than about a quarter of a wavelength the magnitude falls off considerably. In practice the quarter-wave spacing is the maximum for satisfactory directional properties.

The phase of the radiation from the parasitic element is closely related to its length. The element in fact behaves as a tuned circuit. It will resonate at a frequency that is controlled by its length, so that small changes in the length will vary the tuning of the element. As in a tuned circuit, this not only varies the amplitude but also the phase of the current. This phase will control the direction of the minima, and is illustrated in Fig. 25. In this the spacing between the dipole and parasite has been kept constant, and the currents in the two elements are assumed to have equal amplitudes.

The addition of a director or reflector element to a dipole will make other changes apart from the directional effects. The forward gain of the aerial can be increased. The impedance at the centre of the dipole will also be changed and, although no general rule can be made about this, it is usually assumed that it will be reduced to below 75 Ω.

The various factors that have been discussed can be illustrated by the curves in Fig. 26. In these the amplitude of the current in the parasite is shown as a function

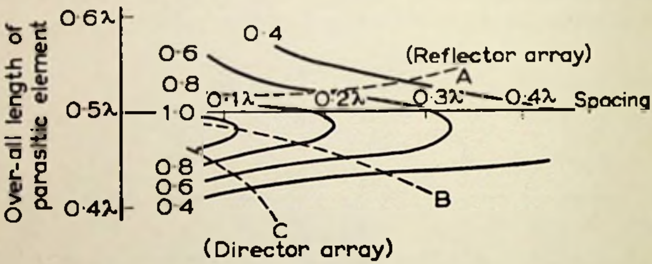


Fig. 26. Graphs showing the approximate current in a single parasitic element, as a function of its length and spacing from the dipole element

—— *Figures denote ratio* $\frac{\textit{Current in parasite}}{\textit{Current in dipole}}$

– – – *A = minimum response at back (reflector array)*

– – – *B = limiting curve between a director and reflector array*

– – – *C = minimum response at back (director array)*

of the length of the parasitic element and its spacing from the dipole. The length and spacing for a director and reflector array are also shown. These curves are based on certain theoretical assumptions, so they will not necessarily predict the exact behaviour of this type of aerial. One way in which they can be in error is that they do not allow for scattering by the supporting mast, and this can have a serious effect with vertical polarization. They do give a reasonable picture of the method of operation of aerials with one parasitic element.

It has been seen that the addition of a parasitic element to a single dipole will change the impedance at its terminals, the amount of which will depend both on the separation between the two elements, and also on the length of the parasite. Now both these factors will be a function of the frequency at which the aerial is used, so that they will both influence the over-all bandwidth of the aerial. As a general rule the bandwidth of a two-element aerial will be less than that of the dipole on its own, but an actual value for this will depend on so many factors that it can only be given for individual aerials.

EXAMPLES OF H AERIALS

The over-all performance of an H aerial can only be judged if all the characteristics such as its polar diagram, gain impedance and bandwidth are considered together. It would be impossible to do this for all the possible combinations of spacing and parasitic length, so that three important examples will be taken. These are reflector type aerials with spacings of one quarter and one seventh of a wavelength, and a director type aerial with a spacing of one tenth of a wavelength.

The first of these, the reflector aerial with a spacing of a quarter of a wavelength between the dipole and the reflector, has very good properties. One example of such an aerial has directional properties as shown in Fig. 27, a gain of about 4½ dB relative to a half-wave dipole, and impedance properties such that it presents quite a good match to 75 Ω feeder. It has a wide bandwidth compared with other parasitic aerials; with a resistive load of 75 Ω the half-power points will be approximately 5 per cent either side of the operating frequency. This means that for an aerial designed for use at 45 Mc/sec it will have a bandwidth of about 5 Mc/sec.

The H aerial with a spacing of approximately one seventh of a wavelength has many advantages for television reception. It can have good directional properties, and sufficient bandwidth, but its gain will be slightly less than an aerial with a quarter wavelength spacing. The importance of this particular spacing is that it is the shortest cross-arm that is practical for an H aerial, because if it is reduced beyond this the electrical characteristics deteriorate and there is also a risk of 'picture flutter' caused by the relative movement of the dipole and the reflector elements in a wind. It is possible to have a wide variety of directional characteristics with this spacing by a choice of the length of the reflector. One example is given in Fig. 28, and this aerial has a forward gain of about $3\frac{1}{2}$ dB relative to a half-wave dipole.

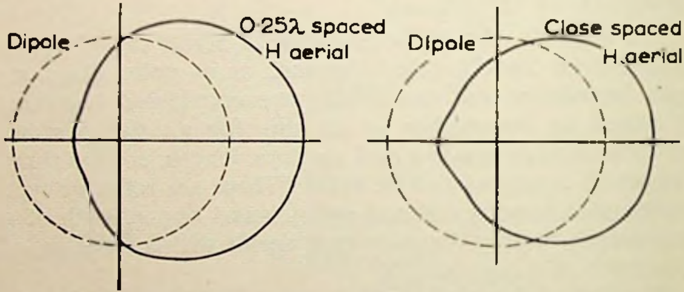


Fig. 27. Polar diagram of a 0·25λ spaced H *aerial (parasitic reflector element)*

Fig. 28. Polar diagram of a close spaced H *aerial (parasitic reflector element)*

The third example, a director aerial with a spacing of one tenth wavelength, is of interest as it is the only configuration in which it is theoretically possible to obtain an infinite front-to-back ratio using one parasitic element only. In practice this is not a very useful arrangement owing to limitations in impedance and bandwidth.

FOLDED DIPOLE

One variation of a parasitic aerial is the folded dipole. In this the parasitic element is very close to the driven element, and in fact is usually connected to it at the outer ends. The spacing is so close that the directional characteristic of this arrangement is practically identical to that of a dipole on its own. It differs from a dipole in two ways : (i) the impedance is increased, which often makes matching easier, and (ii) the effective bandwidth is increased. These two advantages will be discussed separately in more detail.

If a folded dipole is constructed by the method described by its name, i.e. by folding one rod, so that the diameters of the driven and parasitic elements are equal, then its

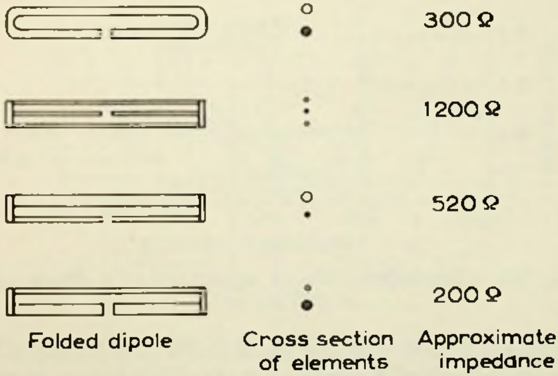


Fig. 29. Examples of 'folded' dipole configurations

impedance at resonance will be four times that of a dipole on its own. It will therefore be increased from about 75 Ω to about 300 Ω. The factor four is derived from the fact that equal and in-phase currents will flow in the two elements. If, however, the currents are not equal, there will be a different multiplying factor. It is possible to construct a folded dipole to match into a range of impedances by a suitable choice of the relative diameters of the two rods, or by having one driven rod and a number of parasitic rods. Some examples of the cross-sections of various folded dipoles are given in Fig. 29, together with the impedance that is obtained in each case. It can be seen that it is possible to match a folded dipole into any load between about 200 and 1,000 Ω. This transformation also takes place if a folded dipole replaces an ordinary dipole in a more complicated array. As an example, an aerial with one reflector and several directors might have an impedance as low as 15 Ω if driven by a dipole, but which could be brought up to 75 Ω by the use of a suitable folded dipole. The use of a folded dipole in this case will not change the directional characteristics of the aerial in any way.

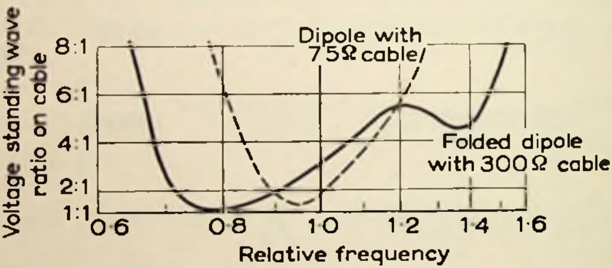


Fig. 30. *Comparison between impedance of a dipole and a folded dipole*

It is often stated that the bandwidth of a folded dipole is greater than that of a simple dipole. This is not necessarily the case, especially if it is part of a more complicated array. On its own, however, especially if it is used with a load having the optimum impedance, it can have a greater bandwidth. This is illustrated in Fig. 30, where the impedance of the folded dipole is shown as a function of the frequency. It is evident that if it is used with a load of 300 Ω there will be a match better than 2 : 1 for a range of frequencies ±10 per cent either side of the mean frequency. The corresponding range for a dipole with its optimum load would only be ±7 per cent.

AERIALS WITH MORE THAN ONE PARASITIC ELEMENT

It is possible to add more than one parasitic element to a dipole in order to improve its directional characteristics.

One such arrangement is the three-element array consisting of a dipole or folded dipole with a reflector and a director element. There is a wide variety of the lengths of the elements and the spacing between them that will give satisfactory performance, but the dimensions given in Fig. 31 represent an aerial with very useful characteristics. The most important of these is its directional characteristics, as its horizontal polar diagram has a broad minimum in the backward direction, together with a front-to-back ratio greater than

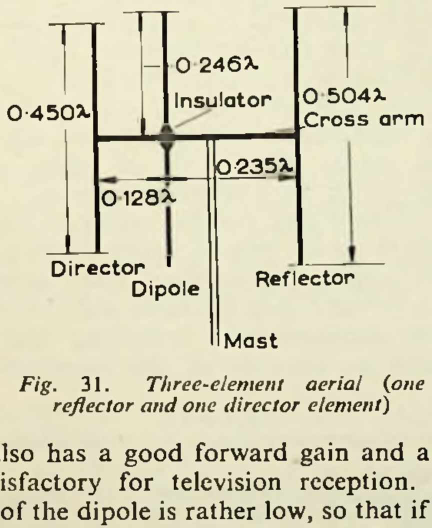


Fig. 31. *Three-element aerial (one reflector and one director element)*

30 dB. It also has a good forward gain and a bandwidth that is satisfactory for television reception. The centre impedance of the dipole is rather low, so that if it has to be used with 75 Ω feeder, then either the dipole has to be folded or else a suitable matching transformer has to be included between the dipole and the 75 Ω feeder.

Although it is relatively simple to construct a theoretical picture to describe the performance of a dipole with one parasitic element only, this would be very difficult with more elements. Most of the facts that are given are therefore based on practical measurements on aerials, backed up wherever possible by calculation.

It is possible to get a performance that is better than that of the three-element aerial by the addition of further parasitic director elements. This type of aerial, known as a Yagi array, has many practical applications. It is the simplest method of constructing a high-gain aerial, as most of the elements only have to be held in the correct position, and there is only one element, that of the dipole, to which the feeder is connected.

It is interesting to note that it is possible to add on as many directors as the mechanical construction will allow, and by doing so there will be a progressive increase in the forward gain. With reflector elements, however, there is usually no advantage in having more than one, unless they are arranged in some form of reflecting screen behind the dipole. This arrangement is relatively rare, and in practice most arrays consist of a dipole or folded dipole, one reflector and one or more director elements.

Both the forward gain and the width of the main lobe will be functions of the over-all length of the aerial. There is no exact relationship between these quantities, but generally the forward gain increases and the width of the forward lobe decreases with increasing over-all length. Table 3 gives an example of the magnitude of these quantities.

Table 3

Total number of elements (including dipole and reflector)	*Forward gain (relative to half-wave dipole)*	*Beam width (3 dB points)*
3	5 dB	106 degrees
6	7 dB	74 degrees
9	9 dB	48 degrees

The bandwidth of the aerial will decrease as more director elements are added, and this will often be a limiting factor in determining its over-all size. A slight change in the bandwidth can be made by suitable design of the dipole element, but this is usually small, as the parasitic elements themselves have much greater control over it.

The over-all length of the reflector element is usually slightly longer than the dipole, while the director elements are shorter, and in some designs the length of the director elements get progressively shorter towards the front of the array. The reason for this can be seen if it is assumed that the Yagi array is radiating a signal. In this case the current in the dipole radiates and also induces current to flow in the first director. This in turn radiates, and induces currents in the next director, and the process is repeated down the aerial. The length of the directors and their spacing are chosen for the radiation to add up in the forward direction. Each parasitic element is loaded by the two elements on either side of it, with the exception of the end element. For this to radiate a signal that will enhance that from the rest of the array, it has to be made slightly shorter than the other elements. The reflector element does not contribute significantly to the forward gain of the aerial, its main function being that of reducing the response in the backward direction.

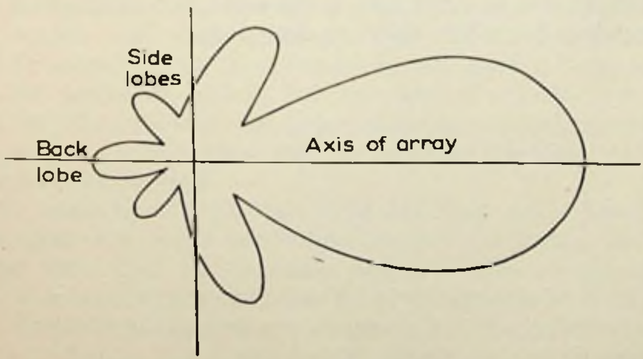


Fig. 32. Polar diagram of a long Yagi type aerial (nine-element aerial for use in band III)

A typical polar diagram of a very long Yagi aerial is shown in Fig. 32. It will be noticed that there are a number of side lobes, and also a lobe in the backward direction. It is impossible to remove these subsidiary lobes with this type of aerial, and they might be a disadvantage in some applications. For many cases, however, especially when the forward gain is the most important factor, the existence of these irregularities in the polar diagram is of no importance.

SUMMARY

The electrical characteristics of a half-wave dipole element and also a half-wave parasitic rod have been discussed. These are both very important as they are the basic parts of Yagi type aerials, and they constitute a very large proportion of the aerials at present used for the reception of television and UHF broadcasting.

Up to now all the aerials have been discussed generally, and no reference has been made to their frequency of operation. As an example the three-element aerial shown in Fig. 31 can be made to operate either in band I or in band III. The dimensions in the two cases will obviously be different, but the electrical performance, such as the gain and polar diagram, will be substantially the same, independent of the frequency for which they are designed.

6

Aerials for Single-Channel Reception

Dipole aerial – Simple directional aerials – Three-element aerial – More complicated single-channel aerials – Summary

IT has been seen that there are a number of electrical properties that can be associated with television receiving aerials, such as their gain, directional properties, impedance and bandwidth. The conditions under which an aerial is used will determine the relative importance of these factors, so that as each aerial is being discussed, its uses and its electrical performance will be given at the same time. There are other factors associated with the system adopted in any particular area, these being the polarization of the signal and the impedance of the cable used in the installation. The polarization is usually either vertical or horizontal, and the cable is either 75 Ω coaxial or 300 Ω balanced. All these factors have a marked influence on the design of aerials, but for most of this chapter it will be assumed that the polarization is vertical, so that in general the elements will be vertical, and that 75 Ω coaxial cable is used.

The majority of the aerials to be described will be for the reception of a single television channel, which may be in either band I or III. In many instances such aerials will also give satisfactory reception on other frequencies outside the range for which they are designed, but this is incidental to their design. The discussion of aerials that are intended for multichannel or broadband reception will be made in a later chapter.

DIPOLE AERIAL

The basic aerial for single-channel operation is the single dipole. This can be mounted horizontally or vertically, depending on the polarization of the signal, see Fig. 33. In the horizontal case there is no difficulty in supporting the aerial, but when it is vertical the mast has to be cranked so that it can be kept well clear of the lower element. The length of the elements is usually about 95 per cent of a quarter wavelength, and this arrangement gives a very satisfactory match to 75 Ω feeder. The bandwidth is more

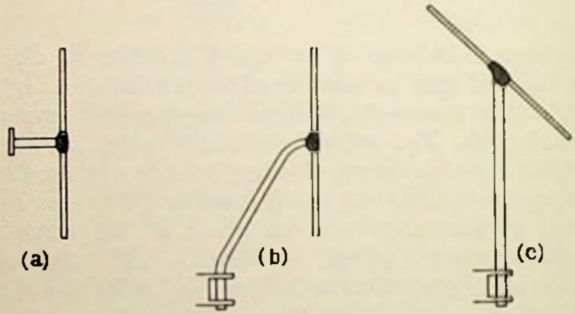


Fig. 33. *Dipole aerials*
(*a*) *Vertical polarization, wall mounted*
(*b*) *Vertical polarization, chimney mounted*
(*c*) *Horizontal polarization, chimney mounted*

than sufficient for single-channel operation even at the lowest frequencies that are employed.

It has already been seen that the theoretical directional properties of this aerial in the horizontal direction are a circle for vertical polarization, and a figure of eight when the dipole is horizontal and illuminated with a horizontally polarized signal. In practice these are generally near to the experimental curves, except in the case of a vertical dipole, where the presence of the mast can have a marked influence on the response.

The dipole aerial can be used where there is a reasonably strong signal, in areas where there are no ghost signals or signals that might cause interference. This applies particularly to ignition interference, so that it should not be used near to main roads unless the strength of the television signal is sufficient to swamp the interference. It is a useful aerial in country areas where the advantages to be gained from a more directional aerial are not required. It is interesting to note that dipoles are used only on bands I and II, and are rarely seen for band III reception. The reason for this is that ghosting with a dipole would be more serious on band III compared with the lower frequencies, and also that the cost of such an aerial would be out of proportion with the cost of the mast and lashing, etc., needed to support it.

SIMPLE DIRECTIONAL AERIALS

The simplest, and the most common aerial that has directional properties is the dipole with one parasitic element, such as the H type aerial as shown in Fig. 34. In this the length of the dipole element is approximately 95 per cent of the quarter wavelength. The parasitic element is usually a reflector spaced one eighth to one quarter wavelength behind the dipole, and as it is a reflector it has a length slightly longer

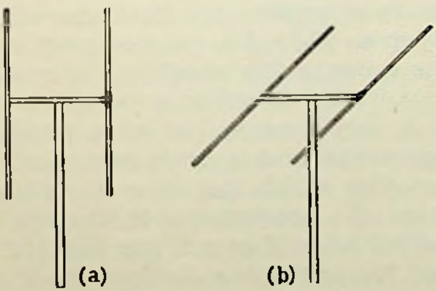


Fig. 34. H *aerials*
(*a*) *Vertical polarization*
(*b*) *Horizontal polarization*

than that of the dipole. The bandwidth of this arrangement is sufficient for single-channel operation, and it can be used with 75 Ω feeder. The directional properties of this type of aerial have already been discussed in Chapter 5. The curves given refer to aerials for vertical polarization, but the patterns are similar for horizontal polarization, except that they then have additional minima at the sides and, of course, when used for receiving a horizontally polarized signal the elements are parallel with the ground. The aerial has a gain above that of a dipole, but the exact magnitude of this will depend on its design.

This type of aerial can be used in areas where an otherwise good signal is marred by ghost or interference signals. It can also be used where there is a fairly low field strength, when it will give an improved signal compared with that from a single dipole. The first of these applications makes use of the directional characteristic of the aerial. It should be oriented for the minimum response in the direction of the unwanted signal, but in cases where this would also involve a loss of the main signal, a compromise must be found in the direction for it to point. A second application of these aerials depends on their forward gain. This is important as it increases the signal compared with the background noise signal generated in the first stage of the receiver. This is quite distinct from ignition or other forms of interference which show up as white dots on the screen, as the background noise causes a fine 'roughness' over the whole of the picture. It is also described as 'snow'. None of these descriptions is very accurate, but it is a phenomenon that is very characteristic and is easily recognized.

There are other aerials that have a performance very similar to that of a conventional H, the two most usual having the shape of an X or a K (see Fig. 35). The X will be considered first as this is a development of the basic H aerial, in which the length of the cross arm has been reduced to zero. The elements are then fixed at one point, two of them are connected to a transmission line and form the driven element, while the other two elements form the parasitic element. As the effective spacing between the 'dipole' and the parasitic elements is quite small, full use can be made of the properties of a closely spaced director aerial. The parasitic elements in an X usually form a director element and are therefore shorter than the dipole. They are pointed towards the transmitter.

Its characteristics are very similar to the H type aerial that has already been described, except that it usually has less forward gain. Despite this its applications are basically the same as those for the H. It is interesting that there are

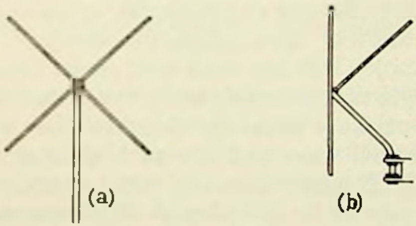


Fig. 35. Simple directional aerials
(a) X *aerial*
(b) K *aerial*

some instances where an X and an H with very similar directional properties can have marked differences in their ghost rejection abilities. There are places where ghosts can be removed with an H and not by an X, and vice versa. This is because an aerial with elements that are not vertical will have a certain response to horizontally polarized signals. If the ghost has components that are horizontal, and it is quite likely that this will be so, then these can enter the aerial. It is also quite possible for this type of ghost signal to mix with and cancel out a vertically polarized ghost, resulting in a clearer picture. It can also operate the other way round, in that the horizontally polarized ghost signal will show, whereas with an H type aerial it would not be seen. On the average it has been estimated that the ghost-removing properties of an H and an X are about equal.

The K aerial differs from those that have been described so far in that the pole supporting the aerial is an active element. It is found that it is better to support it by a 'driven' element, and not by one that is parasitic. In a K aerial, therefore, the aerial is held by an insulated sleeve at the bottom of one of the sloping elements, the other sloping element being connected to the transmission line. The two vertical elements form a parasitic element, and again this is made a director element. The performance is very similar to those that have already been described, and it therefore has applications for use under similar conditions.

There is another type of dipole element, the end-fed half-wave dipole. This has been used on its own in the same way as a single dipole aerial, but its most usual application is with one or more parasitic elements. The impedance at the end of a half-wave rod is very high, and if it is to be used with 75 Ω coaxial cable, then a special matching transformer has to be introduced. It is convenient to support an aerial of this type by the dipole element itself, and to have the matching transformer in the supporting pole, but it can be held by a separate pole if necessary. Such a dipole with one parasitic element is similar to the H type aerial that has already been described, and its electrical characteristics will be very similar.

THREE-ELEMENT AERIAL

The next type of aerial in order of complexity is one with one director and one reflector element illustrated in Fig. 36. Such an aerial can have very good directional properties. It is of interest as it represents a fairly ambitious aerial for band I and also the simplest outdoor aerial for band III.

It has already been seen that the impedance at the centre of the driven element is usually quite low, and some form of transformer must be introduced. On band I, a very convenient form of transformer consists of a quarter wavelength

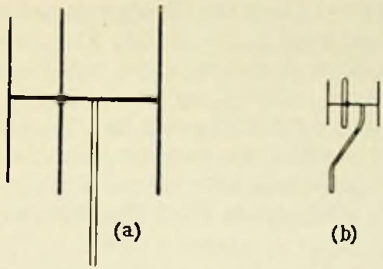


Fig. 36. Three-element aerials
(a) For band I reception, with a straight dipole
(b) For band III reception, with a folded dipole

of 50 Ω cable connected between the terminals of the dipole and the feeder to the receiver. Now, if an impedance of Z_L is at the end of a quarter wavelength of feeder having a characteristic impedance of Z_0, the impedance at the other end of this feeder is given by :

$$\frac{Z_0^2}{Z_L}$$

Substituting 50 Ω for Z_0, then the impedance of the main cable, i.e. 75 Ω, will be transformed to a value of 33 Ω, and this is the value of the load across the terminals of the dipole. This will usually be nearer to the impedance of the aerial than that of the cable by itself. The other transformation technique which is more economical in band III where the frequency is higher, is to utilize a folded instead of a single dipole. This will usually transform the impedance of the aerial by a factor of 4, in other words an impedance of 19 Ω can then be matched into 75 Ω cable.

There are numerous other methods of making a connection between the cable and the dipole element of a multi-element aerial in such a way that a suitable impedance transformation is made, the most important of these being the 'Delta' match. In this the dipole element is continuous, i.e. it has no insulator at the centre. The connection to the feeder is made through two bars to a point on the elements, forming the Greek letter Δ, as shown in Fig. 37. A small range of impedance matching can be obtained by selecting the exact point at which the bars are joined to the elements.

It is possible to have a wide range of designs for a three-element aerial, quite apart from the different methods of

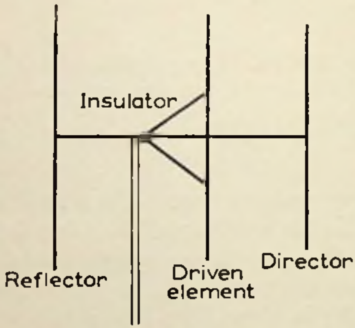


Fig. 37. A three-element aerial with a delta match on the dipole element

feeding the 'dipole' element, as both the lengths of the parasites and their spacing from the dipole can be varied. Each arrangement, however, will have a particular electrical characteristic. A typical directional pattern is shown in Fig. 38, and in this case the aerial will have a forward gain of approximately 5½ dB relative to a half-wave dipole. It is possible to increase the value of the forward gain above this, but only if a deterioration in the directional characteristics can be tolerated. An aerial with this performance can be made to work either in band I or in band III, and the applications in the two cases are quite different.

In band I its use is reserved for areas of low field strength or for installations where a clean signal with very little interference is required. This aerial is quite a large structure, especially when used on British channel 1, when the length of the boom is about 8 ft. It is possible to have Yagi type aerials for these frequencies with more than three elements, but for most purposes it is one of the largest types of television receiving aerials. On band III, however, it is one of the smallest outdoor arrays that it is economical to make. Even though it is much smaller than its band I counterpart, it will have similar electrical properties. Its application is in areas of moderate field strength or in places where there are ghost signals, conditions which on band I are usually satisfied with an H type aerial. This does not mean that in

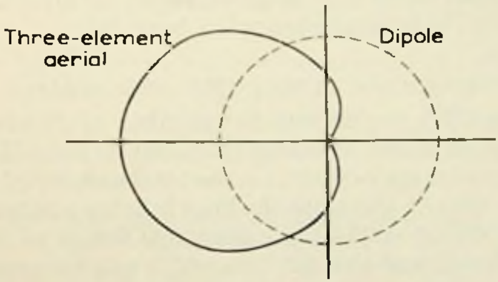


Fig. 38. Polar diagram of a three-element aerial

places where an H type aerial is used on band I, a three-element aerial will necessarily be satisfactory on band III, as the propagation conditions on the two bands will be different.

It is interesting to consider the bandwidth of the three-element aerial in both the bands. With this type of aerial the bandwidth will be limited by the resonance of the director and reflector elements, and not by the bandwidth of the element connected to the transmission line. As the frequency is changed, the directional characteristics will change, with a corresponding change in the forward gain. For the normal type of three-element aerial used for television reception, this change in the gain with frequency will be more important than changes in the impedance of the feed-point, and this applies for the aerial either with a dipole and matching transformer or when a folded dipole is used. On band I the useful bandwidth will be about 4 Mc/sec, while on band III it will have increased to about 15 Mc/sec, because of the increase of frequency. This means that on the lower band a given aerial will only cover one channel, while on the higher band, in the British system, it will cover three channels. These figures are for an average three-element aerial, although aerials of this type have been constructed to cover a greater range of frequencies than this. There are, however, other applications where special characteristics are required, when it is often necessary to limit the bandwidth to an individual channel in band III.

MORE COMPLICATED SINGLE-CHANNEL AERIALS

It is possible to increase the number of directors on a Yagi type aerial for television reception on band III up to a maximum of seven or eight, i.e. the total number of elements is nine or ten. At this stage the limit is being reached, as any further increase makes the mechanical design of the aerial more difficult, and also the bandwidth will become limited.

As an example of the performance of these larger aerials, the directional characteristics of a six-element Yagi is shown in Fig. 39, and this has a forward gain, compared

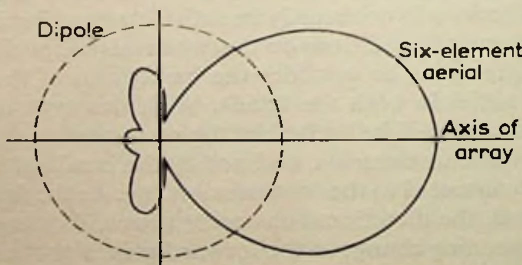


Fig. 39. Polar diagram of a six-element Yagi array (one reflector, folded dipole and four director elements)

with a half-wave dipole, of approximately 7 dB. As a general rule the forward gain will increase and the width of the forward lobe will decrease with the addition of each director. As Yagi type aerials have good directional properties they can be used both for the rejection of ghost and interference signals, and also in areas of poor signal strength.

Only one more type of single-channel aerial will be discussed and that is the broadside array consisting of two

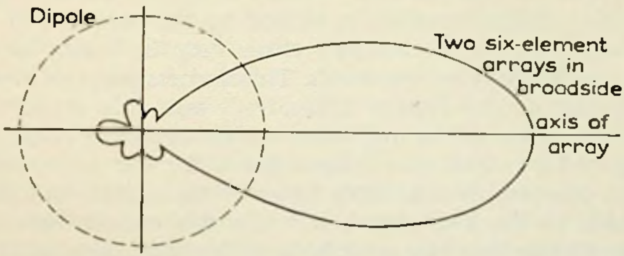


Fig. 40. Polar diagram of a broadside array consisting of two six-element aerials

Yagi aerials placed side by side. There are three advantages in doing this : the forward gain is increased, the polar diagram is improved, and it is possible to make the impedance matching of the array more precise. A normal Yagi aerial will usually contain several lobes in its polar diagram, but when two such aerials are placed side by side it is possible to choose the spacing in such a way that some of these lobes are cancelled out. This can be seen by comparing Figs. 39 and 40, the latter being the polar diagram of two six-element aerials spaced apart by a distance of 0·7 wavelength. It is not possible to calculate exactly the directional characteristics of such an array from that of the individual aerials, as the individual patterns will be modified by the proximity of the other aerial. It is interesting to note that this improvement in the horizontal polar diagram can only be achieved if the aerials are placed side by side. If they are stacked one above the other, and this is a more convenient arrangement with horizontally-polarized aerials, the horizontal polar diagram will be unaltered, but the vertical pattern will be improved. Vertical stacking is usually only employed as a means of getting more signal by virtue of the increase in the gain.

The gain of the over-all array will be approximately 3 dB above that of the individual aerials, but no exact figure can be given for this for two reasons. First, the forward gain of the individual aerials is altered by the presence of the second aerial, and secondly there may be losses in the harness linking the two aerials. This harness plays an important part in this type of array, as it not only transforms the impedance of the individual aerials to such a value that they will combine to a value suitable for the cable, but it must also ensure that both sides of the aerial contribute equally to the final signal. It is for this reason that rigid transmission lines are preferable to flexible cables, as these can be cut accurately to the correct length. They can also be chosen to have a wide range of impedance values and they will introduce very little loss into the system.

SUMMARY

It has been shown that there are a wide variety of single-channel aerials, ranging from a single dipole to a broadside Yagi array. Each type has its own particular application, although there is only a gradual change between one aerial in the range and the next one. Further comments will be made on the choice of an aerial in a later chapter, where it will be shown that the electrical characteristics should play an important part in the final choice.

As a general rule it can be stated that the performance of an aerial will get better as its over-all size is increased, but parallel with this there is an inevitable increase in cost and in the unsightliness of the aerial at roof level.

7

Combined aerials

Factors in design – V aerials – Two-dipole aerials – Combined aerials with one dipole element only – Summary

IN many countries, particularly Great Britain, North America and Australia, there are certain areas served by more than one television transmission. It is possible of course to have separate aerials for each transmission, but this is often cumbersome and a more practical solution is to have a single aerial capable of receiving all the signals. This will then operate with a single feeder between it and the receiver. These combined aerials, as they are called, can be made in a wide variety of forms, and it would be quite impossible to describe all the different types that are available. Only the more important will therefore be discussed, the selection being made in such a way that the various principles of operation can be explained.

There are limitations in the use of this type of aerial. Basically, their use should be confined to areas where the signal strengths on the various channels are of similar magnitude, and with some aerials, for the signals to arrive from the same direction. This necessitates the use of co-sited transmitters, i.e. transmitters that either use the same mast for their radiators, or which are relatively close together. It is possible, however, in certain cases to use combined aerials when the transmitters are not co-sited, especially if a rotating device is fitted to the aerial. On the other hand there are areas served by co-sited transmitters where combined aerials do not give satisfactory results. This is likely to occur both on the fringe of the service area and in places where there are serious ghost problems, and under these circumstances it is better to resort to individual aerials for the different channels.

FACTORS IN THE DESIGN OF COMBINED AERIALS

There are three important factors which govern the design of combined aerials and which are responsible for the apparent differences between those used in Great Britain and in the U.S.A. These factors are the polarization, the choice of feeder that is to be used between it and the receiver, and the frequency range to be covered.

The majority of the transmitters in Great Britain use vertical polarization, while in the U.S.A. horizontal polarization is used. Dipole and parasitic elements in the former case are vertical, while in the other case they are horizontal. The electrical design of the two types is basically the same, but this change in polarization makes a pronounced difference in the appearance of the aerials. In both cases the polarization of the various channels are the same. If this were not so, for example if the band I signal were vertically polarized and the band III horizontally polarized, then a completely different range of combined aerials would be required. In the present development of television this combination has not arisen, so that all combined aerials that will be discussed are for the reception of several channels having a common polarization. The exception to this is when it is required to receive FM on band II, which is horizontally polarized, on the same aerial as television when this is vertically polarized. This combination can be resolved by the use of a 'two-dipole' type of aerial, which will be discussed later.

The second factor determining the design of combined aerials is the type of feeder to be used, or more precisely the impedance into which the aerial has to be matched. This can be illustrated by considering the impedance of a fan type dipole, which might have a value of 75 Ω at its first resonance, and rising to a value of about 600 Ω at twice this frequency. This is shown in Fig. 41, which is an Argand diagram giving the impedance of this type of aerial as a function of the frequency. It can be seen that if used with 300 Ω feeder, the mismatch would correspond to a standing wave ratio of less than 3 : 1. This would not be so if 75 Ω feeder were used, as in this case there would be a very good match at the first resonance, and again at three times this frequency, but throughout the remainder of the range there would be a very serious mismatch. If a standing wave ratio of up to 3 : 1 can be tolerated, then it is usually easier to

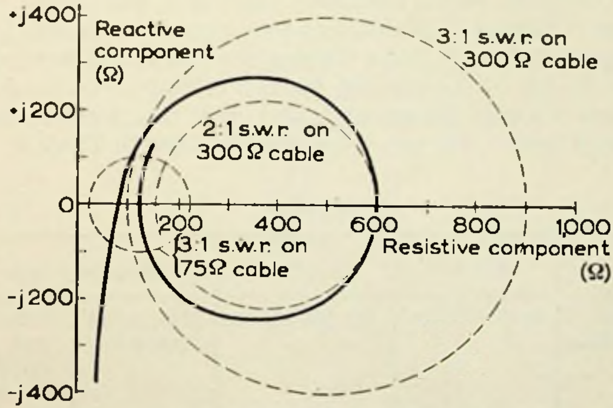


Fig. 41. Example of the impedance of a fan dipole aerial over a wide range of frequencies

design a broadband or combined aerial for 300 Ω than for 75 Ω feeder. Combined aerials are possible with 75 Ω feeder and some of the techniques that have been evolved for these will be described later.

The last factor of importance is the frequency range that the aerial needs to cover. If it is assumed that two channels only have to be covered, one in band I and the other in band III, then the design will depend on whether the ratio between the frequencies of the two channels is 3 or 4. As an example consider a dipole in the form of a V. As will be seen later this shape for a dipole is chosen for its directional properties, but it will have similar impedance properties to a straight dipole, or even the fan dipole described in Fig. 41. If its first resonant frequency when the elements are a quarter wavelength is f, its impedance will be approximately 75 Ω. At a frequency of $2f$ it will have a very high impedance, say 800 Ω, while at $3f$ it will have returned to 75 Ω and at $4f$ it will again be near to 800 Ω. This type of aerial will therefore be very suitable for locations where there are two channels with a frequency ratio of 3, and where 75 Ω cable is employed. If the frequency ratio is 4 the aerial will be quite unsuitable and a different technique will be needed. This is one of the reasons for the difference between the aerials in Great Britain and the U.S.A. The frequencies at present used in the two countries are given in Table 4.

Table 4

	Band I	*Band III*	*Frequency ratio*	
Great Britain	41–68 Mc/sec	185–201 Mc/sec	Min. 2·7 : 1 Max. 4·9 : 1	Both 3 : 1 and 4 : 1 covered in range
U.S.A.	54–88 Mc/sec	174–216 Mc/sec	Min. 2·0 : 1 Max. 4·0 : 1	Mean value 3·0 : 1

It can been seen from this that whereas an aerial designed to cover a 3 : 1 frequency range would probably be suitable in the U.S.A. it would be unsuitable in some areas in Great Britain, in particular in the London area where channels 1 and 9 are used. This was the first requirement for combined aerials in Great Britain and in this case the frequency ratio between the channels is very nearly 4.

V AERIALS

The first specific type that will be discussed is the V aerial, which is found with various modifications depending on the application. This type of aerial has been mentioned above, where it was shown to be most suitable in areas where the ratio of the frequencies in the two bands is approximately 3 : 1. It has been seen that if this is so, then it is possible to obtain a reasonable match to 75 Ω cable in the two bands. This is for a single V, but there is a requirement both for an aerial with a performance better than a single

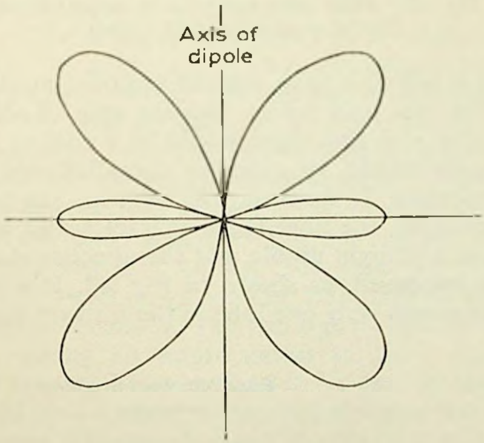


Fig. 42. Theoretical polar diagram for a dipole aerial, having three-quarter wavelength elements

V, and also for this type of aerial to be used with 300 Ω cable without the introduction of a large mismatch.

Why is it necessary to bend the dipole into a V shape? The answer is to be found by considering the directional characteristics of a dipole whose elements are three-quarters of a wavelength. This is shown in Fig. 42, where it can be seen that although it will have a small lobe in the required

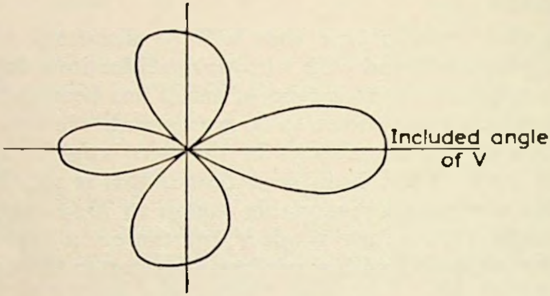


Fig. 43. Polar diagram of a V aerial, having three-quarter wavelength elements

direction it will also have marked response in other directions. This not only means that the gain of the aerial is reduced, but also that there would be a risk, at least with vertical polarization, of excessive aircraft flutter and ignition interference. If, however, the elements are bent into a V configuration, the impedance characteristics are similar to those of a straight dipole, but the directional characteristics are improved, as shown in Fig. 43. It will be seen that there is now only one lobe in the forward direction.

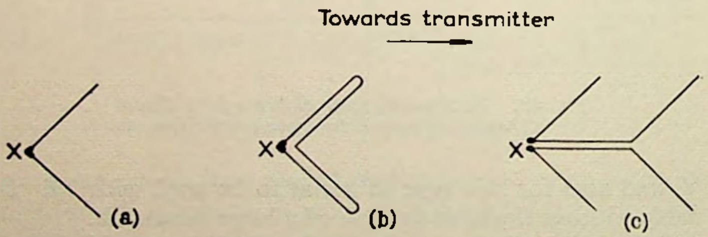


Fig. 44. V aerials

(a) Single V dipole
(b) Folded V dipole
(c) Double V aerial
X indicates the feed-point

This aerial, as shown in Fig. 44 (a), is of simple construction, and is a useful general purpose aerial in areas where there is adequate signal in the two bands. It has poor ghost-rejection properties, but it is inevitable that an aerial designed to cover a wide range of frequencies has inferior characteristics to one designed to operate at one frequency only. If, therefore, there are serious ghost problems in areas where a combined aerial would otherwise be satisfactory, the only solution is two aerials, one operating in each band. Each one can then be chosen to suit the conditions in that band, and they can be oriented separately to give a clean picture on all channels.

If the single V aerial is required to be used on 300 Ω feeder, then the most suitable arrangement is to fold each of the elements (Fig. 44 (b)). This will then present a reasonable match to this type of feeder in both the bands, and will still possess all the other characteristics of the simple V aerial.

The gain and directional characteristics of this type of aerial can be improved by having two of them, one in front of the other, and connected together by an air spaced transmission line (Fig. 44 (c)). The signal received by the front V will travel down the line and arrive in phase with that from the second V. The two signals will therefore add together, giving an improvement in the forward gain. Also the spacing between the two Vs can be chosen such that it will have a better directional characteristic than one V on its own. The impedance of the system is more difficult to establish from a simple picture. The impedances of the two Vs will combine to give a composite value, but the two elements are so close together that the impedance of the individual sections will be changed from their original value. The resulting impedance will depend on the length of the elements, the spacing between them and also on the characteristic impedance of the transmission line joining them. It is in fact possible, by a suitable choice of all these parameters, to make this type of aerial operate with either 75 or 300 Ω feeder. The one with 300 Ω feeder is usually associated with horizontal polarization, and its polar diagram in this case is given in Fig. 45.

One important aspect of this type of aerial is its broad band characteristics. The signals from the two V aerials will arrive in phase at the point where the cable is connected at all frequencies, as the velocity of the signal down the short length of air spaced transmission line joining them will be the same as that of the signal itself in free space. This ensures that the directional characteristics have a maximum in the forward direction throughout the range of frequencies

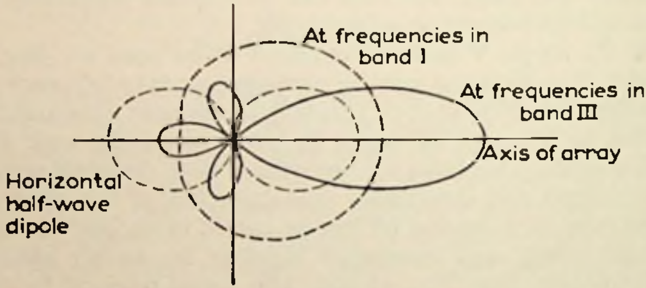


Fig. 45. Polar diagram of a double V aerial at the optimum frequencies in the two bands

for which the aerial is designed. Furthermore, as the two parts of the aerial are connected by a length of transmission line that is either quarter or three-quarter wavelength, it can be shown that the reactive components of the impedance of the two halves will cancel each other out. This gives the aerial satisfactory impedance characteristics over a wide range of frequencies. It is claimed that this type of aerial will give satisfactory performance from 54 to 88 Mc/sec, and also from 174 to 216 Mc/sec. It will in fact cover the majority of these frequency ranges, but the performance will begin to deteriorate at the edge of these bands.

Another type of aerial very popular in the U.S.A. is one that is normally called a 'Conical' aerial. It is based on the idea that a dipole in the form of a cone has a wide frequency response, and this cone is simulated by two or more rods connected together at the centre. It is usually found in one of two forms, as shown in Fig. 46. In one the 'dipole' element consists of three rods each side of the insulator, and the reflector of one rod only. In the other the dipole has two rods each side, and the reflector is made in the same way. In all cases the dipole is bent forward, but not to quite such an acute angle as in the V aerial. It is claimed that this aerial is satisfactory over all of bands I and III, and in fact there are a large number of aerials of this type

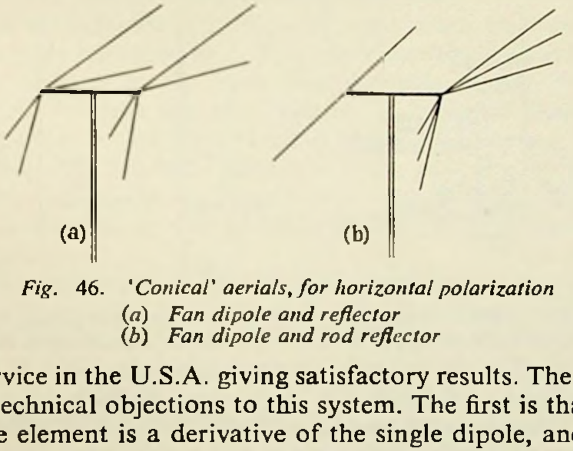


Fig. 46. *'Conical' aerials, for horizontal polarization*
(*a*) *Fan dipole and reflector*
(*b*) *Fan dipole and rod reflector*

in service in the U.S.A. giving satisfactory results. There are two technical objections to this system. The first is that the active element is a derivative of the single dipole, and will have an impedance that is nearer to 75 Ω than the value required to match into 300 Ω feeder, so that when used with this type of feeder there will inevitably be a considerable mismatch. The second is that the reflector is a resonant element, and it can therefore only be effective over a small range of frequencies in each band. The fan type reflector will undoubtedly be better in this respect, but even this will not give perfect results over the whole of the two bands.

It is interesting to note that the performance of a broad-band aerial cannot be improved over the whole of the band of frequencies by the addition of parasitic elements. These have to be tuned to a particular frequency and are therefore ineffective over the whole of the band. They are occasionally added to a broad-band aerial in order to boost its performance at one particular frequency, such as at the top end of the band.

TWO-DIPOLE AERIALS

The second species of combined aerial that will be discussed is that which has two distinct dipoles connected

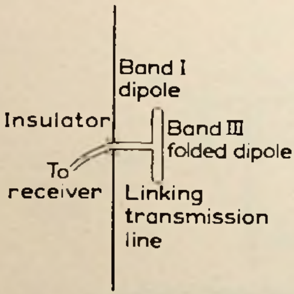


Fig. 47. Basic two-dipole combined aerial

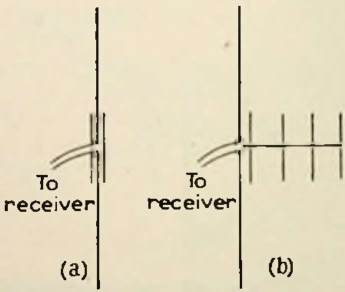


Fig. 48. Combined aerials, having only one dipole element

(*a*) *Short rods near to dipole element*

(*b*) *Aerial with additional parasitic rods*

together by a transmission line. This construction lends itself to frequency ratios of 4 : 1 between the two operating frequencies, and although the same principle is often employed in other cases, it is this one that will be described. The basic arrangement consists of a dipole for the lower frequency coupled by a transmission line to a folded dipole for the higher frequency, as shown in Fig. 47. When this aerial has a feeder connected to the band I dipole, at the lower frequency the length of the transmission line is chosen such that the band III dipole with the line is equivalent to an open circuit. It will then have the performance of a dipole, the low-frequency part being the only active element. At the higher frequencies, however, the dipole, being one wavelength long, will have a high impedance and will therefore be inoperative. The impedance of the transmission line is chosen such that the folded dipole will match the feed cable. The folded dipole will then be the only active element. This then is an arrangement that is satisfactory at two frequencies separated by a ratio of 4. It is possible to enhance the performance in either of the bands by the addition of one or more parasitic elements.

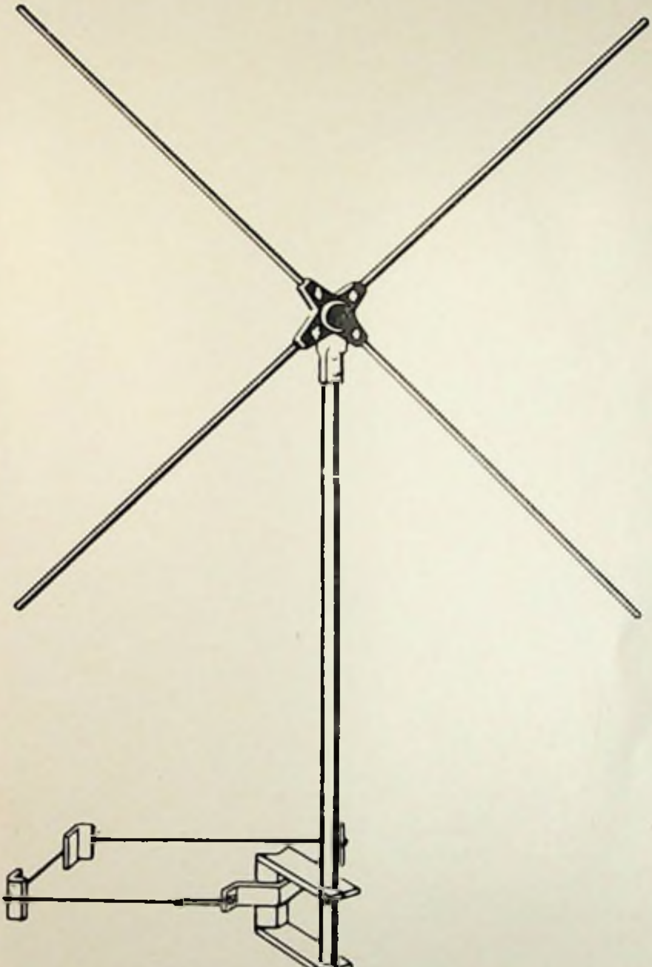
This arrangement can also be used when the ratio of frequencies is nearer to 3. The exact method of operation is not so easy to see, as it then depends on the mutual coupling between the two dipoles. It is found that this arrangement is more satisfactory if the feed cable is connected to the high-band dipole, and not, as in the first case, to the centre of the low-band dipole. This arrangement can also be boosted by the addition of one or more parasitic elements.

The applications of this type of aerial can be examined by considering the single channel aerial that is equivalent on both of the bands. In band I it will be equivalent to a dipole or an H aerial, depending on whether or not the parasitic element is included in the aerial. On band III it will have a performance slightly inferior to a three-element aerial, that is if it contains one director element for band III, as the band I dipole element will have an effect similar to that of a reflector at the higher frequencies. If there is more than one band III director, then it will have a performance equivalent to a multi-element Yagi aerial in this band. It must be noted again that combined aerials have their limitations, and in difficult locations it will often be more satisfactory to resort to individual aerials for the two bands.

Another example of a two-dipole aerial is in a combined aerial for television and FM in band II, assuming that the television bands are vertically polarized, while the FM band has horizontal polarization. The problem is simplified by the harmonic relations between the bands, assuming for example frequencies of 45, 90 and 180 Mc/sec in bands I, II and III respectively. It is then possible to have a horizontal half-wave dipole for band II connected direct to the feed-point of a vertical half-wave dipole for either of the television bands. The performance in any of the bands can be enhanced by the addition of suitable parasitic elements.

COMBINED AERIALS WITH ONE DIPOLE ELEMENT ONLY

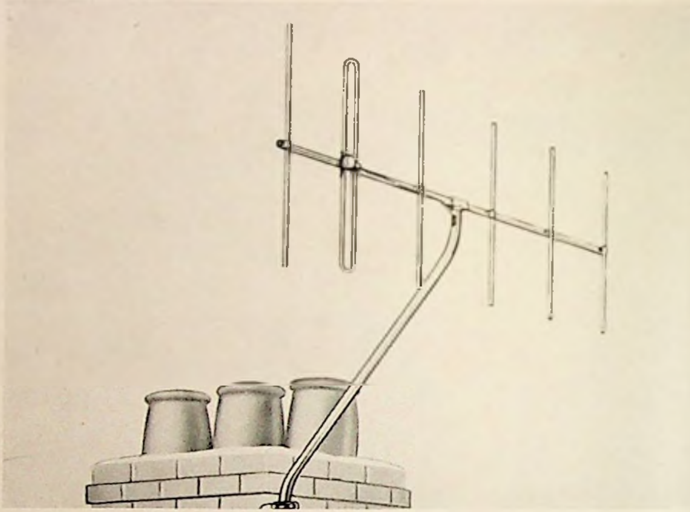
Another class of combined aerial is that which has a dipole resonant at the lower frequency, together with one or more half-wavelength rods at the higher frequency, as in Fig. 48. Another feature of this arrangement is that one of the short elements is fairly near to the centre of the main dipole element. This arrangement can have reasonable response in the two bands. The method of operation is obscure, but the electrical performance of this system can be explained in the following way. Assume that the aerial consists of a dipole element with a short rod tuned to a frequency about four times that of the dipole, and placed alongside it. This short rod will form, with part of the dipole, a transmission line leaving approximately three-quarters of a wavelength at the higher frequency exposed and free to radiate. The end impedance of this will be relatively low, in fact an impedance that can easily be matched into 75 Ω cable. It would appear, therefore, that at the lower frequency this will behave as a normal dipole, while at the higher frequency it will act as two end-fed rods spaced apart. This is in fact the case, except that the centre element, being approximately half-wavelength, will resonate, and behave as an active and not a passive element. This will not only affect the over-all directional characteristics of the aerial, but it will also enable further parasitic elements to be added to it. This technique has also been applied to



[By courtesy, Antiference Ltd.]

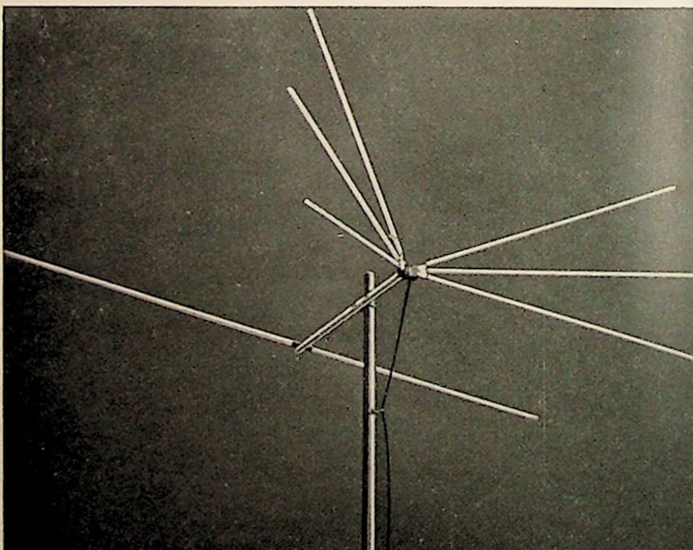
Plate I. Antex aerial

facing p. 88]



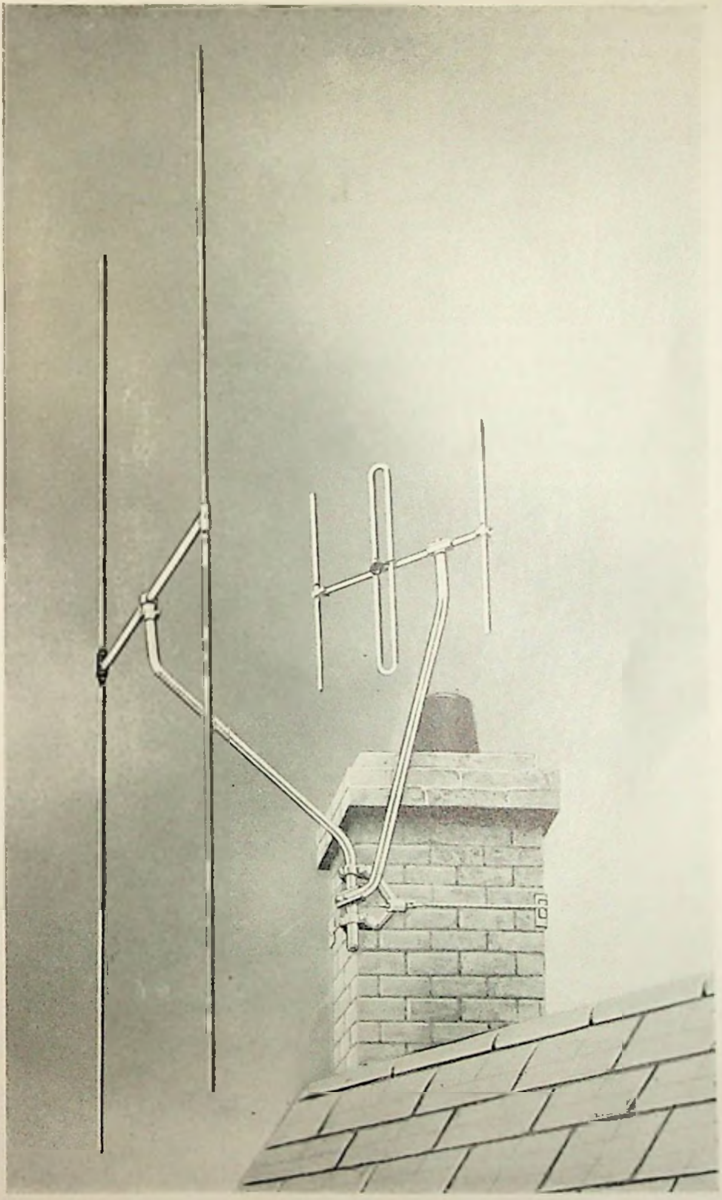
[By courtesy, Belling & Lee Ltd.]

Plate II. Six-element band III aerial



[By courtesy, Channel Master Corpn., U.S.A.]

Plate III. 'Conical' broadband aerial for horizontal polarization



[By courtesy, Belling & Lee Ltd.]

Plate IV. Junior-H band I aerial and three-element band III aerial mounted on same chimney

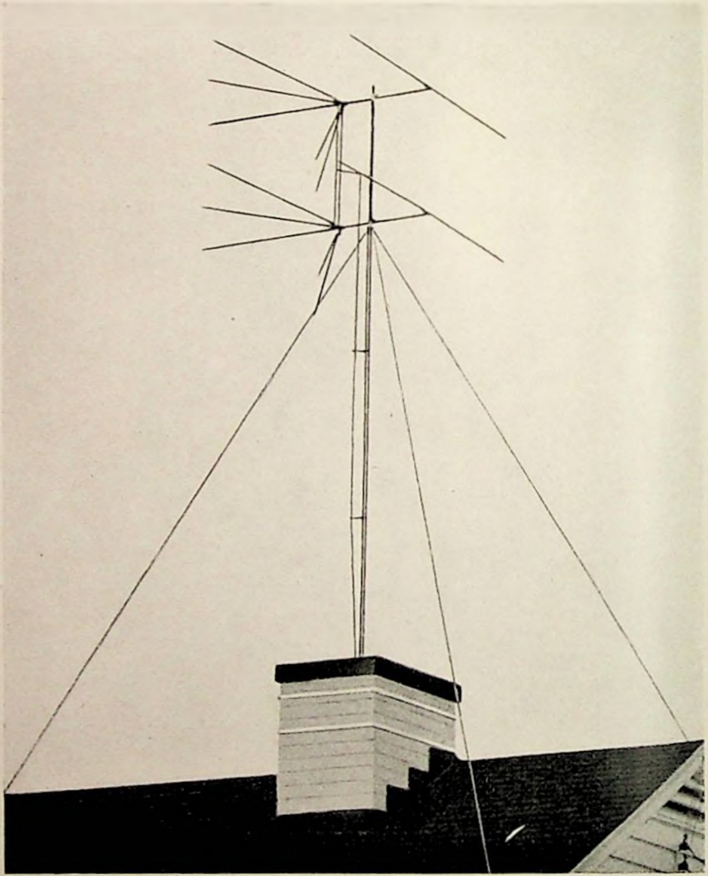
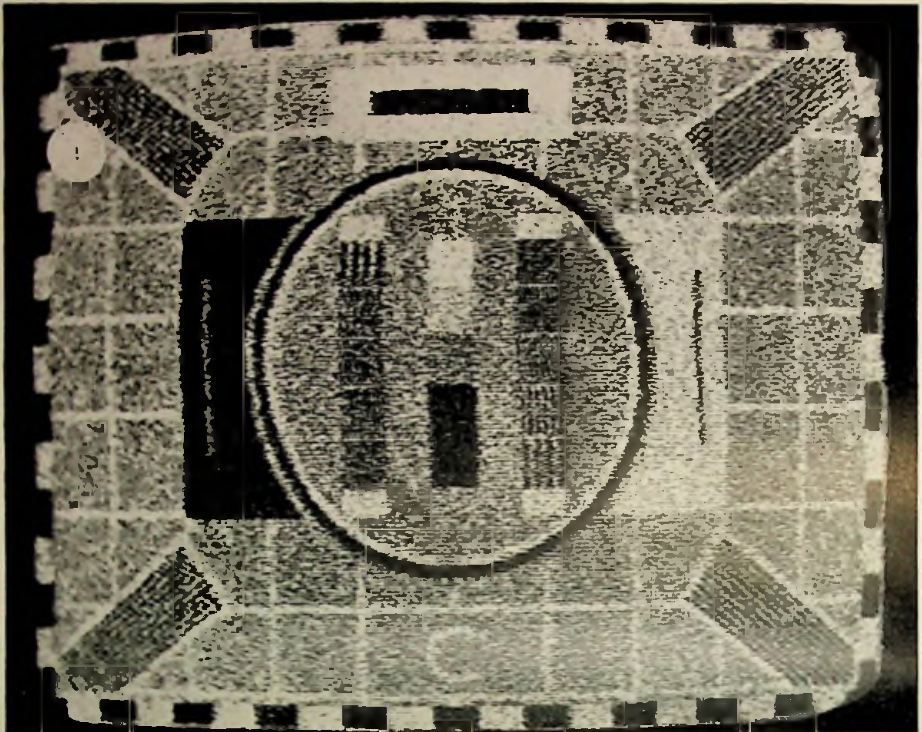


Plate V. Two-stack conical aerials for fringe reception of several TV channels

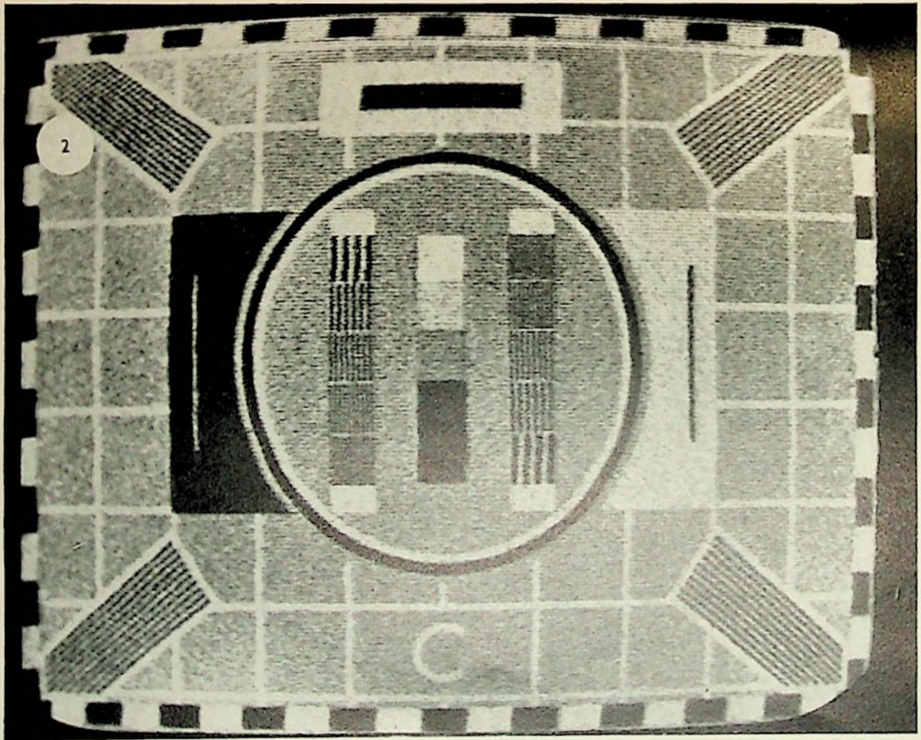
[*By courtesy, Belling & Lee (Australia) Pty. Ltd.*]

Plate VI. Double V and folded V aerials for multi-channel reception of horizontal polarization



[By courtesy, the Research Department, B.B.C. Engineering Division]

Plate VII. RMS signal-to-noise ratio 16dB, showing changes of picture quality due to receiver noise



[By courtesy, the Research Department, B.B.C. Engineering Division]

Plate VIII. RMS signal-to-noise ratio 22dB, showing changes of picture quality due to receiver noise

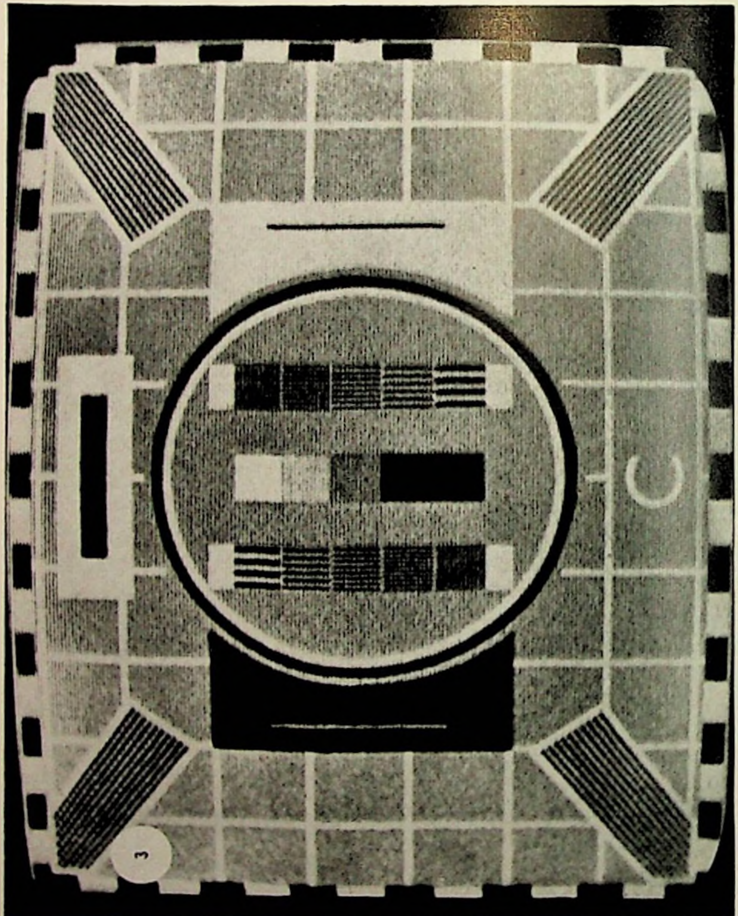


Plate IX. RMS signal-to-noise ratio 28dB, showing changes of picture quality due to receiver noise

[*By courtesy, the Research Department, B.B.C. Engineering Division*] aerials for receiving two frequencies separated by a ratio of 3. In this case the parasitic elements have to be arranged to cancel out the unwanted lobes of a dipole when operated in a higher mode on its own.

There is another technique that needs to be described, which enables a parasitic element to be effective in two bands simultaneously. The method, illustrated in Fig. 49, is to divide a parasitic element that is normally half a wavelength at the lower frequency into sections that are each approximately half a wavelength at the higher frequency.

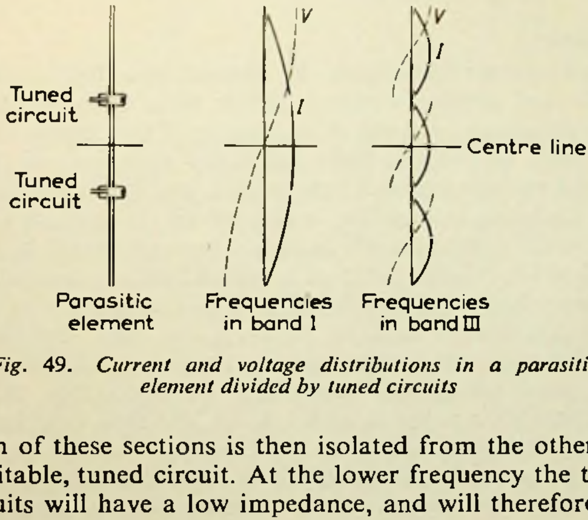


Fig. 49. Current and voltage distributions in a parasitic element divided by tuned circuits

Each of these sections is then isolated from the others by a suitable, tuned circuit. At the lower frequency the tuned circuits will have a low impedance, and will therefore not affect the performance of the parasite, considered as a continuous rod. At the high frequency the separate sections will be isolated from each other, and the system will act as a number of individual parasitic elements placed end to end. It is only necessary to apply this technique when the ratio between the two frequencies is 4, but it has also been applied when the ratio is 3 : 1. The same technique can be applied to a driven element, but in this case only the centre section will be connected to the transmission line. At the high frequencies the outer sections rely on a small amount of mutual coupling between them and the inner, or active, part.

This method has the disadvantage that at the higher frequency there is a parasitic element held at its end and spaced away from the main cross-boom of the array. Unless great care is taken in the mechanical design of the system there will be a tendency for this rod to sway in the wind, and this is likely to cause a certain amount of picture flutter.

SUMMARY

Five distinct techniques, V, conical, two-dipole, single-dipole and divided element aerials have been described, each technique enabling it to operate in two bands simultaneously. In practice there are many variations of these, and the various methods can be used together in one array. It is therefore impossible to discuss all the various possibilities. Individual aerials have not been discussed in great detail as the whole subject of combined aerials, particularly as they apply in Great Britain, is still in a state of flux, with experiments still in progress on new techniques. Whichever system is employed it is the aim to have an aerial with good directional properties, an impedance that is resistive with a value of either 75 or 300 Ω in both bands, and a gain that increases as the frequency is increased.

Very few aerials have all these characteristics, and the choice of a particular aerial is often made with other, non-technical, factors in mind. It has been shown, however, that most of the designs that are available are based on certain sound assumptions. In the design of this type of aerial there is always a good deal of development by experimental methods, with detailed investigation of those ideas that show advantages. The result of this is that many of the designs, although satisfactory in practice, cannot be fully understood by drawing a simple theoretical picture.

8

Choice of Aerial

Propagation of radio waves – Relationship between gain and field strength – Choice of an aerial from its gain – Choice of an aerial from its directional characteristics – Other electrical factors – Choice of a combined aerial – Choice of an aerial for reception in Band II – Summary

UP to now the characteristics of a number of different types of aerials have been described, but there is the important question :'Which type of aerial is required in a given installation?' With the reception of broadcast signals below 30 Mc/sec the question is rarely asked. In this case, if the aerial is not included in the receiver, then it is advisable to have it as large as possible and raised as far as is practical from the level of the ground. It is only when problems such as interference are encountered that the choice of aerial arises, and then it will depend on the particular problems at the receiving site. The remainder of this chapter will therefore be concerned with the choice of aerials for television reception, or for the reception of FM signals in band II.

It is essential first to look more closely into the propagation of the waves, and to investigate some of the effects taking place in their journey between the transmitter and the receiver. When the field strength of the signal at the receiving site is known, it will be possible to select the correct aerial.

PROPAGATION OF RADIO WAVES

There are four factors that can influence the strength or quality of the signal at the receiving site, these being the reflection of the signal by objects or the ground, the diffraction of the signal by buildings and hills, the attenuation of the signal as it passes through buildings, trees or even the atmosphere itself, and the refraction of the signal by the atmosphere. Each of these will be considered in more detail.

The question of reflection has already been discussed, as it is this that is responsible for ghost images and aircraft flutter. Its importance goes beyond this, as reflection also gives rise to standing wave patterns in the vicinity of the aerial. The reflecting objects giving rise to these will be sufficiently close for a double image not to be seen. Nearby buildings, other chimneys and other such objects will produce a horizontal standing wave pattern, giving rise to large variations of the received signal as the aerial is moved about. The ground will also reflect the signal, and this will give variations of the field strength as a function of the height above the ground. The practical importance of this is that if it is found that an aerial when first installed gives an inferior picture, it is often possible to improve it by shifting the aerial by a few feet. This can often be accomplished, especially with aerials with cranked masts, by moving the position of the mast by a small amount.

Diffraction is the process which enables the signal to bend round solid objects, so that it can be received behind buildings and hills. The amount by which the wave is bent is related to its wavelength, a wave with a short wavelength (high frequency) will be diffracted less than one with a long wavelength (low frequency). In most installations the best direction for the aerial to point is towards the transmitter, but if the wave that is being received has been diffracted, then the direction of arrival will be altered. It is often found that, when there are a number of aerials on a row of houses they often point in different directions, although each one may have been oriented correctly. This is partly due to the variations in the direction of arrival of the signal at each site. This is not the only reason for this, however, as the presence of ghost signals can produce the same result.

The attenuation of the signal is another important factor. It will be attenuated as it travels away from the transmitter, in the same way that the light from a lighthouse gets fainter as the distance from it is increased. The attenuation also plays its part in built-up areas. Buildings are not completely opaque to radio waves; not only will waves be diffracted round them, but there will also be a certain amount of penetration through the walls. In strong signal areas there

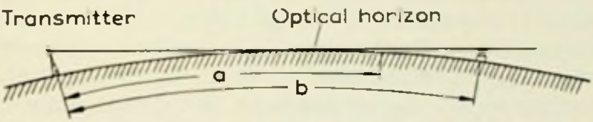


Fig. 50. ***Reception beyond optical horizon with a smooth earth***

(*a*) ***Maximum theoretical range for aerial at ground level***

(*b*) ***Maximum theoretical range for aerial mounted at chimney level***

will therefore be a possibility of receiving a signal inside the house, in the attic or even one of the downstairs rooms. The signal as it enters the building will be attenuated, so that usually the signal strength inside will be less than that outside, even if the aerials were at the same height above the ground in the two cases. It is impossible to give a figure for the amount of attenuation caused by brickwork, etc. This would depend on the exact construction of the wall as well as the dampness of the outside surface, but even if the attenuation were known, it would still be of very little value. The signal after it enters the room will be reflected by a wide variety of objects, such as the wiring in the house. There will in fact be a large standing wave pattern inside every building, making the idea of field strength meaningless.

Refraction will only become a significant factor when fringe reception is considered. This is a very important region as regards aerials, however, as it is in these areas that the majority of the problems arise. The light from the lighthouse would travel out to the horizon and would not be seen beyond this from ground level. This is illustrated in Fig. 50, where it can be seen that the range will be increased if the observer is at a greater height above the ground. The same applies, to a certain extent, with radio waves, but now the waves bend over the horizon so that they can sometimes be received by an aerial at ground level. Again, however, the strength of the signal will increase very rapidly as the aerial is raised from the ground, explaining the forest of tall masts in some towns in fringe areas.

Two processes play their part in the bending of the waves past the horizon, diffraction of them by the ground and also refraction by the atmosphere. Refraction only takes place when there is a change of density in the air, and this effect will be closely associated with the local weather conditions. It does not mean that when refraction is taking place, there will necessarily be an improvement in the signal. There is a possiblity that under these conditions there will be interaction with the diffracted signal, giving rise to fluctuations in the signal level. This is one of the uncertainties of reception in the fringe areas. The variations in the signal, or fading as it is sometimes called, is a property of the waves themselves. Very little can be done about this by aerial design, except that the gain should be as high as possible, so that the signal will be maintained at a reasonable level above the receiver noise for as great a proportion of the total time as possible.

There are other effects that occur when long distance propagation is considered, but this is beyond the scope of this book. This long distance propagation of television signals is a nuisance as it sets a limit to the minimum separation between two stations operating on the same channel. There is always a risk when two stations share a channel that there will be a break through of one station on the receivers in the fringe area of the other station. This will produce patterning on the screen, which can be a very annoying form of interference.

It is now possible to make a general survey of the way in which television signals are propagated, showing in particular the main differences between signals in bands I and III. The service area of a transmitter will be defined approximately by the visual horizon from the transmitting aerial, assuming of course that the transmitter power is sufficiently great for the signal to spread out to this distance. The actual service area will extend beyond this, the increase in range depending on both the local ground contours and the frequency of the signal. The lower the frequency, the farther the signal will travel beyond the horizon. In fringe areas, and places screened by hills, if two signals in bands I and III are available, it can be expected that the band I signal will usually be stronger than that on band III. This difference in signal can be partially made up by suitable aerial design, by arranging that the forward gain of a combined aerial is higher on band III than band I.

In any particular area there will be wide variations of the signal level. This is illustrated in Fig. 51, which shows the way in which the signal level can vary along a street. It is taken from an actual series of measurements, in which an aerial was mounted on the top of a van, and the signal level measured as the van was driven slowly along the road. It can be seen that there are deviations over 6 dB either side of the mean value. It is also evident that there can be violent changes in the signal level over distances as short as 30 ft, which means in practice that there can be large differences in the signal between adjacent houses.

Despite the local variations in the signal level, it is possible to consider the mean level in a particular area. The most convenient way of illustrating this is by drawing contour maps showing areas which have a mean signal level greater than a certain value. These can be used for defining the service areas of a given television transmitter, which are classified in two ways, the primary area and the

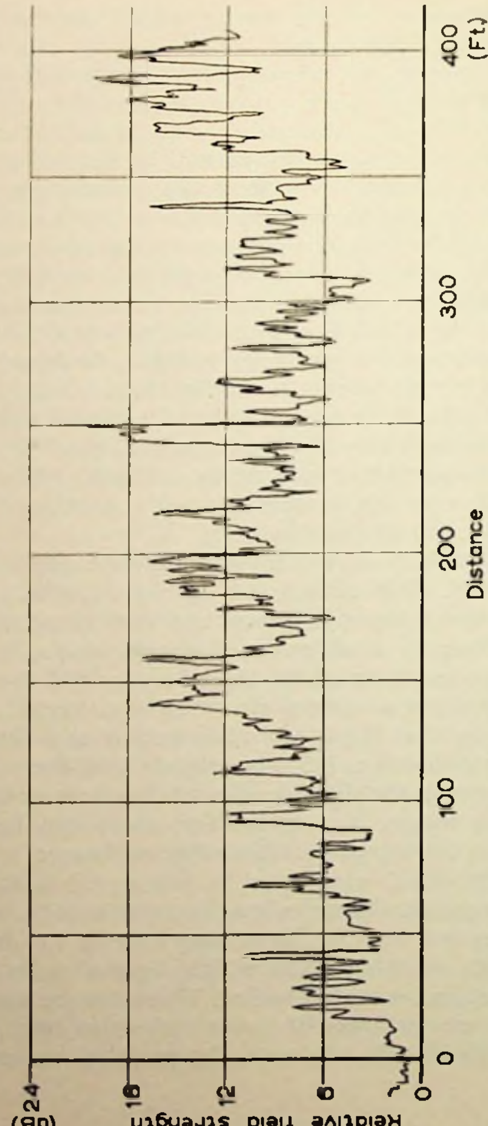


Fig. 51. *An example of the variations of field strength along a road (built-up area). Measurements made in band III, with the receiving aerial approximately 20 ft above road level* secondary area. In the primary service area it is assumed that most installations will receive a good signal, while in the secondary service area most installations will receive a satisfactory signal, but there may be a few locations where the signal level is too low for satisfactory reception. The limiting field strengths for the primary and secondary areas in Great Britain are approximately 500 μV/m and 100 μV/m respectively.

All installation teams are faced with the problem of which type of aerial to use in each particular installation. The choice will be the result of considering many factors apart from its electrical performance, such as the mechanical quality of the aerial, its ease of erection and its price. But here only the electrical side of the problem will be discussed.

RELATIONSHIP BETWEEN GAIN AND FIELD STRENGTH

A certain level of signal is required for a satisfactory picture. The signal voltage has to be sufficiently strong to overcome the noise generated by the first valve of the receiver. This noise is not caused by any fault in the receiver, but is inevitable whenever a high gain amplifier is used, and in fact determines the maximum gain that it is possible for a receiver to have. On the sound, this noise shows up as a background hissing noise, while on the picture it gives rise to a graining effect. It can also affect the line synchronization of the picture, causing vertical lines to become jagged.

Some examples of noise on a signal are given in plates VII–IX. In these the relative levels of the picture and noise have been changed to show the picture quality with a given amount of noise. These are not a true representation of this type of noise, because with a still picture the associated continual movement cannot be shown. There is a difficulty in measuring the signal/noise ratio with television signals, and in these pictures both are measured as an r.m.s. value, and the ratio between them expressed in decibels. With the British system, the signal level is usually measured by the amplitude of the signal when peak white is being transmitted, and there will be a conversion factor which will depend on the type of picture, to convert this to the r.m.s. value of the video signal. A signal to noise ratio of 16 dB with test card C represents a poor picture, while if the ratio is increased to over 28 dB, then the picture quality is reasonable. On the basis of these figures, a commercial receiver with a 75 Ω input and having reasonable sensitivity will give a satisfactory picture with a signal of 100 μV at its input terminals.

The reason for giving these figures is to find out the gain required by an aerial for use in a given field strength, and conversely to find the lowest field strength that can be received with a given aerial. Now, it has been shown in Chapter 2 that the signal given by an aerial with a gain G relative to a half-wave dipole is :

$$V = \sqrt{\left(\frac{R_a\, G\, G_d}{120}\right)} \frac{\lambda}{\pi} \frac{Z_L}{Z_a + Z_L} \cdot E$$

where Z_L is the impedance of the load, Z_a is the impedance of the aerial, the resistive component of which is R_a, and G_d is the gain of a half-wave dipole relative to an isotropic radiator and has a value of 1·635, λ being the wavelength of the signal. Substituting these values, assuming that both the load (the receiver) and the aerial have impedances of 75 Ω, the terminal voltage becomes :

$$V = \frac{\lambda\sqrt{G}}{2\pi} E$$

It is now possible to calculate the signal at the receiver for any given field strength, and for illustration the field strengths at the edge of the primary service area will be taken as an example. The value given above is 500 μV/m. It will be assumed that the loss on the feeder will be the same on both bands and have a value of 3 dB, and that the gain of the aerial is 6 dB on band III and 3 dB on band I. Substituting these values, the signal at the receiver comes out to be 480 μV on band I and 170 μV on band III, both of which are adequate for a reasonable picture.

CHOICE OF AN AERIAL FROM ITS GAIN

It would be possible to measure the signal level at each site where a television aerial is going to be installed, and calculate the gain required by the aerial and choose the appropriate one. But in actual fact this would not be practical, as the time involved in making the measurements would completely outweigh the saving of expense by being able to use an inexpensive aerial, such as a dipole, intead of a more elaborate aerial. Moreover, the more elaborate aerial might easily be necessary for other reasons. The installer needs to know the type of aerial that will be satisfactory in the majority of installations in a given area. It would be possible to get this information from a field strength contour map, if this were drawn with sufficient detail, but in practice the choice is usually made on a trial and error basis with a few installations. Various aerials are tried in a number of sites, and it may be found that at nearly all these sites a six-element aerial gives a satisfactory picture, bearing in mind that it is advantageous to have a signal level that is more than sufficient. This type of aerial will then be used at all further installations, and only in a few, where it is shown to be unsatisfactory, will it have to be changed for a more ambitious one. Local knowledge of an area by an installer is a far better guide in the choice of an aerial than theoretical predictions based on mathematical formulae.

CHOICE OF AERIAL FROM ITS DIRECTIONAL CHARACTERISTICS

The question of gain has been discussed, but the directional characteristics also have to be considered. The ideal polar diagram would consist of a narrow forward lobe with good rejection of the signal in all other directions. This is only possible with an elaborate and expensive aerial. In practice the forward lobe will be far from narrow, for example the width of it in a band I aerial might be at least 120 degrees, and in the backward direction several minor lobes will be present. Which of these shortcomings can be tolerated? The answer can only be found by considering the site conditions. If it is a very noisy site, with interference signals arriving from a variety of directions, then a narrow forward lobe is to be preferred, even if this means that there are small minor lobes in other directions. If, on the other hand, there is one ghost signal to be removed, then the width of the forward lobe is unimportant, but it is essential that the directional response pattern has a good minimum. Here again it is only by trial and error methods, with a knowledge of local conditions, that the correct aerial can be chosen.

OTHER ELECTRICAL FACTORS TO CONSIDER

The other electrical factors to consider are the impedance of the aerial and the polarization which it is intended to receive. Both of these will be common to all installations in a given area, so they will not normally present any problem. An aerial made by a reputable manufacturer will have been designed for use with a particular type of feeder, and it will therefore have a reasonable impedance match when used under the correct conditions. It is interesting to note that receiving aerials are used under such a wide variety of conditions that it would be impossible to have a perfect match in all installations. It would be impractical to match each aerial individually, but the mismatch introduced in a practical installation will not normally cause any marked deterioration in the quality of the picture.

CHOICE OF A COMBINED AERIAL

In areas where there is more than one transmission available it is often possible to use a single combined aerial instead of separate aerials for each channel. Before using such an aerial, it is worth while considering the following questions :

(a) Are the signal levels on the various channels sufficiently near to one another for the gain-control circuits in the receiver to handle the differences when the receiver is switched from one channel to the other ?

(b) Is the direction of arrival of the signals suitable for a combined aerial ? If the signals are coming from different directions, will it be possible to use a combined aerial ?

(c) Are there ghost or excessive interference signals on either of the bands ?

This is another problem that can only be answered by experience and knowledge of the local conditions in a given area. It must also be remembered that there are so many uncertainties in the use of this type of aerial, that they may be quite satisfactory in one place, but of very little value in a nearby locality.

CHOICE OF AN AERIAL FOR RECEPTION IN BAND II

The same factors influence the choice of a receiving aerial for the reception of frequency modulated signals in band II as for the reception of television. Forward gain is required so that the signal will swamp both the receiver noise and any interference signals. Directional characteristics are also necessary to reduce any interference, and also to reduce the effects of multipath propagation. On television this gives rise to ghost images, while with frequency modulation, as has been seen in Chapter 3, serious distortion can be caused.

As with television aerials the best guide to the choice of an aerial for band II can only come from experience and local knowledge of the area. It can usually be reckoned that a less ambitious aerial will be required for this service than for television, and in many cases satisfactory reception will be obtained with a simple indoor aerial. The use of such an aerial, however, must be treated with caution, as it can spoil a system which is intended to give quality reception.

SUMMARY

It can be concluded that when choosing a television aerial local knowledge of reception conditions is the most useful guide. There are other aids, all of which have their uses, these being the published field strength contour maps and the technical data given by aerial manufacturers. In all installations it must be remembered that it is the quality of the picture on the receiver which matters, and the choice and installation of the aerial must be carried out with this final aim continually in mind.

9

Radiofrequency Cables and Accessories

Characteristic impedance of transmission lines – Attenuation of cables – Practical cables – Effects of mismatch on the cable – Operating more than one receiver from a single aerial – Diplexers

So far only the aerial has been considered, except for a brief mention of the need to have a cable to transfer the signal from the aerial to the receiver. Some form of transmission line is needed in nearly every installation for television in either of the bands, or for FM broadcasting. In discussing these radiofrequency transmission lines, three electrical factors will have to be considered, each of which affects the passage of the signal along the cable. The three factors are : the form of the line, i.e. whether it is balanced or unbalanced, its characteristic impedance and its attenuation or loss.

There are two basic types of transmission line, balanced and unbalanced. There is no clear-cut definition to distinguish between them, but one interpretation is that if there is any conductor at earth potential that is carrying the signal, then the cable is unbalanced, all other types being balanced. An example of a balanced line is two parallel conductors spaced a short distance apart, while the most usual form of unbalanced line is the coaxial cable, in which one conductor is surrounded, but insulated from the other conductor. Only these two basic types of transmission line will be discussed here, as between them they represent the vast majority of cables that are available. From the installation point of view, the main difference between them is that a coaxial cable can be fixed anywhere, as the radiofrequency signal is contained inside the cable, whereas with a balanced line the signal produces a field outside the cable, so that for satisfactory results the cable has to be supported on insulators. Before any comparison can be made between them, it is necessary to consider in more detail the impedance of a transmission line, and its attenuation.

CHARACTERISTIC IMPEDANCE OF TRANSMISSION LINES

In order to consider the behaviour of transmission lines at high frequencies, it is essential to introduce the meaning of impedance as applied to a transmission line. Consider a

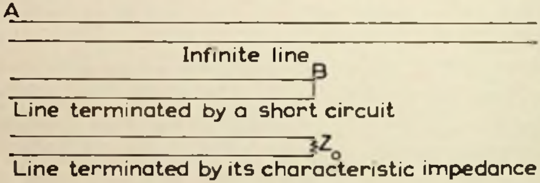


Fig. 52. Termination of a transmission line

very long line starting at a point marked A in Fig. 52, and stretching away into the distance. Now, assume that a short pulse is fed into the line at the point A, this will travel down the line with a certain velocity, and it can be shown that, under certain conditions, the pulse will retain its shape as it travels along. If the line is now shorted out at some point, say B, then when the pulse reaches this point it will be reflected and travel back down the line. It can be shown, both theoretically and by practical experiment, that if the line is cut and terminated by a resistance of the correct value, no reflection will take place. The value of this resistance defines the characteristic impedance of the line, and this is a quantity that is a function of the spacing between the conductors, and their size and shape, but is not a function of the frequency at which the line is operated. If a short length of line is terminated in this way, the input impedance of the line will be the same as if it were of infinite length. If, however, the line was not terminated in this way, but, for example, by a short or open circuit, then its input impedance would vary over wide limits, the variations being functions of both the length of the cable and the frequency of the signal.

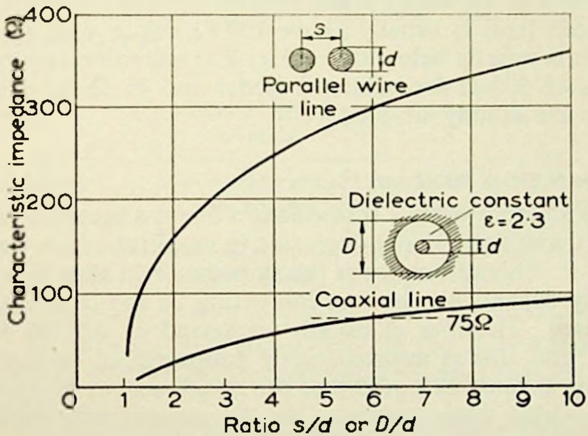


Fig. 53. *Characteristic impedance of balanced and coaxial lines*

The value of the characteristic impedance can be determined from its physical dimensions. Only two examples will be given here, that of an open balanced line in air, and that of a coaxial cable with solid dielectric insulation. For an open line consisting of two cylindrical conductors of diameter *d*, with a spacing *s* between their centres, the characteristic impedance of the line Z_0 is given by* :

$$Z_0 = 276 \log_{10}\left[\frac{s}{d} + \sqrt{\left\{\left(\frac{s}{d}\right)^2 - 1\right\}}\right] \text{ ohms}$$

* See I. A. D. Lewis and F. H. Wells, *Microsecond Pulse Techniques*, page 287, Pergaman, 1954.

while for a coaxial line having a centre conductor of diameter d and an outer conductor with its internal diameter D, the characteristic impedance is given by :

$$Z_0 = \frac{138}{\sqrt{\epsilon}} \log_{10} \frac{D}{d} \text{ ohms}$$

where ϵ is the dielectric constant of the insulation material. Examples of the values obtained from these formulae are given in Fig. 53, where it can be seen that the impedance of balanced lines is usually above 100 Ω, while with coaxial lines it is usually below this value. For television reception, values of 300 Ω for balanced feeder and 75 Ω for coaxial feeder are usually adopted.

ATTENUATION OF CABLES

The attenuation of a transmission line is a measure of the rate at which the signal decreases in amplitude as it travels along it. This differs from the impedance in that it is frequency dependent, the loss increasing as the frequency is increased. The loss is usually expressed in dB/100 ft of cable, and this is approximately proportional to the frequency. It must be noted that the measurement of the loss in the cable when measured in the normal way requires it to be correctly terminated. For a cable not terminated in this way, the apparent loss in a short length of cable can be changed due to the mismatch.

PRACTICAL CABLES

It is now possible to make a direct comparison between coaxial and balanced cables. This will be illustrated by tabulating the various properties of three types of cable: 300 Ω ribbon feeder, coaxial cable with solid dielectric, and coaxial cable with an insulation that is partly dielectric material and partly air.

It will be seen that coaxial cable has advantages over balanced feeder, both in the ease by which it can be fixed

Table 5. Properties of radiofrequency cables

	300 Ω *balanced*	75 Ω *solid*	75 Ω *low loss*
Characteristic impedance ..	300 Ω	75 Ω	75 Ω
Attenuation: at 50 Mc/sec at 200 Mc/sec	 1·3 dB/100 ft 2·5 dB/100 ft	 3·4 dB/100 ft 6·8 dB/100 ft	 1·6 dB/100 ft 3·6 dB/100 ft
Approximate relative cost ..	1	2	6
Fixing ..	Needs stand-off insulators	Can be fixed by any method	
Weathering ..	Affected by moisture on surface	Unaffected by weather except if dampness penetrates the end of the cable	
Typical aerial ..	Folded dipole	Simple dipole	

and by its weathering properties. On the other hand 300 Ω balanced feeder has less loss and is cheaper than its coaxial equivalent.

In any particular area the choice of feeder, at least between 300 and 75 Ω, will be determined by the input circuit of the receiver. It is possible, however, to change the impedance and also change from a balanced to an unbalanced system by a suitable transformer, but the use of this type of unit is not to be recommended unless there are other reasons for its use.

EFFECTS OF MISMATCH ON THE CABLE

An installation will consist of an aerial connected by a length of cable to the receiver. It has already been shown that the aerial is designed with its impedance as near as possible to that of the feeder, and the receiver manufacturer aims to match the input impedance of the receiver to that of the cable. In practice there is always a certain mismatch at both these places, and there is a possibility that this will cause degradation of the final picture.

Due to the mismatch between the aerial and the cable, the signal will not be passed to the cable with the maximum of efficiency. The loss will be small, however, unless there is an excessive mismatch. The magnitude of the loss of signal is shown in Fig. 54, where the loss is plotted against the mismatch between the cable and aerial. This gives a theoretical value for the loss which would only be realized in a

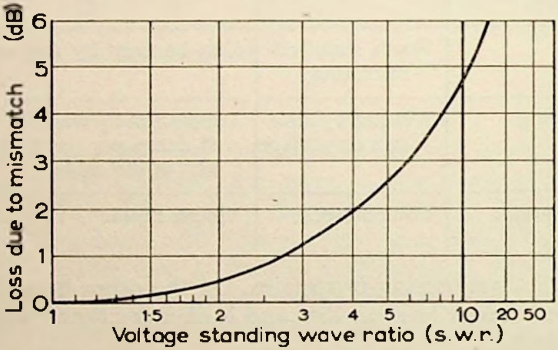


Fig. 54. Loss due to mismatch on a transmission line

practical installation if the cable was correctly terminated at the lower end.

The signal on entering the cable travels down it, and if a mismatch also exists at the receiver will be reflected back up the cable. It will be reflected again at the aerial and finally reach the receiver, delayed from the main signal by an amount determined by the length of the cable. It would be expected that a ghost image would result, but in practice this does not happen. For a second image to be seen it would have to be displaced in time by at least one microsecond (on the British system), which means that the total length of cable would have to be about 300 ft. Assuming that the cable has an attenuation of 4 dB/100 ft, and that the signal suffers a reduction of 6 dB when being reflected by the mismatch at the top and at the bottom, then the second image will have an amplitude 36 dB below the main signal. The second image will not therefore be noticeable, so that the picture quality will not deteriorate. For a short cable run, however, if a very serious mismatch occurs both at the top and at the bottom of the cable, two effects can occur. If the cable is short, it is possible that the signal which has travelled the extra journey up and down the cable will still have an amplitude comparable with the original signal. Its displacement will not be sufficient to cause a degradation of the definition of the picture, but it can add to the signal to improve the signal level. This improvement will change as the length of the cable is altered, the changes repeating every time the length is altered by half a wavelength. This effect can be utilized to advantage in difficult installations by cutting short lengths off the cable until the best picture is obtained.

The second, and often more serious, effect of a short cable run with a serious mismatch at the aerial end, is that it is possible for it to cause ringing in the receiver. The short length of cable will combine with the input circuit of the receiver to form a resonant circuit, and this in turn may cause any sharp changes in the picture to produce a 'ring' that shows as a series of light and dark images. An example is found with an indoor aerial which is usually intended for use in strong signal areas. This type of installation usually has a very short length of cable, and when there is a bad mismatch between the cable and aerial, this type of ringing can be produced.

There is one way in which the impedance properties can be used to improve the input impedance properties of a receiver. A second length of cable is connected across the input socket of the receiver, as shown in Fig. 55. The length of the stub is reduced by cutting off short lengths until the best picture is seen on the screen. When this condition has

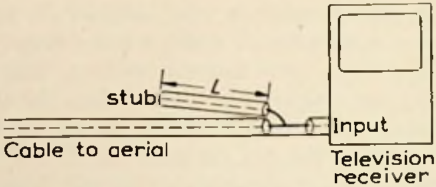


Fig. 55. Matching of a receiver by a short stub. (The length L of the stub is varied to produce the best picture)

been reached, the impedance of the stub will be such that it will cancel out the reactive component of the input impedance of the receiver, thus producing a better match on the cable. It must be pointed out that this will only be satisfactory at one particular frequency, so that if several signals are available this technique can only be used to match one channel at a time.

OPERATING MORE THAN ONE RECEIVER FROM A SINGLE AERIAL

The behaviour of short lengths of non-terminated feeder at the frequencies used for television can produce undesirable effects if more than one receiver is to be operated from a single aerial. The trouble arises from the properties of a short length of feeder, whose length is a multiple of a quarter wavelength. If this length of cable has an open circuit at the far end, it will behave in exactly the same way as a short circuit. In a practical installation it is impossible to predict the exact length of cable used, so that all cables, however short, must be terminated by their characteristic impedance. For a single receiver working from a single aerial there is no problem, as in this case the cable is terminated at the top by the aerial and at the bottom by the receiver. If there are two receivers it is not satisfactory to put a T junction in the cable, as the lead to one receiver might be of such a length that it would spoil the picture on the other receiver. There are, however, several ways in

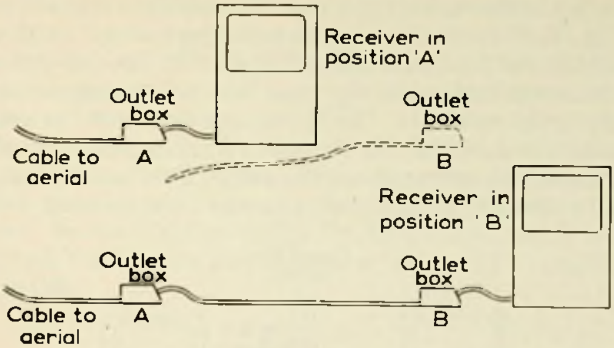


Fig. 56. Operation of a receiver in either of two places

which multiple outlets can be arranged, and those that use passive networks only will be discussed now.

The simplest suitable arrangement if one receiver is required in one of two places is a straightforward extension lead. This is illustrated in Fig. 56, where the normal down lead is connected to the outlet box A. If the receiver is plugged into the second box B, then the fly lead is plugged into the outlet A. This is very satisfactory in practice, except that although there are two separate outlets, it is only possible to have one receiver in operation at any one time.

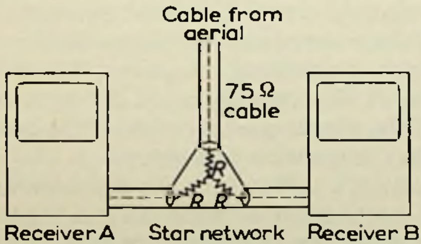


Fig. 57. Operation of two receivers simultaneously, by means of a star network. All resistors of equal value, R = 27 Ω

This can be overcome by the use of a star network, as shown in Fig. 57. This consists of three resistors, each of 27 Ω, connected in the form of a star. One point of the star connects to the aerial lead, while the other two points connect to the leads to the receivers. The input impedance of the system is maintained at 75 Ω, so that there is no degradation of the picture due to mismatch on the cable. This system can give rise to trouble if only one receiver is connected to the

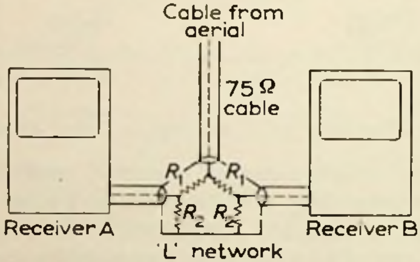


Fig. 58. Operation of two receivers simultaneously, by means of a double 'L' network. Value of resistors :

$R_1 = 100\ \Omega$
$R_2 = 150\ \Omega$

network, unless the other outlet is terminated by a 75 Ω resistor. There is a loss inherent in this type of system, due to the facts that the signal is divided between two receivers and because there are resistive elements in the circuit which absorb a certain amount of the power. The over-all loss in the star network illustrated here is 6 dB. In terms of power, a quarter of the power goes to each of the receivers, while half is lost in the resistive network.

The star network suffers from the disadvantage that there is very little attenuation between the two receivers, so that adjustments to one can affect the picture on the other. There is an alternative network of resistors, which again maintains the correct impedance in the system, but in which the coupling between the receivers is reduced. This is shown in

Fig. 58. In the lead to each receiver there is an L network of resistors, the series resistor having a value of 100 Ω and the parallel one 150 Ω. With this there is a loss of 9¼ dB between the aerial and each receiver, but the isolation between the receivers is now 19 dB. As can be seen there is a greater loss with this system, but if there is sufficient signal then it is to be preferred to the simple star network. Again if only one receiver is being used, the other outlet should be terminated with a 75 Ω resistor, but if this is omitted, the resulting mismatch is only 1·25 : 1, which is negligible.

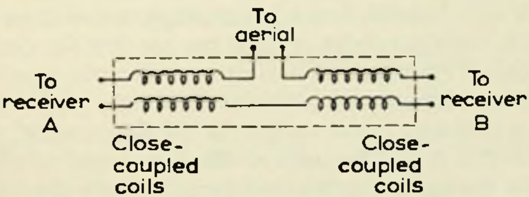


Fig. 59. Circuit for the simultaneous operation of two receivers, without the use of resistors

Both these systems can be extended to be used with more than two outlets, and they can also be used with balanced cable. The values of the components and the insertion loss figures are given in Appendix III. As these resistive networks are in the aerial lead, and therefore operating at frequencies up to 200 Mc/sec, the length of the connecting wires must be as short as possible. It also means that the earth connection between the outers of the coaxial cables must be short, and this is often achieved by enclosing the network in a small metal box.

There is a further method of feeding two receivers from a single aerial by using a lossless network consisting of two closely wound coils. This system lends itself to balanced cable, and it is in this form that it is illustrated in Fig. 59. The dimensions of the coils have to be chosen to produce the correct matching in the system, and this method can be designed to cover a wide range of frequencies. As there are no resistances in the circuit to absorb the signal, the loss between the aerial and each receiver could be as low as 3 dB. It has certain advantages over the resistive networks, but it will usually be more expensive to manufacture than its resistive counterpart.

DIPLEXERS

One very important unit is that for combining two different frequency signals on to one cable. This has been given a variety of names, such as diplexer, cross-over unit, combining unit, etc., but the first of these, diplexer, will be used in this book. Two examples of their use are first for combining the signals from separate aerials operating in bands I and III on to a common cable, which will usually go to a receiver having a common input socket for all frequencies, see Fig. 60. Secondly, it can be used at the lower end of the cable from, for example, a combined aerial to split the signal for use with a receiver having separate inputs for the different bands.

In order to illustrate the electrical requirements of this type of unit, the first case will be taken, in which the cables from two aerials are combined into a single cable. The first

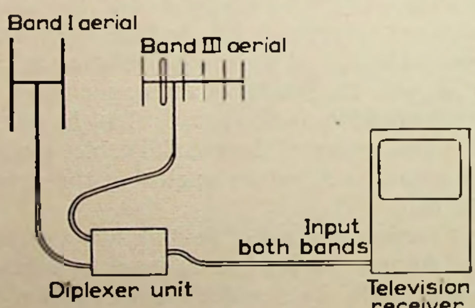


Fig. 60. Use of a diplexer for combining two signals on to a single cable

and most important requirement is that the loss introduced by the diplexer in either band should be as low as possible. Furthermore, the two aerials should be isolated electrically from each other. The reason for this is that by doing so any interference or ghost signals in one band picked up by the aerial intended for the other band will not then cause any deterioration of the picture quality. There is another reason for needing this isolation between the two aerial circuits. Each aerial will have an unknown impedance at frequencies other than that for which it is designed. If no diplexer were used, then unless the lengths of cable were carefully chosen, there would be a serious mismatch introduced by the aerial not in operation in the band being received.

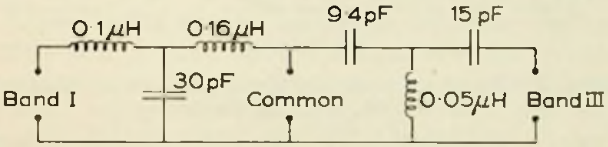


Fig. 61. An example of the circuit diagram of a diplexer (for use with a 75 Ω system)

The most satisfactory circuit consists of a high- and low-pass filter, as shown in Fig. 61. This is for a 75 Ω system, where the band III signal is connected to the high-pass side, and the band I signal to the low-pass side. A typical performance curve for this type of unit is that in Fig. 62, where it can be seen that the loss introduced by the unit is less than 1 dB over both the bands.

Other circuit arrangements are possible, and it is also possible to have networks for combining signals in band II with those in the television bands. These units have application with receivers which have a common input for bands I, II and III, and also when aerials designed for all the three bands are used.

SUMMARY

Some aspects of radiofrequency cables, and the accessories

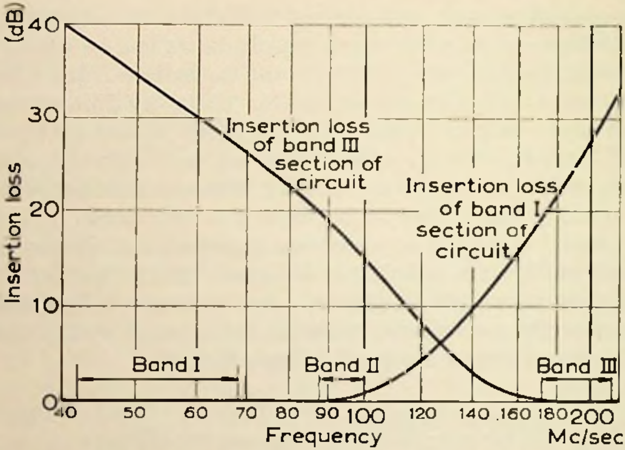


Fig. 62. *Performance curve of the diplexer circuit shown in Fig.* 61, *in a* 75 Ω *system*

that are associated with television installations have been discussed. The choice of feeder for a given installation has a direct influence on the type of aerial that will be employed. Also, the input circuit of the receiver usually determines whether balanced or coaxial cable is used, although the same general principles apply to both types.

When considering the operation of more than one receiver from a single aerial, no mention has been made of distribution amplifiers. This is a separate subject, closely associated with the design of the radiofrequency circuits in receivers, so that it will not be discussed in this book.

10

Mechanical Design of Aerials

Stresses in aerial elements – Element clamps and dipole insulators – Design of cross-arm and mast – Methods of fixing the installation – Loft aerials – Summary

THE mechanical features are some of the most important items in aerial design, especially for those that are intended to be mounted out of doors. Under these conditions the aerial has to withstand battering from all weathers for periods of many years. During its life no part of it, such as an element, must break off, and there must be no corrosion that would cause degradation of the electrical performance. It can be seen that high engineering standards must be maintained if all these conditions are to be satisfied. It is also necessary for the aerial to be capable of easy assembly, and for it to be of economic cost. The main component parts of a chimney-mounted H aerial are shown in Fig. 63.

It is usual to make the mast, cross-arm and elements of the aerials for television tubular with a circular cross-section, although other cross-sections are sometimes used, but the estimate of the strength of these would be made in the same way as with the cylindrical material. An individual element will be considered first, as these present the simplest problem, that of a single tube clamped at some point. A parasitic element for band III aerials is usually a single rod clamped at its centre, while in band I this arrangement would be inconvenient to handle, as the over-all length would be up to about 11 ft. Instead, the element is made in two halves, held together at the centre at the point where it is fixed to the cross-arm. Before describing the design of

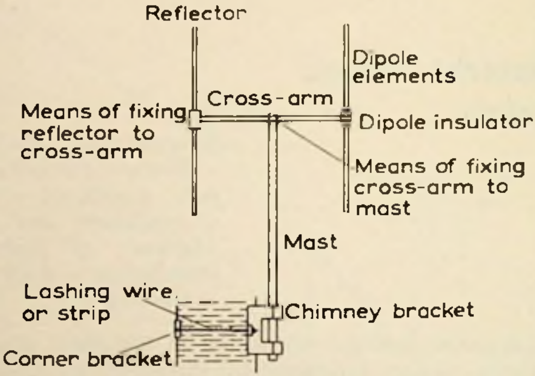


Fig. 63. *Parts of a chimney-mounted* H *aerial*

clamps in more detail, the stresses in the tubes themselves will be discussed.

STRESSES IN AERIAL ELEMENTS

Only half an element will be considered, consisting of a vertical tube held at one end. This is only half an element from the electrical point of view. It is often described loosely as an 'element', but usually there is no confusion caused by this double definition.

Any wind will cause a horizontal force on this rod, which will tend to make it turn at its point of support. It is possible to calculate, at least approximately, the force exerted by a given wind if the diameter of the rod is known. This calculation is for a steady wind, but in practice not only will individual gusts reach quite high values of wind velocity, but repeated gusts and swaying of the elements will produce extra strain on the rod. The usual design procedure is to calculate the material required for a steady wind of say 100 m.p.h., and then allow a fairly generous safety factor. This is not the whole story, as there are other things that cannot be predicted by any theoretical calculation. As an example there is a minimum strength for the elements, below which they are liable to be bent or damaged in some way in any one of the many stages between the factory and the final installation, e.g. in transit. The required strength can only be judged from experience, but it means that in some instances the elements have to be made more robust than the wind calculations predict.

The material used for the elements is usually an aluminium alloy, as this is light and of reasonable cost and also has the necessary properties from the mechanical point of view. The elements are made of tubing of between $\frac{5}{16}$ in. and $\frac{1}{2}$ in. diameter, and two methods of construction are most commonly used, either drawn or butt-jointed tubing. There are many technical reasons both for and against each type, one of which will be mentioned here. Butt-jointed tubing is formed by rolling a strip of material into the form of a cylinder, so that, as the name implies, there is a join running the length of the tube. Now, this is not sealed in any way, the tube remaining intact by the stress put into the material during the rolling process. When the element is subject to forces from, say, a wind, the walls of the tube are not stressed to the same extent as with drawn tubing, but the two edges at the join move relative to each other. The practical result is that if two elements, one made by each method, and having the same mechanical strength, are subject to either wind or vibration tests, the butt-jointed tubing will outlive the drawn tubing.

There is another point to consider in the design of the elements themselves, and that is mechanical hum. This can originate in two ways : by wind blowing across the open end of a tube, or by the element itself vibrating in the wind. The first of these is relatively unimportant, becoming apparent only under certain circumstances in the case of masts. The other, the vibrating of the element itself, can be more serious. It was found that when aluminium alloy was first used for the elements, the resonant frequency of a band I element in a moderate wind could be of the order of

100 c/sec, and in certain cases this would resonate with the air column in the chimney. The result of this was that a loud hum was heard throughout the house whenever a moderate wind blew. This can be overcome by damping the elements in some way so that the amplitude of the vibration and hence the sound produced is sufficiently low. There are several ways in which this can be accomplished; one of the simplest, which is also very effective, is to fill each element with sawdust. Any vibration of the element is then damped out by the relative motion of the particles of sawdust.

The design of elements for horizontal aerials does not present any real differences compared with those having vertical elements, as the forces due to winds are far greater than that of their weight. There is a risk that in certain circumstances heavy birds may bend horizontal elements when they perch on them, but this risk is usually quite small, and can be allowed for when the aerial is designed. One way of counteracting the risk of elements getting a slight bend is to give each one a small uplift, which will not affect the electrical performance of the aerial. By doing this, if any of the elements get slightly bent, the over-all appearance of the aerial remains tidy.

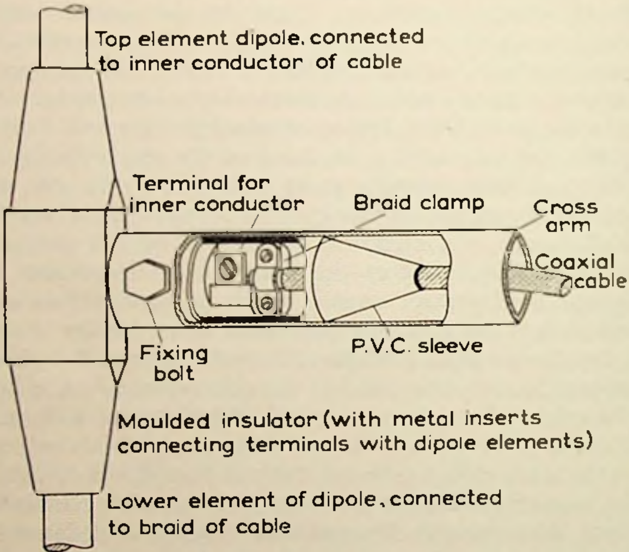
ELEMENT CLAMPS AND DIPOLE INSULATORS

The next part of the aerial to consider from the mechanical aspect is the method of fixing the dipole and parasitic elements to the cross-arm. As there is such a wide variety of designs, none of them will be described in detail, but the basic principles will be given. The elements should be clamped in such a way that the minimum of strain is put on any one point. Any hole, slot or kink in the tubing will be a weak point, and in time the wear imposed by vibration and corrosion from the weather will cause it to break at this point. The ideal method is to clamp the element so that the strain is taken over a fairly large area. The same requirements apply to the cross-arm, but to a lesser extent, as it is of a much larger diameter and usually more robust.

As the elements of band I aerials are made in two halves, the central fixture has to act as both an electrical and a mechanical join between the two tubes. In band III, however, the length of the tube is such that it can be constructed in one piece, so that the fixing has only to hold it in the correct position relative to the cross-arm.

The insulator at the centre of the dipole also presents some interesting problems. These can be summarized in three parts, (a) the mechanical support of the elements, (b) the electrical characteristics of the insulator and conductors associated with it, and (c) the method of making the connection to the down lead. The mechanical problems in a dipole insulator are very similar to those of the centre fixing of a parasitic element, namely good mechanical strength, with no places of excessive strain in the elements themselves. The second factor, the electrical properties of the insulator, grow more important as the frequency is increased, and therefore need greater consideration in band III as compared with band I. It has been seen in an earlier chapter that the dipole has a feed-point impedance, and this should be approximately the same as the characteristic impedance of the cable. Now, the theoretical impedance of a dipole is that at the inner ends of the two elements, and this will only have the same value at the point where the cable is connected if the leads between the elements and the cable connection form a transmission line of the correct impedance. In practice, however, an aerial is usually designed with a given insulator in mind, and the elements adjusted to counteract the extra inductance or capacity introduced by the leads. It means that if an aerial working on one frequency has to be redesigned to operate at a different frequency, then the elements will not necessarily be scaled in proportion to the wavelength, as the capacity or the inductance of the insulator will remain constant. It has been assumed that the material used for the insulator does not introduce resistive losses, and in practice this will be the case.

The third factor mentioned was the method of connecting the cable. Only coaxial cables will be considered, as with most aerials using balanced 300 Ω cable it is connected externally, and the problem is very much simpler. With coaxial cable, not only has there to be a good electrical and mechanical connection between the inner and outer conductors and their appropriate terminals, but the whole



[*By courtesy, Belling & Lee, Ltd.*]

Fig. 64. An example of the connection of coaxial cable to a dipole insulator

unit must be made waterproof, so that there is no risk of water entering the inside of the cable. One method is shown in Fig. 64, where it can be seen that the cable passes into a conical PVC sleeve, which can be cut to such a length that it fits snugly over the outer of the coaxial cable. The conductors are fixed to terminals moulded into the insulator itself, and the whole assembly fits inside the cross-arm of the aerial. This arrangement has been found to be satisfactory in practice, with very little risk of the cable being damaged by the ingress of water.

DESIGN OF CROSS-ARM AND MAST

The cross-arm is usually of drawn tubing of circular cross-section, but other cross-sections, such as square, have been used. In calculating the mechanical strength required for the cross-arm, both the windage on the cross-arm itself and the end loading from the elements have to be considered. This is usually a very strong part of an aerial, and it is seldom that the cross-arm breaks, although there have been cases of aerials with very long cross-arms which have developed a marked sag. This might not seriously affect the electrical performance of the aerial, but it makes the installation look very untidy.

The mast is a very important part of an outside installation, and it has already been seen that for best results the aerial should be as high as possible. It is obviously not necessary to have every aerial mounted on the top of a very tall mast, so that they vary in length from a few feet to as much as fourteen feet, and have diameters anywhere between 1 and 2 in. Some are straight while others are cranked. The reason for having cranked masts is that with vertically polarized aerials it is possible, with a shorter mast, to hold the lower elements clear of the roof. There are other reasons, such as enabling the mast to clear any overhang on the chimney. It is interesting to note that in the U.S.A. where all the aerials are horizontal, nearly all the installations have straight masts. There is another, non-technical, reason for this, in that the masts are sold separately from the aerials, and cannot be tailored to suit a particular aerial. In Great Britain, however, aerials are usually sold in conjunction with their masts, so that cranked or other specially shaped masts are possible.

A large number of variations have now sprung up with the addition of band III aerials to masts of band I systems. It would be impossible to give a list of the different arrangements that are used as there are so many of them. The aim is to have the two aerials, one for each of the bands, spaced as far as possible from each other, and at the same time have a structure that is mechanically strong. The mechanical strain at the base of the mast is very important when extra aerials are added to an existing array, as the original mast was probably not designed to carry the extra load. If the manufacturers' recommendations are adhered to then there should be no risk, but unfortunately there are many installations where unnecessary risks have been taken, giving rise to aerials that are not only unsafe, but liable to sag and look untidy.

METHODS OF FIXING THE INSTALLATION

Last but not least in outdoor installations is the means of fixing the mast to the building. Most aerials are held in this way, although there are a few cases where for some reason or another the mast is separate from the building, and clamped to the top of its own pole or tower.

The two most usual methods of fixing the mast to a building are by a chimney or a wall bracket. Whichever method is used the bracket must be sufficiently strong to support the aerial under all conditions, especially in strong or gusty winds. In a wind the aerial will not only sway, but there will be torsional strain on the mast, so that it must be firmly gripped by the support bracket.

With a chimney-mounted aerial the bracket is held by a wire or strap placed round the chimney, and tensioned by some device on the bracket. The chimney is therefore in compression, and the strain is taken by the four corners, and not only by the support bracket. It is essential to have a chimney that is structurally sound, but with an average sized chimney, if the lashing is more than a few courses of brick below the top, then the weight of these bricks will prevent any serious strain on the remainder of the brickwork.

With a wall bracket the position is different, as now all the strain from the aerial has to be taken by a few fixing points. Each one, which will consist of a nail or bolt in the building, has to be of sufficient strength, with no risk of it becoming dislodged. The part of the building that is used must be sufficiently strong, and this is usually the case if one of the main walls is used. Care must be taken if other parts of a building, such as window-sills, are used, and it must be established that these are securely fixed to the main structure.

LOFT AERIALS

An increasing number of loft installations are now being used, and in these many of the design features of outdoor aerials are not required. Furthermore, they are not usually seen once they are installed, so that the styling that is essential for an indoor aerial is not necessary. It must be remembered that in most loft installations the aerial has to be taken up through a small trapdoor, so that it has to be assembled after it has been taken up to the attic. Ease of assembly is therefore a very important factor in this case.

The mechanical design of these aerials is usually based on their equivalent outdoor aerial, but there is also a number of types, both for band I and band III reception, which have been designed specially for this application. Although mechanical strength is not so important in this case, it is still important that no poor electrical connection should develop during the life of the aerial. This would seriously affect the quality of the picture, and would be a fault that would be difficult to trace.

SUMMARY

Various aspects of the mechanical design of aerials have been discussed, ranging from the elements themselves to the fixing bracket for the whole array. Unfortunately, there are many aerials that have twisted since they were first installed, or one or more of their elements have broken off. This can only be blamed on the shortcomings of the mechanical design of the aerials together with, in some cases, poor installation. A large number of aerials with all the masts vertical and all the elements in their correct places can look tidy, but it only requires a few of them to be broken or bent for it to become a blot on the skyline.

11

Installation of Aerials

Planning – The installation itself – Checking – Examples of poor pictures – Earthing

MANY of the advantages to be gained from a well designed aerial will be lost if it is not installed correctly, so that in this chapter some of the aspects of aerial installation will be discussed. This is a subject that can only be learned by practical experience, and there are many 'tricks of the trade'. It is not the purpose here to describe in detail how an installation should be carried out, as this will vary from site to site, but to indicate some of the points that should be borne in mind.

There are three parts to any installation, the planning, including the choosing of the aerial and accessories, the erection of the aerial and securing the feeder, and finally the testing and adjustment of the whole system.

PLANNING THE INSTALLATION

Choice of aerial, feeder and accessories need not be discussed in detail, as the various items have already been described. All installations should be carried out on the basis of their staying up for many years, as it is a nuisance to have to repair or replace a relatively new aerial. It must be remembered that if the time for erecting ladders, etc. is considered, it can be an expensive job merely to re-align the aerial. It is best, therefore, to be sure that the whole installation is correct when it is first installed.

The choice of cable will depend on the strength of the signal picked up by the aerial and the distance from it to the receiver. It is always an advantage to have plenty of signal at the receiver. In fringe areas, therefore, where the signal level is low, and where the aerial will probably be installed high on the building, low-loss cable will be needed. If,

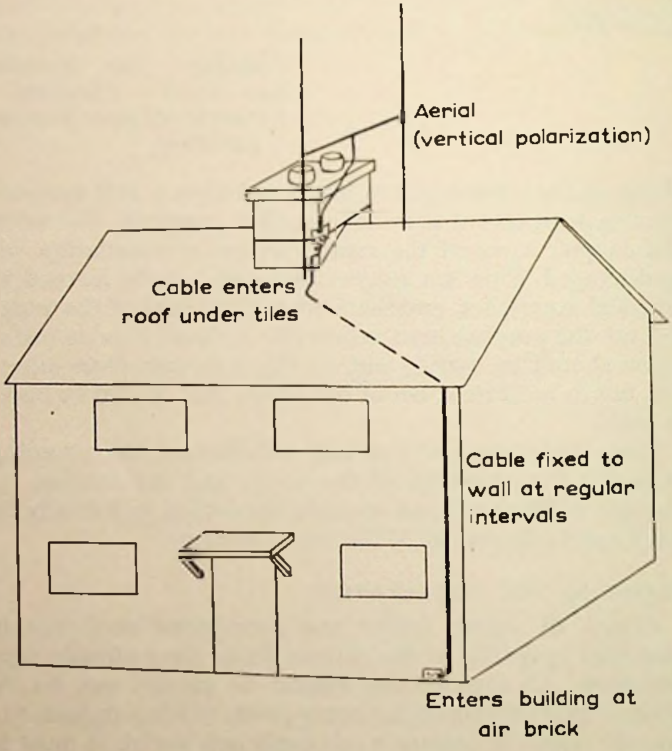


Fig. 65. An example of an installation using coaxial cable

however, there is a higher signal level, it will often be satisfactory to use the less expensive cable that has a greater attenuation. Then there are all the accessories, such as outlet boxes, to consider. Items such as these are not always necessary from the electrical point of view, but they complete any installation.

Once the component parts of the installation have been chosen, the layout must be planned. The first question is, 'Where is the receiver to be installed?' This should really be answered by considering it as part of the furnishing of the house, although it is always an advantage to keep the technical aspects in mind. Having settled the position for the receiver the location for the aerial should be considered. It will be assumed in this case that an outdoor aerial will be needed, as it is only with this type of installation that many

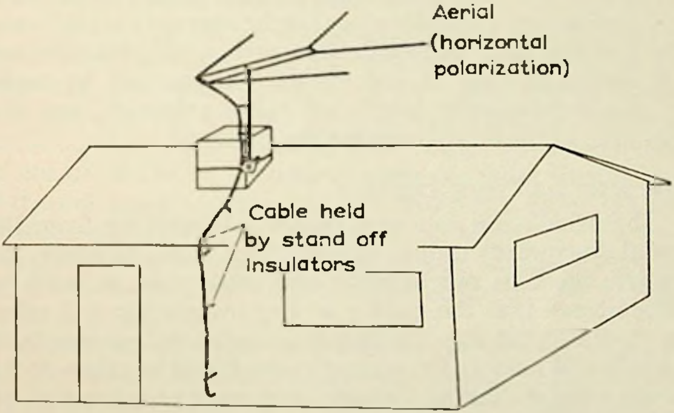


Fig. 66. Typical installation using balanced 300 Ω cable

of the problems arise. However, in areas where there is plenty of signal and very little risk of ghost signals it will be possible to use an indoor aerial, while in other areas with slightly less signal a loft aerial will be possible. But whether it is a loft or outside aerial, the correct position for it will have to be found and the route for the cable determined.

The choice of a wall-mounted, or one of the many types of chimney-mounted aerial will depend on local conditions, such as the strength of the signal, the presence of interference and the possibility of ghost signals. In order to illustrate the important points, an installation requiring an aerial at chimney height will be discussed. In this case it will be necessary to choose a suitable chimney, which should be as near as possible to the receiver, but if there is any likelihood of ignition interference, as far as possible from road. These two requirements are often in direct conflict with one another, and in fact the choosing of the best position for an aerial is something that can only come with experience.

With the position of the aerial and the receiver decided, a route for the cable can be found. This should be as direct as possible, and a suitable place for the entry of the cable into the building must be found. Two such typical installations are shown in Figs. 65 and 66. An estimate can be made of the approximate length of cable required, and the planning of the installation is then complete.

THE INSTALLATION ITSELF

The installation can now be started, working from the aerial downwards to the receiver. First of all, however, the ladders must be put in place and made firm. It must be remembered that the quality of any installation will often be judged by the way in which it is carried out, so that both outside and indoors the greatest care should be taken of the house and furnishings. Outside, care must be taken that no tiles are broken, and that undue weight is not put on the guttering or that damage is not done to the outside of the building. Be sure that all the necessary parts for the installation are available, as well as the correct tools, as otherwise a lot of time can be wasted. It is also essential to use the correct tools for the assembly of aerials, as the wrong spanner, or a pair of pliers, can easily damage the protective coating that has been applied. Rust or corrosion may then take place, which may lead to the aerial becoming unsafe. These are all points that are obvious to a good workman, but which are often forgotten.

The fixing bracket can now be installed. In the case of a chimney-mounted aerial this means putting the lashing wire or strap round the chimney, and tensioning it until the bracket is securely fixed. All except the most fragile chimney will hold the average aerial and this is, in fact, a very satisfactory method of support. Care must be taken with wall-mounted aerials, as the weight of the aerial and any stresses on it from winds will have to be taken by the fixing nails and by the local area of brickwork surrounding them. It must be established that they are secure and that the wall is sufficiently strong for the installation.

The cable should now be fixed to the aerial, but the exact method will depend on the design of the dipole insulator. Remember, however, that the cable will be exposed to all weathers, and water entering it can give rise to many troubles later on. Another point to watch is the connection of the conductors on balanced feeder, or the inner conductor of coaxial cable. In both cases these are fairly fragile, and if there is any corrosion they will break very easily. This is closely tied up with the design of the aerial, as in a well designed cable connection there will be sufficient support for the cable to ensure that these small conductors are not strained in any way.

The aerial can now be placed in the bracket, and the screws or nuts tightened sufficiently to keep it in position. The final securing of the aerial will take place later, when it has been adjusted to give the best picture. At this stage it will only be necessary to point the aerial in approximately the correct direction. This can usually be found from local landmarks, but in extreme cases it will be necessary to resort to a map and compass.

No rigid rules can be laid down for the installation of the cable, but the route from the aerial to the receiver should be as direct as possible. Coaxial cables can quite satisfactorily be run alongside guttering or other metal objects, or even through a conduit, although it is not recommended that it is run alongside mains wiring, both from the safety aspect and also from the probability that this might give rise to interference. Balanced feeder on the other hand is more difficult to install, as it has to be kept away from all objects, brickwork, tiles, gutters, and even the mast of the aerial itself. Special stand-off insulators have been developed for this purpose which support the cable, and which introduce negligible loss into the feeder. It is usual to twist balanced feeder two or three times between each insulator. This nominally reduces stray pick-up on the feeder, and it also gives a finished appearance to this type of installation.

The cable should be fixed at sufficiently close intervals for it to remain secure at all times. It should not be draped over gutters without a suitable clip or support, otherwise movement of the cable on the edge of the gutter will quickly cause damage to the insulation or the outer conductor. It is possible to bring the cable over the tiles, and clips are available for holding it in place. One method that is sometimes used is to bring the cable into the attic under one of the tiles, and this can often be done without removing or damaging any of them. The advantage of this is that there is then no need for a long cable run exposed to the weather, as it enters the building as soon as it reaches the roof. There is also the advantage that there is very little risk of water entering the building alongside the cable. There are other ways of bringing the cable into the building, through the woodwork at the side of a window, through an air brick and as a last resort through a hole in the outside wall. A small U shaped loop should be made in the cable just before it enters the building, and this will act as a water trap, to prevent water running down the cable and into the house. As a further precaution it is often advantageous, if any holes are drilled, to make them slope upwards as they enter the building.

CHECKING THE INSTALLATION

The installation is now complete except for any final adjustment that may be necessary to the aerial. The last step is therefore to connect a receiver to the cable and observe the quality of the received picture. The most usual troubles are lack of signal and the presence of ghost signals. The first of these will be considered later, while if ghosts are present it will be necessary to make adjustments to the aerial. It should be moved round and if possible moved horizontally until they are removed, or of sufficiently small amplitude to be unnoticed. This is a two-man job, one observing the screen while the other adjusts the position of the aerial. When the correct position has been found then the fixing nuts should be tightened, and a final check made on the complete installation.

It has been assumed that only one channel will be received, but the same principles apply if reception is possible from more than one station, except that the problem of adjusting the aerial becomes more involved. The aim is to get a clear, ghost-free picture on all the channels, and to have the signals all of approximately the same amplitude. The choice of the aerial plays a very important part here. It will always be found to be easier to have an installation satisfying these conditions if there are separate aerials for the different channels, with the signals being combined with a suitable diplexer unit. For reasons of cost and ease of erection, combined aerials are often used, and in the majority of cases these give very satisfactory results, but with them probing on site becomes far more important.

EXAMPLES OF POOR PICTURES

It is interesting to investigate some of the poor results that have to be put right at this last stage in the installation. First of all there may be poor signal strength. This will show up as a 'noisy' picture, which in many cases will not hold line or frame synchronization. There are several ways of improving the signal strength, quite apart from resorting to a more expensive aerial with a higher gain. The first is to be sure that the aerial is pointing in the correct direction, which might not be the direction to be expected from a bearing on the transmitter. The next is to see if the aerial can be moved in any way. Usually an increase in the height above the ground will increase the signal, but also in most cases a lateral movement of the aerial will also produce variations in the signal strength. Another corner of the chimney can therefore be tried, or even another chimney if one is available. A small increase can sometimes be obtained by using a cable with a lower loss. There are, therefore, several different possibilities to try, but with few exceptions the use of an extra amplifier is not the solution to a noisy picture. Most modern receivers have sufficient gain for the 'noise' of the first valve to be seen on the screen when the gain is at maximum, and any additional amplifier will produce a signal to noise ratio that is no better than that of the original receiver. The main exception to this is when a very long down-lead is used, when the loss in this may be appreciable; in this case it is sometimes an advantage to have an additional amplifier at the top of the feeder near to the aerial.

The second and more important cause of poor picture quality is ghost signals. The choice of aerial is very important here, although it is sometimes found that an aerial that has poor ghosting properties in one location may be very good elsewhere. To remove ghosts, the aerial should be moved round until the best picture is obtained. If, however, this technique does not give satisfactory results, then the position of the aerial can be moved. Very small movements can produce very marked changes in the visibility of the ghosts, for instance, if the aerial is supported by a cranked mast, then small movements of this, keeping the fixing bracket in the same place, and the aerial pointing in the same direction, can produce marked changes. The practical removal of ghost signals is an art that can only be learned by experience. No hard and fast rule can be given, and the solution will be different with every installation. It is a problem that is very closely linked with the aerial, as once the main and ghost signal have entered the cable together, the separation of them at a later stage becomes impossible.

The third thing to look for is interference signals. The most important point is that the aerial should be as far as possible from any source of interference. If it is found that this is troublesome, and if it is also established that it is entering the receiver through the aerial, then the only solution is an aerial with a higher gain and better directional properties. It is always much better to suppress the interference at the point where it is generated, but this is not always possible.

EARTHING THE INSTALLATION

It is always advisable to earth the mast of an outside installation by running a fairly heavy conductor from it to an earthing point. This gives a small amount of protection against lightning, and it also keeps the installation safe in the event of mains voltage coming in contact with any part of the aerial system. There is an important point to watch in this respect. In some receivers the failure of a certain condenser in combination with the live and neutral leads being interchanged, can cause the voltage on the aerial to rise to that of the live side of the mains. This can be dangerous, especially when it is remembered that the aerial is often adjusted from the top of a ladder, and even a small shock could make one lose balance. It is advisable, therefore, to check that the aerial is perfectly safe before adjustments are made to it. This may seem to be an unnecessary precaution, as a fault of this type is so rare, but as it is so dangerous it should not be overlooked.

12

Measurement of Aerial Characteristics

Testing site – Measurement of directional characteristics – Measurement of gain – Measurement of impedance – Summary

IT has been seen that there are a number of electrical characteristics that describe the performance of an aerial, the most important of these being the directional characteristics, the forward gain and the impedance. Conventional equipment can be used to measure these characteristics, but great care has to be taken in siting the aerial during the measurements, otherwise false results may be obtained.

The most satisfactory method is to use a reliable testing site, so this will be discussed in greater detail first.

TESTING SITE

It is essential when measurements are made on a receiving aerial that the signal arriving at it has a plane-wave front, and is of uniform field strength in the region where the tests are taking place. These conditions are rarely encountered in a practical installation, but it is only by doing this that measurements can be repeated, either at the same site at other times, or in other locations. It is usually reckoned that the measurements made under ideal conditions represent the average performance of an aerial when used under practical conditions. What, therefore, are the requirements for a testing site ?

It is assumed that it is necessary to have a uniform field strength at the place where the aerial is to be tested. This means that the electric vector should be of constant amplitude, and be in a uniform direction, i.e. vertical or horizontal at all points, depending on the polarization. There must be no standing-wave pattern at the site, especially if accurate directional characteristics are required. A very small standing-wave pattern can fill in the minima of a polar diagram. As an example, a voltage standing-wave ratio of only 1·2 : 1 could make an ideal aerial, with zero response in a certain direction, have an apparent front to minimum ratio of only 20 dB.

It is inevitable that there will be a variation of the field strength with increase of height above the ground. It is essential, therefore, that the aerial is placed at a standard height above the ground, particularly if comparison is to be made between two different aerials. A reasonable height for television receiving aerials is twenty to thirty feet, as this represents the height above the ground of a typical practical installation.

The size of the testing site will depend on the accuracy required for the measurements, and the origin of the radiation. It is possible to use either the radiation from a distant transmitter or else the signal radiated from a local aerial. Whichever method is used there will be a direct wave to the aerial being tested. There will also be a risk of reflection from local objects, such as trees at the edge of the site, or the hut or building in which the measuring equipment is housed. These reflected signals will give rise to a standing-wave pattern which will lead to erroneous results.

Usually a larger area of flat ground will be required if a distant transmitter rather than a local source is used, as there will then be greater illumination of objects at the edge of the site. Measurements of directional characteristics also require more space than gain measurements. In the former case the standing-wave pattern will change the minimum of the polar diagram where the response of the aerial may be at least 30 dB below that in the forward direction. For gain measurements, however, the aerial is always directed towards the direct signal, and a standing-wave pattern has less effect on the measurement. It is important, however, that the field is uniform in the region of the aerial being tested and that it is polarized in the correct direction.

It is possible to calculate the area required for making measurements on aerials, but a given site should be checked by electrical measurements before it can be considered to be satisfactory. It is usually more convenient to have a local source of radiation than to rely on a distant transmitter, as it is then possible to test the performance of an aerial over a range of frequencies. There is another advantage in having this arrangement, the possibility of interchanging the signal source and the receiver. It has been shown in Chapter 2

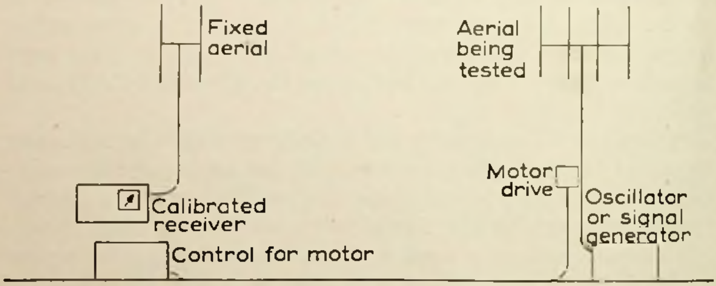


Fig. 67. The measurement of aerial directional characteristics

that this can be done without altering the performance of the aerial, and it is often more convenient to make tests on a receiving aerial by radiating a signal from it.

Examples of the measurement of the directional characteristics, the forward gain and the impedance will now be given, and in the first two it will be assumed that the source of radiation is local, although it is possible to make these measurements by using a distant transmission.

MEASUREMENT OF DIRECTIONAL CHARACTERISTICS

The aerial to be tested should be mounted at the top of an isolated pole in the centre of the testing site, at a height of approximately 30 ft above the ground. There must be some means of rotating it through 360°; this can be achieved by fitting a motor drive to the mast. The second, fixed, aerial will be at the edge of the testing site, and it is convenient to carry out the measurements from a point near to this second aerial.

An example of the method of making this measurement is shown in Fig. 67. A signal generator is connected to the aerial being tested, and a receiver to the fixed aerial. There are various precautions that have to be made if reliable results are to be obtained. It is assumed that the site has been shown to be satisfactory, and that there are no reflections from objects at the edge of it. Two sources of error will be mentioned, but there are other factors that can cause incorrect results. First, there should be no direct interaction between the signal source and the receiver, and it is for this reason that it is suggested that wherever possible they should be physically separated from each other. Secondly, there must be no radiation from the lead connected to the aerial under test. This is likely to happen if a horizontal type aerial is being tested, using, say, a balanced feeder, but connected to a signal source which has a coaxial output. In this case a balance-to-unbalance transformer has to be introduced into the system, and care taken that there is no out of balance signal on the aerial.

Errors usually show up as asymmetry in the measured polar diagram, even though the aerial being tested may be symmetrical. Errors will be most marked in the minimum of the response pattern, the depth of the minimum being changed from the true value. In serious cases it is possible for the width of the forward lobe to be changed, and also for extra minima to be introduced into the pattern. Incorrect polar diagrams can be very misleading, as this will give a false picture of the performance of the aerial.

MEASUREMENT OF GAIN

The aerial to be tested should again be mounted at a height of about 30 ft on an isolated pole in the centre of the testing site. It has already been shown that the site requirements are different than for the measurement of the directional characteristics. It can usually be assumed that a site that is satisfactory for measuring directional characteristics will be more than sufficient for gain measurements.

It has been seen that the gain of an aerial is always given in relation to some reference aerial, the reference aerial usually being a half-wave dipole. This means that the signal received by the aerial is measured, then the aerial replaced

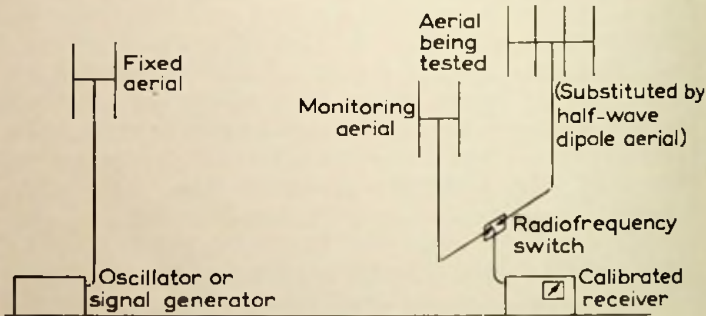


Fig. 68. The measurement of aerial gain

by the reference aerial, and the signal measured again. Now, in practice it usually takes some time to change these aerials, and there is always a risk that one of the characterisics of the measuring equipment will have drifted. One method of overcoming this difficulty is illustrated in Fig. 68, where it can be seen that a third, monitoring, aerial has been introduced. This should be fairly near to the aerial being tested, but of course not so near that it will change its electrical performance. A signal is radiated from the fixed aerial, and received by the aerial under test and the monitoring aerial. The aerial being tested is now replaced by the half-wave dipole reference aerial, and the signal again compared with that from the monitoring aerial. From this it is then possible to calculate the gain of the aerial.

This method has the advantage that it eliminates the errors due to drift in the equipment, and that it can be employed over a range of frequencies. As in all measurements on aerials, there is a possibility of errors, particularly if radiation is allowed to occur from parts of the system other than the aerials themselves. One grave source of error can arise from the positioning of the reference dipole aerial. This must be placed in exactly the same position as the aerial being tested, in particular at exactly the same height above the ground.

It is difficult to make accurate measurements of the forward gain, and unless great care is taken, with particular attention to all the details, it is impossible to arrive at a result that can be repeated at a later date under different conditions. As the gain is a function of the aerial itself, it should remain constant, even though its measurement may be made under a variety of site conditions.

MEASUREMENT OF IMPEDANCE

This measurement differs from those described above in that it does not depend on a signal arriving externally to the aerial. For this reason a large testing site is not required, although it is advisable to have the aerial as far as possible from other objects. In particular the measuring equipment itself has to be away from the aerial under test.

One method of measuring the impedance is illustrated in Fig. 69. In this an RF bridge is used, and requires the use of both a signal generator or oscillator and a receiver. The aerial is connected to the bridge by a length of cable, which can be of the type normally used with the aerial. The reading on the bridge gives the impedance at the lower end of the cable, and this can easily be expressed as a standing-wave ratio on the cable. If, however, the impedance at the terminals of the aerial is required, it is possible to make a correction for the cable by using a Smith chart.

There are many places where errors can be introduced in this measurement. The aerial should be mounted as high as possible above the ground, as the ground reflection of the signal can influence the impedance of the aerial. The use of coaxial cable between the aerial and the bridge can also influence the result, especially if the aerial is electrically balanced. It is essential in this case to use a balance-to-unbalance transformer between the aerial and the cable.

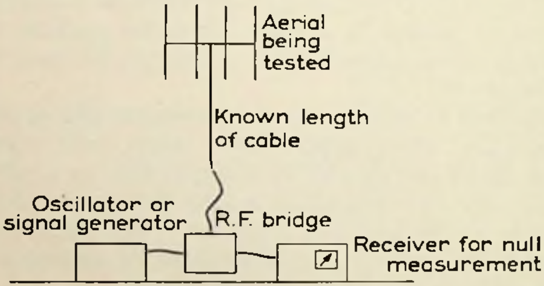


Fig. 69. The measurement of aerial impedance

This must be designed in such a way that it is possible to calculate the impedance of the aerial to which it is connected, and for this reason it is usually better to use transformers consisting of lengths of transmission line rather than those constructed with coils.

SUMMARY

It can be seen that expensive equipment and a proper testing site are essential for reliable measurements of the performance of aerials. Great care must be taken to eliminate all the errors that are liable to occur, and it is by no means easy to establish methods which can be repeated, with a certainty of obtaining the same result each time.

It is possible to make a comparison between aerials using a poor site and inferior equipment, but this type of measurement is of very little value, as the results so obtained can be very misleading.

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Future Development

A GENERAL description has been given of the aerials required for the reception of broadcast and television signals. The basic principles behind their design have been discussed, and their practical use has been considered. Other items that have been included are the various types of cable and the many accessories that are available.

The whole subject is in a state of flux, with new aerials and improvements to existing types being produced all the time. Many of the changes are associated with the mechanical design in an effort to reduce their cost to the lowest possible value. New shapes are sometimes developed for commercial and not technical reasons, although the changes are often backed up by scientific reasons. It is not the purpose of this chapter to forecast the shape of the aerials of the future, but to indicate the trends and future developments that are likely during the next few years.

There is a continual increase in the power being radiated by transmitters, and also in the input sensitivity of receivers. This means that the strength of the signal in the service area is increasing, thus reducing the need for aerials with a high gain. This will mean smaller outdoor aerials, and an ever increasing use of loft and indoor aerials. This is again linked up with the design of receivers, as improvements in the automatic gain control of television receivers lead the way to an even greater use of indoor aerials. This in turn gives rise to a class of aerial designed for use in the same room as the receiver, and made so that they will blend with the internal furnishings of a room.

Another development that is imminent is the use of ferrite aerials for television reception. The advantage is that it will then be possible to construct a much smaller aerial, which will either be less noticeable when used as an outdoor installation, or for indoor use. This development is dependent on the availability of suitable ferrite materials, which have the correct characteristics at band I or band III frequencies. Until these materials are available, it is difficult to obtain a reasonable impedance match between the aerial and the cable. It is essential when using any type of aerial for television reception to be able to separate it from the receiver by a length of cable, otherwise there is a possibility of ghost problems arising.

It is anticipated that in the not too distant future more use will be made of bands IV and V for television reception. When this takes place there will be a need for many more outside aerials. These will be different from those used for the lower bands, as the use of higher frequencies makes sheet and corner reflectors a possibility.

The introduction of colour television will also have its influence on the design of aerials, although it is not anticipated that this will produce any drastic changes in their design.

Appendix 1

THE ratio between the amplitude of two signals is often given in terms of decibels. In terms of power, if there are two signals generating powers P_1 and P_2, then the ratio between them is given by r decibels, where :

$$r = 10 \log_{10} \frac{P_1}{P_2}$$

In terms of the voltage, if two signals produce voltages V_1 and V_2 across resistances of R_1 and R_2, then the ratio between them is r decibels, where :

$$r = 20 \log_{10} \frac{V_1}{V_2}\sqrt{\frac{R_2}{R_1}}$$

Normally the values of the resistances are equal, i.e. R_1 and R_2 have the same value, in which case :

$$r = 20 \log_{10} \frac{V_1}{V_2} \text{ decibels}$$

As decibels are calculated in terms of logarithms, successive changes of signal level are computed by the addition or subtraction of the decibel changes. As an example, if an aerial has a gain of 6 dB compared with a half-wave dipole, and if this is connected to a feeder of loss 3 dB, then amplified by an amplifier with a gain of 10 dB, then the total change between the signal on the ouput of all this and that from the dipole on its own, assuming both are connected to the same value resistance, is :

$$6 - 3 + 10 = 13 \text{ dB}$$

The voltage and power ratios for various decibel values are given in Table 6.

Table 6

Decibels	*Voltage ratio*	*Power ratio*
100	100,000	10^{10}
90	31,620	10^9
80	10,000	10^8
70	3,162	10^7
60	1,000	10^6
50	316	10^5
40	100	10^4
30	31·6	10^3
20	10	10^2
10	3·16	10
0	1	1
−10	0·316	10^{-1}
−20	0·1	10^{-2}
−30	0·032	10^{-3}
−40	0·01	10^{-4}

The voltage ratio corresponding to a given number of decibels is given in Table 7.

Table 7

dB	0	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9
20	10·00	10·12	10·23	10·35	10·47	10·59	10·72	10·84	10·96	11·09
19	8·91	9·02	9·12	9·23	9·33	9·44	9·55	9·66	9·77	9·89
18	7·94	8·04	8·13	8·22	8·32	8·41	8·51	8·61	8·71	8·81
17	7·08	7·16	7·24	7·33	7·41	7·50	7·59	7·67	7·76	7·85
16	6·31	6·38	6·46	6·53	6·61	6·68	6·76	6·84	6·92	7·00
15	5·62	5·69	5·75	5·82	5·89	5·96	6·03	6·10	6·17	6·24
14	5·01	5·07	5·13	5·19	5·25	5·31	5·37	5·43	5·50	5·56
13	4·47	4·52	4·57	4·62	4·68	4·73	4·79	4·84	4·90	4·96
12	3·98	4·03	4·07	4·12	4·17	4·22	4·27	4·32	4·36	4·42
11	3·55	3·59	3·63	3·67	3·71	3·76	3·80	3·85	3·89	3·94
10	3·16	3·20	3·24	3·27	3·31	3·35	3·39	3·43	3·47	3·51
9	2·82	2·85	2·88	2·92	2·95	2·98	3·02	3·06	3·09	3·13
8	2·51	2·54	2·57	2·60	2·63	2·66	2·69	2·72	2·75	2·79
7	2·24	2·26	2·29	2·32	2·34	2·37	2·40	2·43	2·46	2·48
6	2·00	2·02	2·04	2·06	2·09	2·11	2·14	2·16	2·19	2·21
5	1·78	1·80	1·82	1·84	1·86	1·88	1·90	1·93	1·95	1·97
4	1·58	1·60	1·62	1·64	1·66	1·68	1·70	1·72	1·74	1·76
3	1·41	1·43	1·44	1·46	1·48	1·50	1·51	1·53	1·55	1·57
2	1·26	1·27	1·29	1·30	1·32	1·33	1·35	1·36	1·38	1·40
1	1·12	1·14	1·15	1·16	1·18	1·19	1·20	1·22	1·23	1·24
0	1·00	1·01	1·02	1·04	1·05	1·06	1·07	1·08	1·10	1·11
−0	1·00	0·989	0·977	0·966	0·955	0·944	0·933	0·923	0·912	0·902
−1	0·891	0·881	0·871	0·861	0·851	0·841	0·832	0·822	0·813	0·804
−2	0·794	0·785	0·776	0·767	0·759	0·750	0·741	0·733	0·724	0·716
−3	0·708	0·700	0·692	0·684	0·676	0·668	0·661	0·653	0·646	0·638
−4	0·631	0·624	0·617	0·610	0·603	0·596	0·589	0·582	0·575	0·569
−5	0·562	0·556	0·550	0·543	0·537	0·531	0·525	0·519	0·513	0·507
−6	0·501	0·496	0·490	0·484	0·479	0·473	0·468	0·462	0·457	0·452
−7	0·447	0·442	0·436	0·432	0·427	0·422	0·417	0·412	0·407	0·403
−8	0·398	0·394	0·389	0·385	0·380	0·376	0·371	0·367	0·363	0·359
−9	0·355	0·351	0·347	0·343	0·339	0·335	0·331	0·327	0·324	0·320
−10	0·316	0·313	0·309	0·306	0·302	0·298	0·295	0·292	0·288	0·285
−11	0·282	0·279	0·275	0·272	0·269	0·266	0·263	0·260	0·257	0·254
−12	0·251	0·248	0·246	0·243	0·240	0·237	0·234	0·232	0·229	0·226
−13	0·224	0·221	0·219	0·216	0·214	0·211	0·209	0·206	0·204	0·202
−14	0·200	0·197	0·195	0·193	0·190	0·188	0·186	0·184	0·182	0·180
−15	0·178	0·176	0·174	0·172	0·170	0·168	0·166	0·164	0·162	0·160
−16	0·158	0·157	0·155	0·153	0·151	0·150	0·148	0·146	0·144	0·143
−17	0·141	0·140	0·138	0·136	0·135	0·133	0·132	0·130	0·129	0·127
−18	0·126	0·124	0·123	0·122	0·120	0·119	0·118	0·116	0·115	0·114
−19	0·112	0·111	0·110	0·108	0·107	0·106	0·105	0·104	0·102	0·101
−20	0·100	0·099	0·098	0·097	0·096	0·094	0·093	0·092	0·091	0·090

Appendix II

It was shown in Chapter 4 that the gain of a Yagi type aerial can be derived from its directional characteristics by using special graph paper. The response pattern of the aerial in a plane at right angles to the axis of the elements is plotted on Cartesian co-ordinates, the vertical scale being the power response and the horizontal scale being given by the following formula. The distance x corresponding to an angle ϕ from the axis of the array is given by :

$$x = k\int_0^{\phi} F(\phi)\mathrm{d}\phi$$

where $$F(\phi) = \sin\phi\int_0^{2\pi}\frac{\cos^2(\pi/2\cos\eta\sin\phi)}{1-\cos^2\eta\sin^2\phi}\mathrm{d}\eta$$

and $$k = \frac{1}{\int_0^{2\pi}F(\phi)\mathrm{d}\phi}$$

If the height of the vertical scale is unity to the maximum of the curve, then the gain G of the aerial, relative to a half-wave dipole, is given by the reciprocal of the area under the curve. This formula only applies if the individual elements each have directional properties similar to that of a half-wave dipole. An example of the paper is shown in Fig. 70, and an illustration of its use can be seen on page 45, Fig. 15.

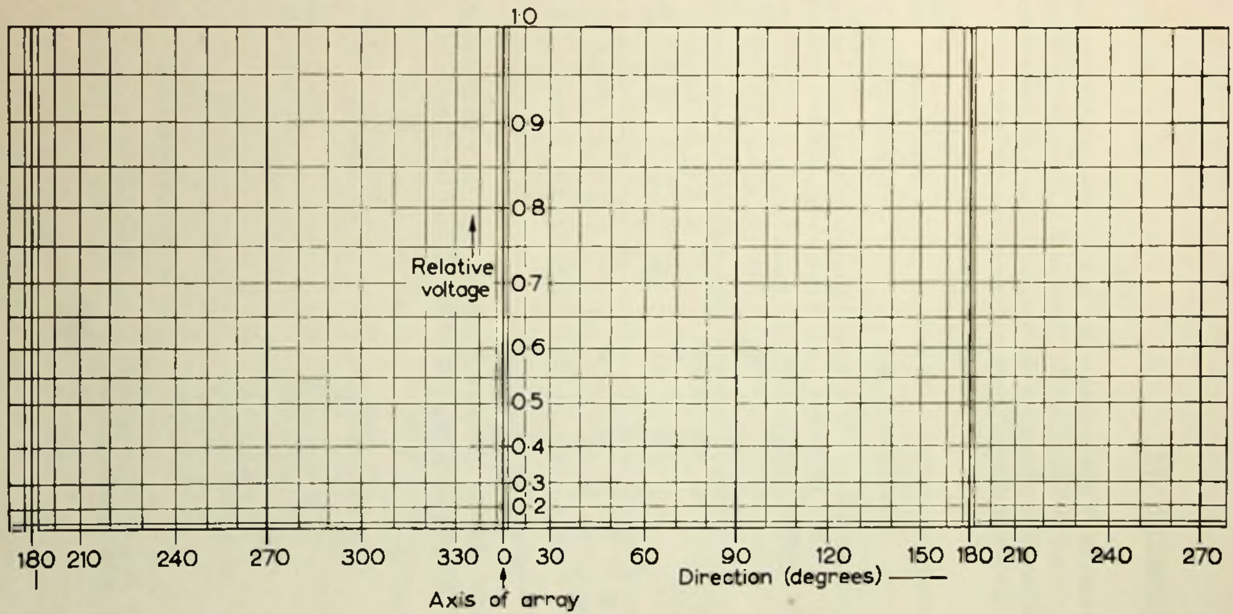

Fig. 70. Special graph paper—Calculation of gain of a linear array of dipoles from its directional characteristics

Appendix III

THE values of the resistors for use in star and L type resistive networks, described in Chapter 9, is given in the following table. This also gives the loss introduced by the network, and the attenuation between the various outlets.

Table 8

Type of feeder	*No. of outlets*	*Star network*		*L network*			
		Resistor values Ω	*Loss or Attenuation* dB	*Resistor values* *Series* Ω	*Parallel* Ω	*Loss* dB	*Attenuation between outlets* dB
75 Ω coaxial	2	25	6	100	150	6	6
	3	38	9½	180	112	14	28
	4	45	12	257	100	17	34
300 Ω balanced	2	50	6	200	600	9½	19
	3	75	9½	360	450	14	28
	4	90	12	514	400	17	34

These are the calculated values, and in a practical network the nearest preferred values would be chosen.

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