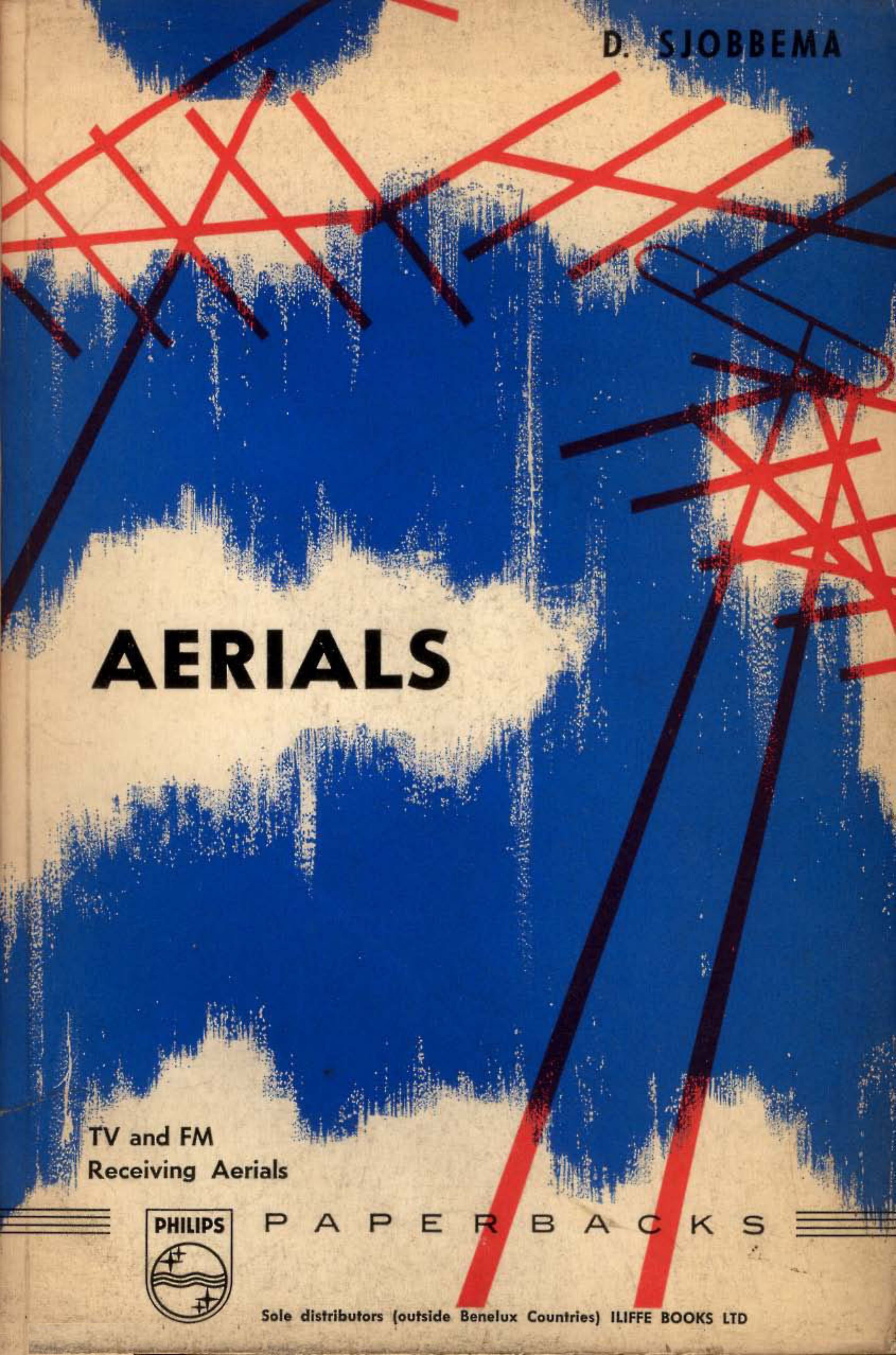

D. SJOBBEMA

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TV AND FM RECEIVING AERIALS

D. J. W. SJOBBEMA

PHILIPS PAPERBACKS

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PREFACE

It was not so very long ago that the aerial was looked upon rather as the poor relation of the radio receiver.

Generally, when buying a radio set we judge the styling and enquire as to the performance, but disregard the fact that the fullest advantage can be taken of the performance, which includes sensitivity, satisfactory short-wave reception and quality of tone, — all very important details in themselves — only if the aerial to which the set is to be connected is installed in the proper manner and also meets certain conditions. For the best results the receiver and the aerial should be regarded as integral parts of a whole receiving system.

With the introduction of F.M. broadcasting and of television the importance of the aerial has come more to the fore, especially since a TV set can be a source of much irritation if used with an unsatisfactory aerial, or with one that has not been properly erected. Interference is thereby introduced which is a direct result of the shortcomings, either of an aerial itself, or of the down-lead to the receiver. Echoes, which take the form of ghosts in the picture, poor definition and interference picked up externally are among the troubles encountered.

In this book, which introduces the reader to various types of aerials, the many problems are considered only from the practical angle. A search through these pages for abstruse mathematical arguments will thus be in vain, for the work deals strictly with the different kinds of aerials and the difficulties encountered in practice by those whose job it is to install them.

Eindhoven, November 1963 D. J. W. Sjobbema

CONTENTS

CHAPTER I

THE ENERGY TRANSFER FROM EMITTER TO RECEIVER

Introduction

The transfer of electrical energy from a transmitting station to a receiver takes place in three stages. It is first fed from the transmitter to the transmitting aerial, whence it is radiated in the form of radio waves. These waves, which carry the sound and picture information for radio and television, span the distance from the transmitting aerial to the receiving aerial, where they once more become electrical energy to drive the receiver. It follows, then that this transfer from transmitter to receiver must depend to a very considerable extent on the properties and the behaviour of both the receiving aerial and the radio waves.

Before commencing a discussion of radio waves, however, it is necessary to say something about electrostatic and electromagnetic fields.

Electrostatic fields

When two electrically charged bodies, for example spheres, are placed at a certain distance from each other an electrostatic field is set up in the space around them. Fig. 1 shows two spheres A and B carrying charges of opposite sign; sphere A is positively charged and sphere B is negative. Now, if a third sphere, carrying a positive charge, is placed at a point C, this will be subjected to a force which tends to displace it, for the positive sphere A exercises a repelling force (arrow K_A in the figure), whilst the negatively charged sphere B imposes an attracting force (arrow K_B) on the positive charge in C. It is found that the magnitude of the force K_A is dependent on two factors, namely:

1. The extent of the charges in the spheres A and C.
2. The distance AC between the two spheres.

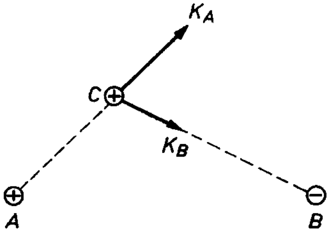


Fig. 1

The greater the charges in A and C, the greater the force K_A exerted upon C and vice versa. Also, this last-mentioned force is inversely proportional to the square of the distance AC; in other words the smaller the distance the greater the force exerted. Hence the force K_A can be said to have two attributes, i.e. a direction (the direction of the arrow K_A) and a magnitude. The arrow representing the force K_A is known as a vector, where the length of the arrow corresponds to the amount of the force.

What has been said in regard to the force K_A applies equally to force K_B, except that there the arrow points towards the negatively charged sphere B because B and C attract each other. Thus a force K_T operates on the positively charged sphere C which is equal to the sum of the forces K_A and K_B. The sum in this case is the sum of the vectors, which can be found by drawing a diagonal in the parallelogram the sides of which are the vectors K_A and K_B (Fig. 2). In general, such a vector sum is written:

$$K_T = \bar{K}_A + \bar{K}_B,$$

where the bars above the symbols K_A and K_B denote that the sum is not algebraic, but vectorial or geometrical.

Field strength

The strength of the electrostatic field at a given point is defined as the force to which a positive charge is subjected, per unit charge, at that point.

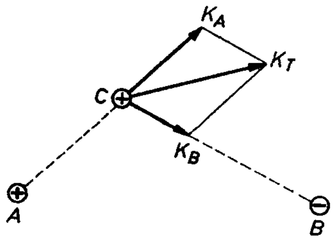


Fig. 2

In accordance with this definition the field strength at point C in Fig. 2 is K_T if the positive charge at that point is equal to the unit charge at C. Therefore, like the force, the field strength has magnitude and direction and can also be represented as a vector. From the above it is seen, then, that the magnitude and direction of the field strength at any given point must be dependent on the charges in the spheres A and B as well as on the position of the particular point relative to these spheres. In Fig. 3 the magnitude and direction of the field strength are shown at various points in the electrostatic field.

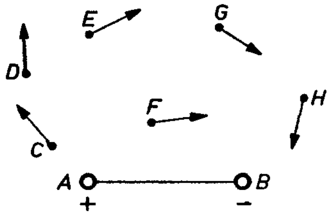


Fig. 3

Lines of force

It is usual to represent electrostatic fields by what are known as lines of force, defined as lines such that tangents drawn to them at a given point indicate the direction of the field strength at that point. Fig. 4 shows our electrically charged spheres A and B with the electrostatic field that exists in the air around them indicated by lines of force; these run from the positively charged sphere A to the negative sphere B. At three points

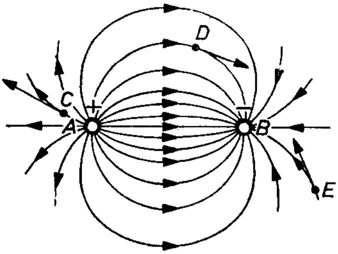


Fig. 4

in the field the direction of the field strength as it occurs at those points is also shown.

Potential difference

The potential difference between two points A and B in an electrostatic field is defined as the energy available per unit charge for transferring a positive charge from A to B. In an electrostatic field such as that depicted in Fig. 5 (homogeneous field) a positive charge at A is subjected to a force $K = F \times q$ which tends to displace it to the right (F is the strength of the field and q the magnitude of the positive charge). This force K is the same at every point between A and B because the field is uniform. It follows, then, that the work done in transferring the charge from A to B, i.e. for the distance A — B is equal to

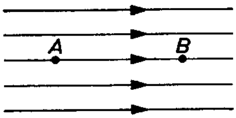


Fig. 5

$$A = K \times AB = F \times q \times AB. \tag{1}$$

According to the definition, this work is equal to the potential difference E between points A and B when the positive charge transferred (q) is equal to the unit charge. Thus the formula (1) can be written as

$$E = F \times AB. \tag{2}$$

In other words the field strength (F) is equal to the potential difference (E) per unit length (A — B) along a line of force

$$F = E/AB. \tag{3}$$

The field strength is accordingly usually given in volts per metre (V/m).

Example

Assuming the voltage between A and B to be 100 V and the distance between them 5 metres, the strength of the electrostatic field between these points will be:

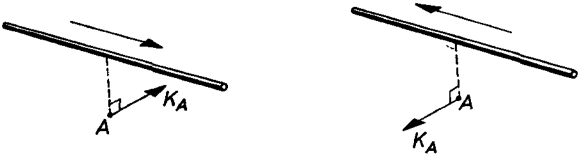
$$F = E/AB = 100/5 = 20 \text{ V/m}.$$

Magnetic fields

When an electric current flows through a conductor, for example a copper wire, a magnetic field is set up round the wire. The presence of this field can be simply demonstrated with the aid of a magnetic needle; if a magnetic north-seeking pole is introduced at point A in Fig. 6, it is thereby subjected to a force that tends to displace it. In the same way as for electrostatic fields, both magnitude and direction can be attributed to this force, which can thus also be represented by a vector.

It is found that the direction of the force is governed by the direction in which the electric current is flowing; if this is from left to right along the wire shown in Fig. 6a, the force at point A will be in a backward direction, i.e. perpendicular to the plane of the paper. Conversely, if the direction of flow is from right to left, the force will act in the opposite direction, that is, upwards from the plane of the diagram (Fig. 6b). It should be noted here that the current flows from positive to negative, and not from negative to positive as in the case of electronic current.

The field strength at a point in a magnetic field is defined as the force to which a magnetic north-seeking pole is subjected at that point, per unit of magnetism (pole strength).



a

b

Fig. 6

According to this definition the direction of the field strength at point *A* is the same as that of the force K_A. The magnitude of the field strength at *A* is dependent on the current flowing in the wire and also on the distance of point *A* from the wire; it is proportional to the current *I* and inversely proportional to the distance *r*.

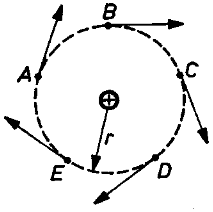


Fig. 7

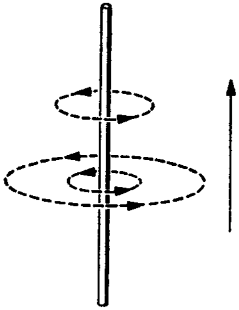


Fig. 8

Fig. 7 shows a circle drawn in a plane at right angles to the wire in which the current is flowing, the centre of the circle being the wire itself, with *r* as the radius. In accordance with the above definition the field strength is the same at all points on the circumference of this circle, the direction of the field strength being in each case at right angles to the radius. In other words, this direction at any given point is represented by the tangent to the circle at that point. This circle therefore conforms to the definition of a line of force as given above (see page 3). The magnetic field surrounding a wire carrying a current can accordingly be represented by lines of force in the form of concentric circles; Fig. 8 depicts a number of such lines of magnetic force surrounding a wire in which a current is flowing.

Electromagnetic fields

The above remarks concerning the magnetic field which surrounds a wire carrying an electric current refer to the case where a current is actually flowing through the wire, this current being the result of a potential difference between the extremities of the wire. Hence there will be not only a magnetic field but also an electric field. If the current is a direct current, a direct voltage will be present across the wire and there will also be an electrostatic field. The magnetic field set up by the current being constant, a certain condition of equilibrium then exists. With alternating current, however, a very different situation arises.

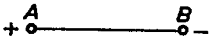


Fig. 9

Fig. 9 depicts two spheres *A* and *B* connected by means of a wire. Let us assume the condition whereby sphere *A* is positive and sphere *B* negative, but with no current actually flowing between them. In sphere *A* there is then a shortage of free electrons and in *B* a surplus, this condition being shown in Fig. 10a. At this moment, as no current is flowing, only an electric field exists around the wire; this field is represented in Fig. 10a by the paths of the lines of electric force. Now, as a result of the difference in the charges in spheres *A* and *B* a current will flow in the wire, that is, from *A* to *B*. (Note that we are not speaking of electronic current, which would pass from *B* to *A*). This current, which increases in strength, produces a magnetic field which also grows in strength. As an electric current is in effect a movement of mobile charge-carriers (electrons), the ends of the lines of electric force move towards one another. The charge in the meantime exists not only in the spheres, but also in the connecting wire, giving rise to the condition shown in Fig. 10b. Since the difference between the charges on the spheres decreases, the strength of the electric field also becomes less, whereas the magnetic field increases in intensity. A very short time later the current reaches its maximum, this being the moment when there is no longer any difference between the charges on *A* and *B*, i.e. the charge is then uniformly distributed in the spheres and connecting wire; the lines of electric force now reveal closed curves instead of curves which terminate at the charges on the spheres or wire as before. The magnetic field strength, which is directly proportional to the current flowing in the wire, is then also at a maximum, in accordance with the situation depicted in Fig. 10c. As will be seen from this figure, the lines of electric force form, as it were, a ring which diverges at a high velocity from the electric system; this velocity (in vacuum, but as an

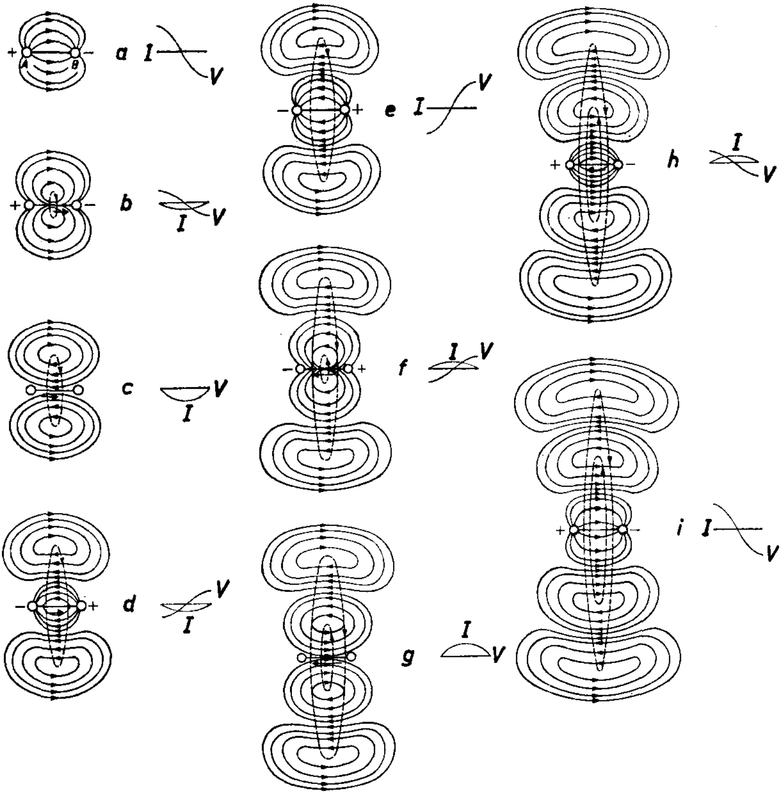


Fig. 10

approximation also in air) is found to be equal to the speed of light, i.e. 300 000 km/sec.

The current flowing through the connecting wire with decreasing strength now recharges the two spheres, i.e. it produces a difference in charge between them, but this time with sphere *B* positive with respect to sphere *A* (Fig. 10d). As a result of this difference in charge an electric field is again set up, differing, however, from the one previously discribed in so far that the lines of force now run from sphere *B*, which is positively charged, to sphere *A*. These lines of force have a repelling effect on the circular line of force produced in the previous phase and tend to depress it.

Subsequently the spheres will both be fully charged again; in other words no current will flow in the wire and a certain steady state is again reached (Fig. 10e). The strength of the electric field at that moment is at a maximum again, whereas the magnetic field strength is zero. The lines of magnetic force and also the closed lines of electric force produced in the previous phases of the process have now disappeared from the whole system of spheres and wire, being as it were pushed out by the new lines of force.

Figures 10f, g, h and i depict the successive phases of the development of the electromagnetic field as described above. In the light of the conditions as outlined, these phases should need no further elucidation, but it may be noted that the occurrence and growth of the electromagnetic field in Fig. 10 is depicted as taking place in the plane of the paper; in actual fact the process evolves in space around the electrical system. In order to clarify the nature of the electromagnetic field the two spheres have been redrawn in Fig. 11 with sphere *B* positively charged with respect to sphere *A* and current flowing through the connecting wire. Fig. 11 thus corresponds to Fig. 10f. Let us now consider the electromagnetic field present at the point *P* at that moment. To avoid making the issue too complicated the location of *P* has been so chosen that distances *AP* and *BP* are equal. The direction of the electric field strength at point *P* which, as stated above, is found by drawing the tangent to the line of electric force at *P*, is represented by the arrow *F*, and the direction of the magnetic field strength at point *P* by arrow *H*. It is seen at once from the figure that the electric and magnetic field strengths at the point *P* are at right angles to each other; the first (the electric field strength) varies in the

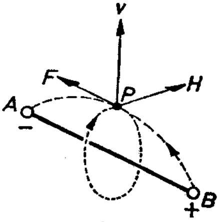


Fig. 11

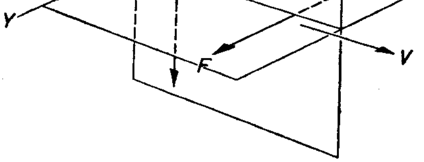


Fig. 12

plane of the paper and the other (the magnetic field strength) in the plane normal to the paper: propagation of the electromagnetic field, however, takes place in the direction *v*, as will be seen from the sequence of the phases (Fig. 10).

Three axes (*X*, *Y* and *Z*) are shown in Fig. 12, all at right angles to one another. If the electric field strength *F* in the horizontal plane as defined by the axes *X* and *Y* varies, the relative magnetic field strength *H* will vary in the vertical plane (axes *Z* and *X*). The direction in which the electromagnetic field develops is given by the *X* axis.

To return once more to Fig. 10, it is seen that zero magnetic field corresponds to maximum electric field (see Fig. 10a, e and i) and that, conversely, when the magnetic field strength is at its maximum the electric field strength is zero (Figs 10c and g). This means that there is a difference in phase of 90° between them. The three axes *X*, *Y* and *Z*, are again drawn in Fig. 13 with the successive intervals of time shown on the *X* axis, i.e. the line of intersection between the vertical and horizontal planes, which show the electric and magnetic field strengths at the point *P* in respect of the different times; the direction in which the field is propagated is here indicated by the arrow *v*. The phase difference between the electric and magnetic field strengths can now be clearly observed. Electromagnetic fields such as those described above are known as quasi-stationary and they occur only at very short distances from transmitting aerials, or, in our example, from the spheres and connecting wire.

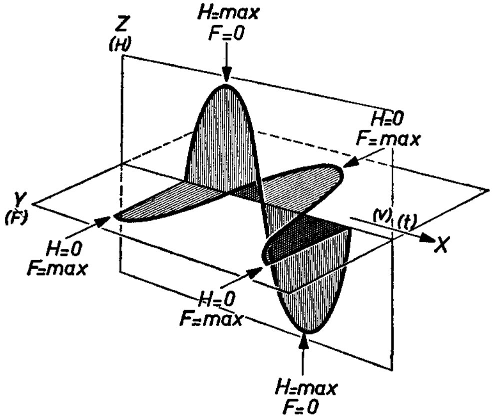


Fig. 13

At greater distances from a transmitting aerial the field strengths are in phase, although the planes in which they vary are at right angles to each other. A field of this kind, i.e. the field of a travelling wave, is shown diagrammatically in Fig. 14.

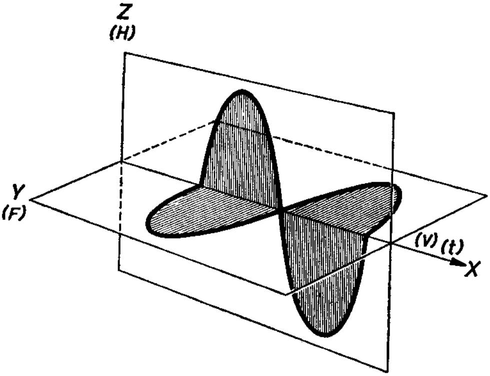


Fig. 14

Summarising, we can say of an alternating current flowing in a wire that:

a. it radiates energy in the form of an electromagnetic field;

b. the electric and magnetic field strengths of the associated electromagnetic field vary in two planes normal to each other in space and also at right angles to the direction of propagation;

c. the electric and magnetic field strengths are in phase (except in the case where the field is at short distance from the transmitting aerial, i.e. 5 to 10 times the wavelength).

The relationship between wavelength, frequency and propagation velocity

When a stone is dropped into still water, say, a pond, the surface of the water is set in motion in the form of concentric circular waves propagated uniformly outwards in the manner shown in Fig. 15. Closer investigation reveals that the particles of water do not move horizontally, however, but vertically. The result of the impact of the stone on the surface of the water is thus that the vertical motion of the water progresses outwards in all directions; in other words a travelling wave motion occurs at a certain speed along the surface of the water. Here too, then, a kind of energy is imparted to the water by the stone striking it.

The wavelength (usually denoted by the Greek letter λ) is the shortest distance between points where the wave conditions are identical, i.e. the distance from *A* to *B* in Fig. 16. Per second, a given particle of water performs a number of up-and-down movements, which means that if one

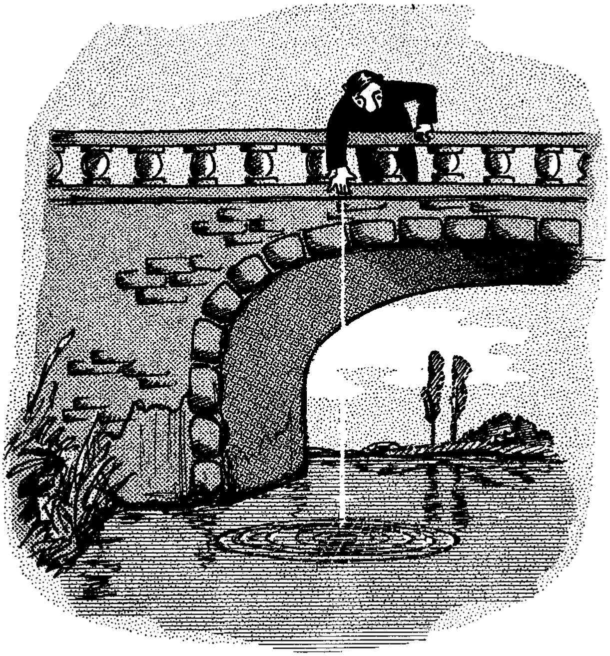


Fig. 15

such movement or cycle takes place in *T* seconds, $1/T$ such movements will take place per second. We say that the frequency of the wave motion is *f* cycles per second.

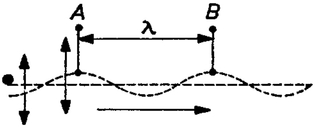


Fig. 16

Per cycle, the wave motion is propagated over a distance equal to $(1/f) \times c = c/f$ metres. (*c* is the velocity of propagation per second), but this distance is also equal to the wavelength for, when the particle of water reverts to its original condition, another particle will be in just the same condition a distance λ further along. Hence:

$$\lambda = c/f, \quad \text{or} \quad \lambda f = c; \tag{4}$$

i.e. *wavelength* × *frequency* = *velocity of propagation.*

In the electrical system of two spheres and connecting wire described above a very similar wave motion occurs, that is, a to-and-fro motion of an electrical charge.

Our discussion so far, of the manner in which electromagnetic fields are produced, has been based on the condition whereby a sphere A is positively charged with respect to a sphere B, with no current flowing in the wire between them, as illustrated in Fig. 10a; as is seen from Fig. 10 this situation is recurrent, the period between successive identical conditions being T seconds. The number of times that this situation recurs per second is thus $1/T = f$ and this is the frequency at which the electrical charge moves to and fro. For example, if the charge makes 10 000 such movements per second from A to B and back to A, the frequency is said to be 10 000 cycles per second.

As the wavelength is understood to be the distance that the electrical charge must cover before once more assuming the orginal condition, this is equal to twice the length of the wire AB in our example. Now, in general, an electrical system of the kind under review is referred to as a half-wave dipole, since the distance AB is equal to half the wavelength ($AB = \frac{1}{2}\lambda$).

The propagation velocity, the frequency and the wavelength bear the following relationship to one another:

$$\lambda \times f = c \tag{5}$$

As already mentioned, the velocity of propagation is roughly equal to the speed of light, i.e. 300 000 km/sec.

The electromagnetic field generated by a half-wave dipole is propagated in space at a velocity which is also equal to the speed of light, the wavelength and frequency of the field being the same as those at which the charge alternates in the dipole, as already discussed.

Example

If the frequency of an electromagnetic field is given as 10 Mc/s (10 000 000 c/s), what is the wavelength of the field?

The field is propagated in space at a velocity of 300 000 km/sec. Using the formula:

$$\lambda = \frac{c}{f},$$

$$\lambda = \frac{300\,000\,000}{10\,000\,000} = 30 \text{ m}.$$

Polarisation of the electromagnetic field

From what has been said about electromagnetic fields it is seen that the magnetic field strength in space is at right angles to the current-carrying wire and hence also to the direction of the electrostatic field strength.

Now an electromagnetic field is said to be horizontally polarised where the plane in which the electric field strength varies is parallel to the earth's surface. Then a horizontally polarised electromagnetic field is set up when a transmitting aerial, or in our case the system comprising two spheres with connecting wire, is suspended parallel to the ground.

The electromagnetic field depicted in Fig. 10 is therefore horizontally polarised. If the system of spheres and wire is rotated one quarter-turn so that one of the spheres is above the other the resultant electromagnetic field is said to be vertically polarised. To give concrete examples it may be added that the electromagnetic waves employed for the transmission of TV picture signals are polarised vertically in Britain for some transmissions and horizontally for others, but only horizontally in Germany and the Netherlands.

Classification of wavelengths

To avoid chaos, the frequencies used for the purposes of telecommunication have been divided internationally into a number of bands, namely:

For radio broadcasting

Long-wave band: 150 — 285 kc/s (2000 — 1050 m).
Medium-wave band: 525 — 1602 kc/s (570 — 187 m).
Short-wave band: 3 — 30 Mc/s (100 — 10 m).
FM radio transmissions (Band II): 87.5 — 100 Mc/s (3.44 — 3 m).

For television

Band I: 40 — 68 Mc/s (7.5 — 4.4 m).
Band III: 174 — 223 Mc/s (1.72 — 1.35 m).
Band IV: 470 — 606 Mc/s (64 — 49.5 cm).
Band V: 606 — 790 Mc/s (49.5 — 38 cm).

The television bands are further sub-divided into "channels"; in the CCIR 625-line system. Band I is divided into 4 channels and Band III into 7 channels. Each channel then has a "bandwidth" of 7 Mc/s.

Bands IV and V comprise 40 channels each, the bandwidth per channel in this case being $\frac{790 - 470}{40} = 8$ Mc/s. For further details we refer the reader to the tables at the end of this book, showing the channel allocations for the various systems.

The relationship between field strength and aerial power

From theoretical considerations it follows that there is a certain relationship between the electrical power fed to a transmitting aerial and the electromagnetic field strength in the air at a certain distance from it. Clearly this will also depend on the kind of transmitting aerial under consideration; if it is a half-wave dipole the above-mentioned relationship is written as:

$$F = \frac{7\sqrt{P}}{d}, \qquad (6)$$

where P = aerial power in watts
d = distance in metres
F = field strength in V/m.

This formula shows that the field strength at any given point is proportional to the square root of the transmitter power as supplied to the aerial, and inversely proportional to the distance between the transmitting and receiving aerials. It should be noted, however, that this formula holds only in the case where the electromagnetic field is freely propagated in space, or in other words is not subject to any such effects as absorption or reflection.

Our two spheres with connecting wire supplied with power from an external source would constitute a half-wave dipole aerial of the kind under consideration.

Example

Given that the aerial power of a television transmitter is 25 kW, the field strength at a distance of 50 km from the aerial will be:

$$F = \frac{7\sqrt{25\,000}}{50\,000} \cong 0.022 \text{ volt/metre or } 22 \text{ mV/m.}$$

If the transmitting aerial is erected relatively near to the ground it is found that the manner in which the electromagnetic field develops depends very largely on the frequency of the field. Where the field varies at a frequency in the long wave range (and to a certain extent also in the medium waves), it is propagated along the ground (ground waves).

At frequencies in the short wave range, however, propagation is mainly by means of reflection from the higher layers of the atmosphere, i.e. the ionosphere. At still higher frequencies the propagation is in a straight line; this applies to the transmission of FM and TV signals.

We shall first consider this last-mentioned category. At these frequencies the electromagnetic field at the receiving aerial usually has two components, namely a direct wave which travels straight from the transmitting aerial to the receiving aerial, and a wave that is reflected from the earth's surface (the reflected wave) in the manner shown in Fig. 17. It is seen that the path of the direct wave is shorter than that of the reflected wave and so reaches the receiving aerial before the other; this means that there is a certain difference in phase between the two waves. Also, generally speaking, the direct wave is stronger than the other, firstly because it has a shorter distance to travel and secondly as a direct result of the reflection of the other wave.

The extent of the reflection, that is the ratio of the strength of the incident wave to that of the reflected wave, apparently depends upon two things, namely the angle of incidence to the earth's surface (φ in Fig. 17) and the nature of the earth's crust at the point where the reflection occurs (the relative permittivity ε and conductance σ).

The way in which reflection takes place is also dependent on the polarisation of the incident wave. With horizontal polarisation the wave as reflected by the earth is always 180° out of phase; its amplitude is the same as that of the incident wave at an angle φ of 0 degrees, but,

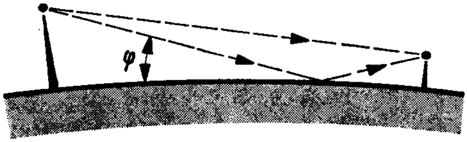


Fig. 17

again with horizontal polarisation, wider angles first show an almost linear decrease in amplitude, this being followed by a more gradual drop.

This effect is illustrated in fig. 18 in respect of earth having a relative permittivity of 9 at frequencies of > 30 Mc/s, with negligible conductance.

In this figure the ratio

$$k = \frac{\text{strength of reflected wave}}{\text{strength of incident wave}}$$ is given as a function of the angle of incidence φ (curve *A*).

In the case of vertical polarisation, with the exception of angle $\varphi = 0$, the effect is very different. At small angles of incidence the ratio mentioned above drops sharply with increasing values of φ and is zero at angles of incidence whereby

$$\cot \varphi = \sqrt{\varepsilon}.$$

For $\varepsilon = 9$, $\varphi = 18° 26'$. (curve *B*).

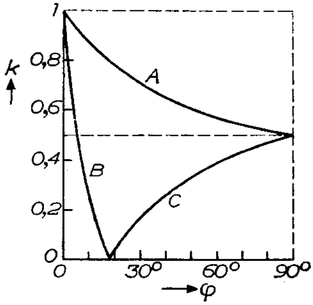


Fig. 18

At this angle the field strength at the receiving aerial is equal to that of the direct wave; at higher values of φ the 180° phase difference is absent, the incident wave is in phase with the reflected wave and the ratio

$$k = \frac{\text{strength of reflected wave}}{\text{strength of incident wave}} \text{ increases (curve } C\text{).}$$

Where the conductance of the earth's surface is not negligibly small this relationship is rather more complex. In this case vertical polarisation produces much stronger reflected signals than the horizontal method owing to the greater absorption. Over what may be called normal ground, however, there is not very much difference in the signal strengths at small incident angles.

As already mentioned, in free space electromagnetic waves are propagated in straight lines. Nearer to the earth's surface, on the other hand, propagation is affected by differences in the density and humidity of the lower layers of air, in consequence of which radio waves are bent down towards the ground; this applies to both the direct and the reflected waves. However, in order to avoid complicated calculations we shall assume that propagation is rectilinear, introducing a certain correction factor where necessary.

The first question that arises in this connection concerns the effective transmission range of the transmitter as governed by the curvature of the earth's surface. The area in which the waves from the transmitting aerial meet the earth's surface is known as the optical horizon. Theoretically, then, the optical horizon of a television transmitter is the boundary at which reception is just possible, assuming the receiving aerial to be at the effective surface of the earth. In practice, however, the range of a transmitter is found to be rather greater than this, albeit in areas beyond the optical horizon reception will not always be free from interference, seeing that the field strength drops steeply with relatively short increases in this distance.

The distance from a transmitting aerial to the optical horizon can be approximated with the aid of the formula:

$$l = 4.1 \sqrt{H} \tag{7}$$

where l = distance from the transmitter aerial to the optical horizon in kilometres and H = the height of the transmitter aerial in metres.

The derivation of this formula can be very easily demonstrated by plane geometry. In Fig. 19, which shows the conditions under review, H denotes the height of the aerial, R is the radius of the earth and k the correction factor refered to above. The problem is then: what is the distance l?

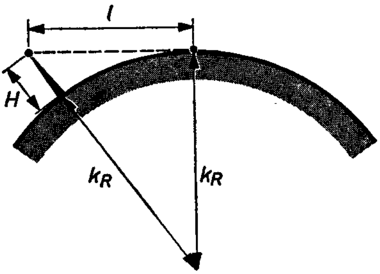


Fig. 19

As the line l is at right angles to the radius of the earth at the tangent:

$$l^2 = (H + kR)^2 - (kR)^2, \text{ or}$$

$$l = \sqrt{(H^2 + 2HkR)}.$$

Now, $R = 6\,370\,000$ metres and $k = 1.33$, so H^2 may be neglected compared with $2HkR$.

$$l = \sqrt{(2HkR)} = \sqrt{(2H \times 1.33 \times 6\,370\,000)} = 4100\sqrt{H}$$

metres.

If the height of the receiving aerial is h, however (see Fig. 20), then the overall distance a direct wave travels from H to h at a tangent to the earth's surface (the radio horizon distance) is:

$$l = 4.1\,(\sqrt{H} + \sqrt{h})\text{ km.} \tag{8}$$

For distances which are less than l, but nevertheless very large compared with aerial heights H and h, the theoretical field strength at the receiving aerial, with vertical polarisation ($h \geqq 2\,\lambda$) and horizontal polarisation ($h \geqq \frac{1}{4}\,\lambda$) is given as an approximation by the formula:

$$F = \frac{88\,H\,h\,\sqrt{P}}{\lambda\,l^2}\text{ V/m} \tag{9}$$

where F = field strength in volts per metre at the receiving aerial.
H = height of transmitting aerial in metres
h = height of receiving aerial in metres
P = aerial power in watts
λ = wavelength of transmitted radio waves
l = distance from transmitting to receiving aerial in m.

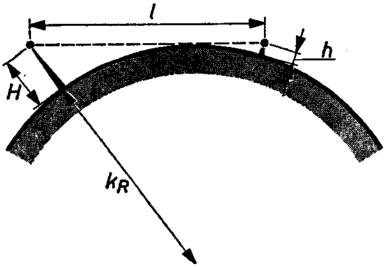


Fig. 20

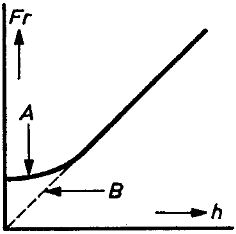


Fig. 21

The above formula applies to flat, open country, i.e. without a single obstacle between the transmitting and receiving aerials. In practice, however, such conditions are rarely encountered and field strengths may be measured at receiving aerials which amount to only one half to one fifth of the theoretical value.

With horizontal polarisation the field strength at the receiving end is practically zero quite close to the ground, but it rises almost linearly with the height of the aerial. The field strength of vertically polarised waves near to the ground is very much higher and is constant for a certain vertical distance, after which it increases gradually to a height of 2λ and then further in the same ratio as for horizontally polarised waves.

Fig. 21 shows, in the form of a graph, the dependence of the relative field strength F_r on the aerial height h. Curve A relates to vertical polarisation and curve B to horizontally polarised waves.

The field strength below the optical horizon can be obtained approximately with the aid of the empirical formula (Beverage; R.C.A. Review):

$$F' = F \left(\frac{l_r}{l_g} \right)^n \qquad \text{volt/metre} \qquad (10)$$

where F = field strength at the optical horizon,
l_r = distance from transmitting aerial to optical horizon,
l_g = distance from transmitting aerial to receiving aerial,
n = power dependent on the frequency of the waves transmitted.

At 40 Mc/s, n is 3.6; at 90 Mc/s it is 5 and at 441 Mc/s it is 9.

This formula shows that the field strength below the optical horizon drops sharply with increasing frequency. At the frequencies in Band IV, where n is greater than 9, the field strength is therefore almost negligible;

hence the range of television transmitters in this band is appreciably less than in Bands I and III.

Example

Given that the aerial height of an FM transmitter is 216 metres and the aerial power 25 kW with a carrier frequency of 90 Mc/s, with a receiving aerial 16 metres from the ground:

a. What is the radio horizon distance between the transmitting and receiving aerials?
b. Assuming flat, open ground between the two aerials, what is the approximate field strength at the receiving aerial?
c. What is the field strength at twice the distance to the optical horizon?

Answers

a. According to formula (8) the distance from the transmitting aerial to the receiving aerial is:

$$l = 4.1\,(\sqrt{216} + \sqrt{16}) = 76.5 \text{ km.}$$

b. According to formula (9):

$$F = 88\,\frac{216 \times 16 \times \sqrt{25 \times 10^3}}{3.14 \times 76.5^2 \times 10^6} = 2450\ \mu\text{V/m.}$$

c. At a distance $2l = 153$ m the field strength is:

$$F' = 2450\left(\frac{76.5}{153}\right)^5 =$$

$$2450 \times (\tfrac{1}{2})^5 = 77\ \mu\text{V/m.}$$

In the light of the above, it will be clear that the range of television transmitters is limited, this being largely dependent on:

a. the height of the transmitting aerial,

b. the aerial power of the transmitter

c. the frequency of the carrier wave.

At the same time, the formulas are approximate and yield reliable results only in respect of flat open country. In large cities, especially, complications often arise as a result of pronounced local absorption and reflection by gas-holders, the steel roof structures of railway termini and so on, all of which tend to produce wide variations in the fields strength. The field strength at the receiving aerial includes various components which more often than not set up very troublesome interference.

Reflections and multiple images

Figure 22 shows a television transmitting aerial *A* sending out a signal. A wave travels direct from this aerial to a receiving aerial on the roof of a house at *C*, whilst another wave reaches the receiving aerial along another path; it travels first to the gas-holder *B* where it is then reflected in the direction of *C*. Hence the path taken by the reflected signal is longer than that of the direct signal from the one aerial to the other.

The reflected signal accordingly reaches the receiving aerial slightly later than the direct signal, seeing that the propagation velocity is the same in each case (300 000 km/sec.).

The time taken by the wave to travel along the path AC is thus $AC/300\,000$ sec (AC in km), whereas the time in respect of the path (AB + AC) is $(AB + BC)/300\,000$ sec. As $AB + BC > AC$, the reflected signal must arrive at the receiving aerial later than the direct signal.

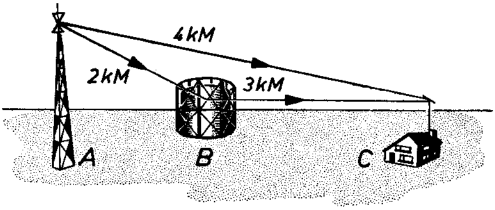


Fig. 22

Let us now see on the basis of a numerical example what effect this difference in timing will have upon the quality of a television picture. We shall assume that the receiver connected to aerial *C* has a 21″ screen; in other words the diagonal of the rectangular screen is nominally 21″ (53 cm). The width of a screen of this size is actually only 44 cm. Assume also that the receiver is operating under the following conditions:

1) Number of pictures per second: 25
2) Scanning: 625 lines, interlaced
3) Flyback period: 16 % of the line scan period.

Now, as the receiver produces 25 pictures per second, one picture is scanned in 1/25 sec. This picture is composed of 625 lines, which are accordingly completed in 1/25 sec.; therefore the time taken to scan one line is:

$$\frac{1}{25} \times \frac{1}{625} = \frac{1}{15625} \text{ sec.} = 64\ \mu\text{sec.}$$

The flyback takes place in 16 % of the time for one line, i.e. 16 % of 64 μsec. or 10 μsec. Therefore the visible lines are scanned in 64-10 = 54 μsec. Now in the example in Fig. 22 the difference between the lengths of paths followed by the direct and reflected waves is 1 km; the reflected signal thus reaches the receiving aerial 1/300 000 = 3.3 μsec later than the direct signal.

We have seen that the visible lines of the picture, which are 44 cm in length are scanned in 54 μsec. A lag of 3.3 μsec therefore corresponds to a path length of:

$$\frac{3.3}{54} \times 44\text{ cm} = 2.7\text{ cm.}$$

So, apart from the image produced by the direct wave transmitted from *A*, there is then a second image which is displaced 2.7 cm with

Fig. 23

respect to the first. As reflected signals are in general not so strong as their direct counterparts, the brightness, and also the contrasts, of the second image are therefore both less than in the first. If the difference is not too marked it looks as though the primary image were casting a shadow (this is plainly visible in the test pattern). Such shadows, which can be very distracting and which are commonly referred to as "ghosts" are officially termed multiple images. An example of a multiple image is depicted in Fig. 23. It may be noted that the effect of reflections on the reception of sound is practically imperceptible, since our ears are unable to detect the difference in phase of the two waves.

One point stands out clearly from the above, that the broadcasting range of television and FM sound transmitters is limited. This being so, how can we account for the fact that in some cases reception is possible over very considerable distances? Television pictures have been received in the Netherlands from as far afield as Spain, Italy, and Russia and, by "received" we mean that, over intervals ranging from one hour to several hours, the field strength has been sufficient to produce fairly acceptable pictures. This can be ascribed to the occurrence of reflections resulting from electrical phenomena in the upper layers of the atmosphere very similar to those accompanying radio waves at wavelengths of from 10 to 200 metres. This particular waveband (short waves) is specially employed by reason of this peculiarity for transmission over great distances (intercontinental communications).

So far we have dealt with the behaviour of radio waves at frequencies in the TV and FM bands. Radio waves at frequencies in the short-wave band behave very differently but, as these are not employed for TV transmissions, we shall not have very much to say about them.

As pointed out, the short-wave band is used for intercontinental transmissions of speech and music, i.e. for very long distances. As the particular feature of radio waves at these frequencies is due to reflection of the waves in the higher regions of the atmosphere, it may be useful to consider the atmosphere itself in more detail.

Structure of the earth's atmosphere

The atmosphere may be regarded as consisting of a number of layers, each distinct from the other by reason of certain specific characteristics which fall under the headings of density, humidity and the effect of the sun upon the air particles. All these have a very pronounced influence on the manner in which radio waves are propagated.

A cross-section of the atmosphere is shown pictorially in Fig. 24. The lower layer, known as the troposphere, extends from the surface of the earth to a height of about 12 km (7½ miles). This layer of air, in which cloud formation is found, apparently affects the propagation of those radio waves that we employ for television and FM sound transmissions (differences in density and humidity).

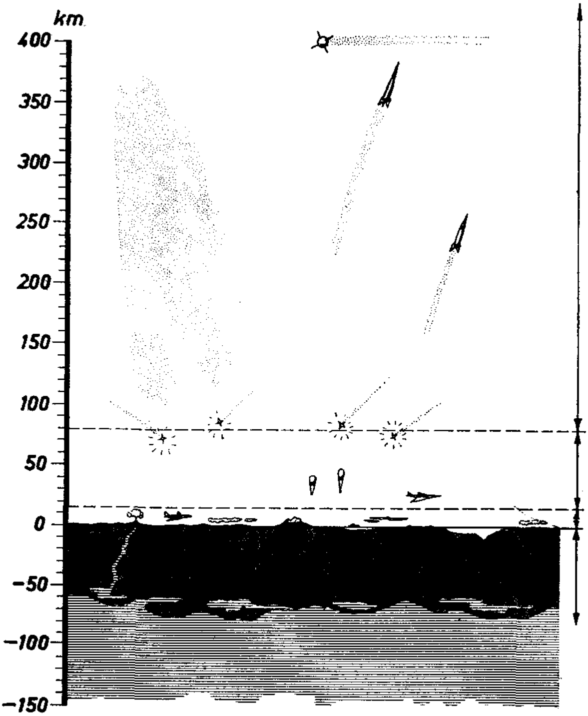


Fig. 24

The second layer, the stratosphere, extends from about 12 km (7½ miles) roughly 80 km (50 miles) upwards; it has little or no effect on the propagation of radio waves, in contrast to the layers above, which are known collectively as the ionosphere. This designation is derived from the ionisation of the air particles that takes place in that zone. The ionisation is due to the action of the sun's rays on the particles. Apart from the light which the sun provides, energy is also emitted in the form of ultra-violet radiations and electrically charged particles which have a modifying effect on the structure of the particles of air.

This modification consists in a splitting of the molecules of air into two parts, namely ions, which possess an electrical charge, the one positive and the other negative. Recombination of the two ions again provides a neutral air particle. Now, the extent of the ionisation that takes place is very greatly dependent upon the velocity at which the particles emitted by the sun collide with the particles of air, and also on the intensity of the ultra-violet radiation. For obvious reasons the further we go from the earth's surface the greater the amount of ionisation, seeing that collisions between the air particles and the solar particles are then more intense; the ultra-violet radiations are also stronger.

In a certain respect, therefore, the ionosphere functions as a shield to protect the earth and all living things upon it from too intense ultra-violet radiation and from bombardment by the solar particles.

It follows from all this that the extent to which the upper layers of air are ionised is governed very largely by the position of the earth on its axis relative to the sun, i.e. the difference between day and night; ionisation is more intense by day than by night. At night only the very highest layers of the atmosphere are ionised, whereas in the daytime the effect penetrates to lower levels, although to a lesser extent, but not below about 30 km (18½ miles). This means, of course, that the ionosphere as such is higher at night than by day. At night-time some of the positive and negative ions recombine to form air particles again in the lower regions of the ionosphere.

Propagation of radio frequency waves from 3 Mc/s to 30 Mc/s

It has been found that radio waves of frequencies of from 3 Mc/s to 30 Mc/s are reflected from the ionosphere. Waves travelling obliquely upwards are accordingly reflected back and return to earth at considerable distances from the transmitter.

Fig. 25 depicts a transmitting aerial (*A*) emitting radio waves, these being propagated uniformly in straight lines in all directions. Now, dependent on the direction of travel, these waves can be visualised as consisting of three groups. Group I passes obliquely upwards and is reflected by the ionosphere; group II comprises waves which travel direct from the transmitting aerial to the receiving aerial and group III reaches the receiver after reflection from the earth's surface.

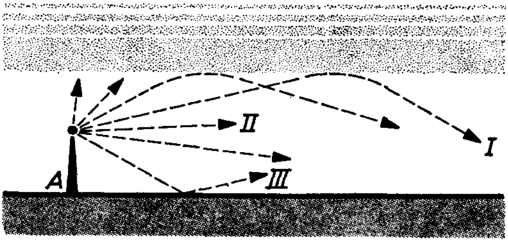


Fig. 25

It has already been mentioned that the degree of ionisation of the higher layers of the atmosphere depends to a great extent on which side of the earth's surface is facing the sun at the time. In marked contrast to daytime only the very highest layers of air are ionised at night. Hence after dark, reflection of radio waves takes place at higher levels than in daylight; in other words, at night (when it is dark between the transmitting and receiving aerials), transmission is effective over greater distances than by day.

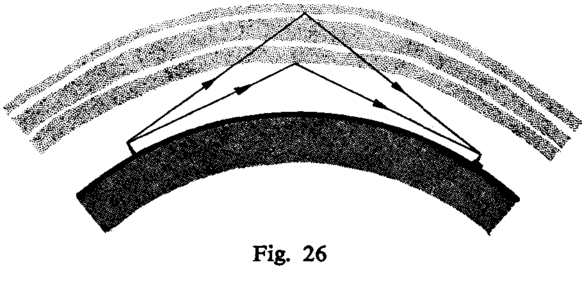


Fig. 26

Fading is another effect produced by phenomena occurring in the ionosphere. To demonstrate this a transmitting aerial, from which two waves are travelling upwards in different directions, is shown in Fig. 26. Wave 1 is reflected from a higher level than wave 2, but both waves meet at the receiving aerial, where the sum of the two waves is thus available.

Now, if the two waves are equally strong at the receiving end but are 180° out of phase with each other, they cancel each other out, which means that the field strength at the receiver will be zero. But, as the reflections do not occur at the same height all the time the two waves are consequently not constantly 180° out of phase, i.e. the phase difference varies. At a given moment there may be no phase difference at all, in which case the field strength at the receiving aerial will be twice as strong as that produced by a single wave. The field strength therefore varies between the sum and difference of the individual field strengths.

The conclusion to be drawn from the above is that the bandwidth of the signals that can be transmitted is limited, for which reason the wavelengths referred to can be employed only for radio (bandwidth about 9 kc/s) and not for television (bandwidth about 7 Mc/s). With the latter, greater bandwidth the various frequencies would not all be received at the same strength in consequence of the fading.

Having now considered the radio waves which constitute the link between the transmitting and receiving aerials we shall in the following chapters discuss the aerial itself and, in particular, aerials for the reception of television signals.

CHAPTER II

THE RECEIVING AERIAL

In Chapter I we have explained that under certain conditions electrical energy can be radiated as another from of energy, namely radio waves. The process can also be reversed, however; if a conductor is placed in the path of an electromagnetic wave it functions in the same way as an obstacle in that it introduces both reflection and absorption. The energy absorbed by the conductor from the electromagnetic field, and which thus becomes available in the conductor, is then converted once more into electrical energy. In short, the principle on which a receiving aerial works is that a part of the energy it absorbs from the electromagnetic field is passed to the radio or television receiver to which it is connected.

Before looking a little more closely at the details of receiving aerials and in particular the kind that is used for the reception of very high frequencies, it will be useful first to obtain a clear picture of what is expected of the aerial, that is, what requirements we should impose upon it in the first place. For the moment it will be sufficient to mention the most important features, which will then be discussed in this and the next chapter.

The principal requirements of an aerial are concerned with the:

1. Maximum sensitivity to the kind of signal to be received;
2. Insensitiveness to unwanted signals (which are ultimately manifested as interference in the sound or picture);
3. Width of the frequency spectrum to be received;
4. Aerial impedance;
5. Mechanical design (to withstand birds and wind);
6. Resistance to corrosion.

The first four of these points will be dealt with in this chapter; the last two, which involve mechanical and insulation problems, are discussed in the next.

The half-wave dipole

In our explanation of the behaviour of electromagnetic fields we have made use of a hypothetical assembly of two spheres connected by a wire. It has been seen that the wavelength of the electromagnetic vibrations radiated by a system of this kind is equal to twice the length of the wire (disregarding the effect of the two spheres.) Now the reverse also applies; if a rod of conductive material is placed in an electromagnetic field, electrical energy is induced in it, which means that a current flows in the rod. In other words the displacement of an electric charge takes place in it.

According to the fundamentals of electricity a conductive rod possesses inductance and capacitance, both of which are uniformly distributed along its length. To illustrate this Fig. 27a depicts a rod which is, as it were, built up from 9 smaller rods, each with its own inductance and capacitance; the figure also shows the distribution of the capacitance over the entire rod. Let us assume that all the capacitances at a given moment possess a certain charge. They will accordingly each discharge across the inductance of their particular parts of the whole. Thus capacitor C_5 discharges a current I_5 through inductance L_5; C_4 a current I_4 through L_4, L_5 and L_6; C_3 a current I_3 through L_3, L_4, L_5, L_6, L_7 and so on. The greatest possible amount of current ($I_1 + I_2 + I_3 + I_4 + I_5$) then flows in the centre of the rod, this becoming gradually less towards the ends, with no current at all at the ultimate extremities (see Fig. 27b). These components of the total current set up magnetic fields in the associated inductances and these, once the capacitors have discharged, ensure that they are recharged, although with reversed polarity. Between the current flowing in the rod and the voltage across its length there is therefore a phase difference of 90°, so this current and voltage may be represented in the manner shown in Fig. 27c.

In consequence of this process a charge moves back and forth along the rod, with the result that energy is radiated in the form of electromagnetic waves as already described in Chapter I. The losses resulting from the a.c. resistance of the material are converted into heat.

On this basis the rod can be replaced by an equivalent arrangement consisting of a source of alternating voltage, an inductor, a capacitor and a resistor in series, as shown schamatically in Fig. 28. It should be noted that the resistance R_a (the specific aerial resistance) virtually consists of two resistances, i.e. the loss resistance R_v and the radiation resistance

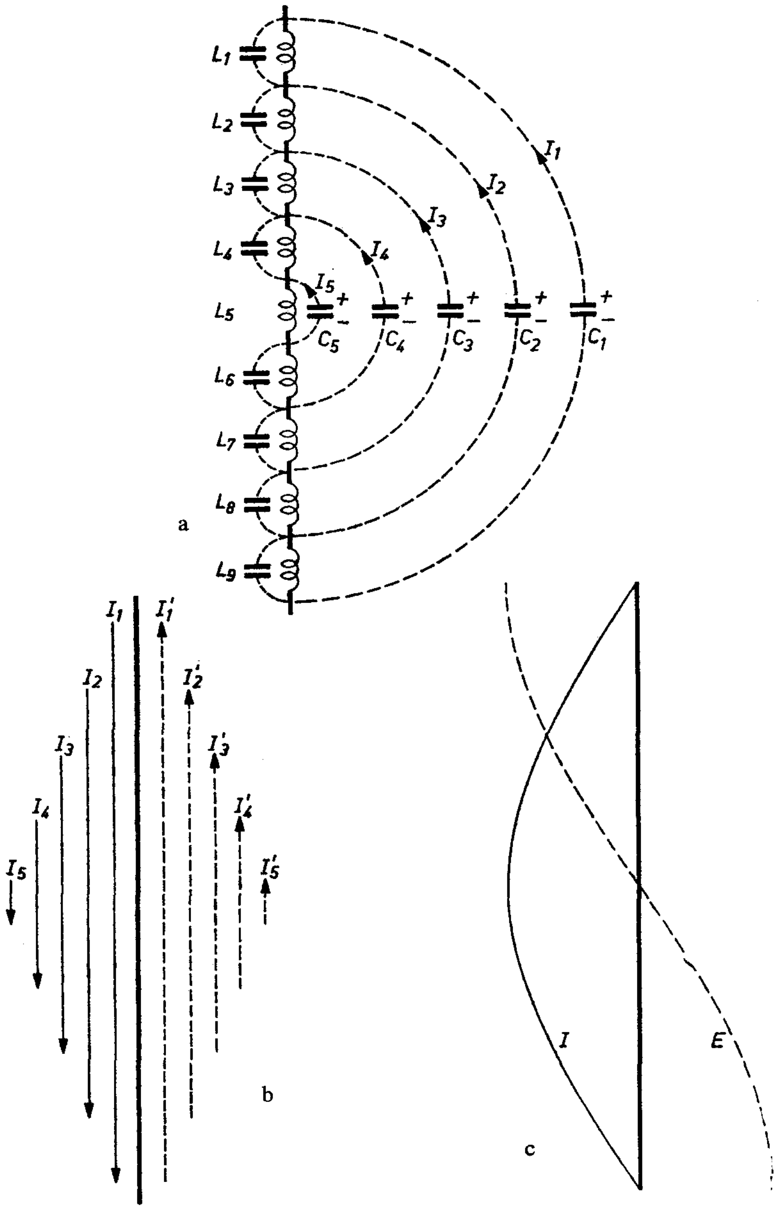

L1
L2
L3
L4
L5
L6
L7
L8
L9
I1
I2
I3
I4
I5
C5
C4
C3
C2
C1
+
−
a
I1
I2
I3
I4
I5
I'1
I'2
I'3
I'4
I'5
b
I
E
c

Fig. 27

R_s. The first of these is a pure radio-frequency a.c. resistance and it is a measure of the energy converted into heat in the rod; resistance R_s, on the other hand, is an a.c. resistance attributable to the energy radiated by the rod in the form of electromagnetic vibrations; the radiation represents a loss of electrical energy in the rod. The radiation resistance R_s is defined as:

$$R_s = \frac{N_s}{I^2_{max.}}$$

where N_s = energy radiated by the rod.

$I_{\text{max.}}$ = maximum r.m.s. value of the current flowing in the rod.

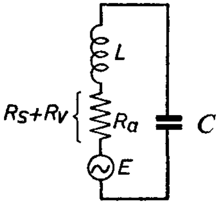


Fig. 28

It is seen from Fig. 28 that the current in the rod reaches a maximum when $\omega L = 1/\omega C$. This state of resonance is produced if the length of the rod is nearly enough equal to half the wavelength of the electromagnetic waves absorbed by the rod, and an aerial of this kind is known as a half-wave dipole.

The first question that may now be asked is: how to extract the maximum amount of energy from the rod or dipole? The answer is as follows.

For the reception of the very high frequencies employed for FM and TV the half-wave dipole is divided into two equal parts, each half, $l = \lambda/4$ in length, being connected to the input of the receiver by means of a flat, twin, cable. A system of this kind, which is depicted in Fig. 29, is known as a straight half-wave dipole; the figure also shows the current and voltage waveforms in respect of this kind of aerial. As the input for all practical purposes is purely resistive, the system shown in Fig. 29 can also be represented by the equivalent circuit in Fig. 30, in which maximum transfer of energy is obtained when:

$$R_a = R_i,$$

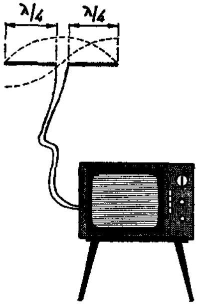


Fig. 29

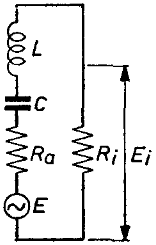


Fig. 30

where R_a = specific aerial resistance, R_i = input impedance of the receiver (this is always given in the operating instructions supplied with the receiver). In the event that $R_a = R_i$, the aerial voltage fed to the receiver is equal to one-half of the voltage induced in the aerial by the electromagnetic field, hence,

$$E_i = \tfrac{1}{2}E.$$

In such cases we say that the aerial and the receiver are correctly matched; one half of the energy induced in the aerial is thus fed to the receiver whilst the other half is re-radiated by the aerial as electromagnetic waves.

The voltage E induced in the dipole by the electromagnetic waves is found to be dependent on two factors:

1. The field strength at that point
2. The effective height of the aerial.

$$E = F \times h_{\text{eff}},$$

where E = induced voltage in volts
F = field strength in volt/metre
h = effective height of the aerial in metres.

The first of the above points implies that the place where the aerial is to be installed must be carefully chosen. In large cities and hilly country very wide differences in field strength are revealed at relatively short distances apart due to masking effects and reflections. This will be discussed in more detail in the next chapter.

In the final analysis the effective height of an aerial has nothing to do with the actual length of the mast on which it is mounted; it should be looked upon as a magnitude that is typical of the kind of aerial employed. For the straight half-wave dipole the effective height is:

$$h_{\text{eff}} = \frac{\lambda}{\pi}$$

This formula shows that h_{eff} is directly proportional to the wavelength of the signal to be received. For example if $\lambda = 3.2$ metres (middle of the FM waveband), h_{eff} will be $\frac{3.2}{\pi} = 1.02$ m for the aerial in question.

For convenience Fig. 31 shows the relationship between the frequency in Mc/s and the effective height in cm of a straight half-wave dipole; the frequency Bands I, II, III, IV and V have also been drawn in the diagram.

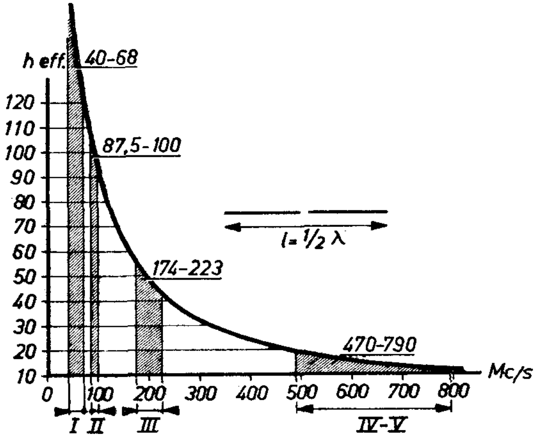


Fig. 31

Example of application

Assuming that the field strength at the aerial is 2000 μV/m and that the effective height of the aerial is 50 cm, the induced E.M.F. will be:

$$2000 \times 10^{-6} \times 0.50 = 10^{-3}\text{V} = 1\text{mV}.$$

In this it is tacitly assumed that the diameter of the dipole is infinitely thin. In practice, however, this would not be possible.

Dipole aerials such as those used for FM and TV usually consist of two tubes, of equal diameter and closed at the ends. Tubes are used instead of solid metal mainly for reasons of lightness. Now, the thickness of the tube has a considerable influence on the various characteristics of the aerial. Fig. 32 shows the radiation resistance (R_s) of a dipole, plotted against the quotient λ/d, where λ is the wavelength in metres and d the diameter, also in metres, of the two tubes of which the aerial consists. For extremely thin rods, i.e. with extremely high λ/d, the radiation resistance is seen to be 73Ω.

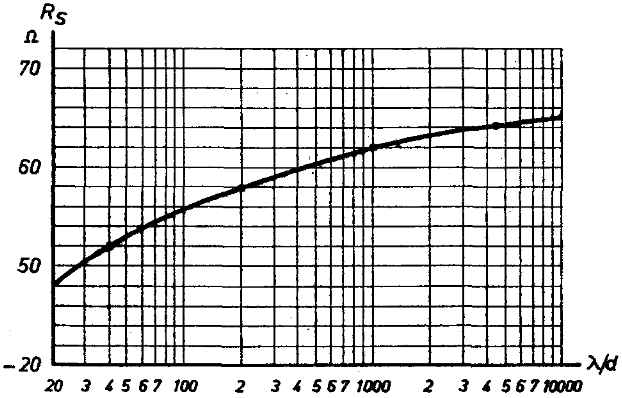


Fig. 32

Example

The thickness of the two rods forming a v.h.f. dipole suitable for receiving signals of 100 Mc/s (F.M. band) is 6 mm ($\frac{1}{4}''$), this being a normal size. This dipole will therefore be suitable for wavelength $\lambda = \frac{300\,000\,000}{100\,000\,000}$ metres = 3 m. The quotient λ/d is thus $\frac{3}{0.006} = 500$. The radiation resistance in the dipole will accordingly be roughly 61Ω (see Fig. 32).

The bandwidth of the straight dipole

We have shown that the response of an aerial corresponds to a certain extent to that of a voltage source with resistance, inductance and capacitance in series with it. This being so, the resonance curve of an aerial can be plotted in the manner shown in Fig. 33. To do this the dipole is placed in a homogeneous field of constant field strength but of varying frequency (hence also varying wavelength). The voltage E_R is thereby the voltage which the dipole passes to the meter. It is seen from Fig. 33 that E_R reaches a maximum at a frequency f_0, which is the frequency at which the length of the dipole is equal to half the wavelength of the electromagnetic field inducing the voltage. Hence:

$$l = \tfrac{1}{2}\lambda.$$

If the frequency is increased, or if it is reduced below f_0, the value of E_R drops.

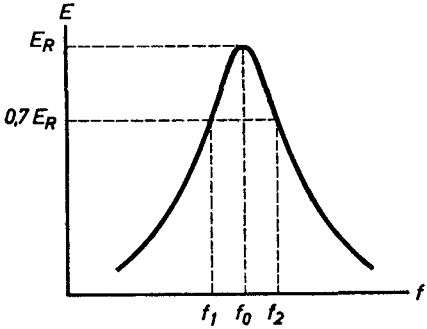


Fig. 33

By definition, the bandwidth of a circuit, and so also of an aerial, is the difference in frequency producing a drop in E_R to a value of 0.7 (3 dB) of the maximum value. The bandwidth of the dipole in respect of which the resonance curve is shown in Fig. 33 is therefore ($f_2 - f_1$) c/s.

It may now be asked: what is the effect on the bandwidth if thicker tubes are used in its construction? To explain the behaviour of the aerial in this case it is necessary to regard it as consisting of a number of thinner rods in parallel. The current flowing in the thick dipole then divides among the hypothetical thin ones. Fig. 34 depicts by way of an example a dipole the thickness of which is equal to five extremely thin rods; in this case the inductance of the dipole is only one-fifth of the value in respect of the thinner dipole, seeing that there are, as it were, five inductances (those of the 5 thin rods) in parallel. The inductance of a thin dipole being denoted by L henrys, that of the thick dipole is thus $L/5$ henrys. On the other hand the capacitance of the aerial with the thick rods will then be higher, being equal to the sum of the capacitances of the thin rods. In our example this will be $5C$ farads (the capacitance of the thin aerial being C farads). If we now denote the inductive and capacitive a.c. resistances of the thin dipole by X_L and X_C respectively ($X_L = 2\pi fL$ and $X_C = \dfrac{1}{2\pi fC}$), then these resistance values as applied to our aerial will be given by: $1/5X_L$ and $1/5X_C$.

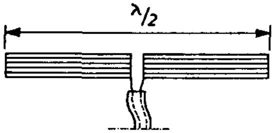


Fig. 34

It can be shown that the resonance curve of a network comprising inductance, capacitance and resistance in series widens according as the inductance is reduced and the capacitance is increased, and from this it

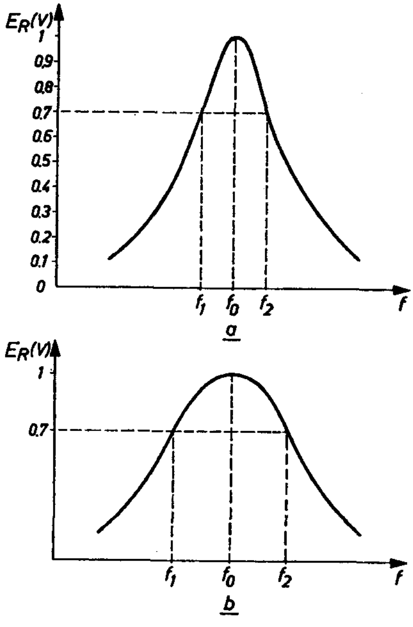


Fig. 35

follows that the pass range, i.e. *the bandwidth, of a dipole, increases with the thickness of the rods of which it is made.*

The resonance curve in Fig. 35a relates to a half-wave dipole with thin rods and that shown in Fig. 35b to the same aerial, but having thick rods.

In this connection it may be noted that E_R, the voltage at the aerial terminals, is given by the formula:

$$E_R = E \times \frac{R_s}{\sqrt{[R_s^2 + (\omega L - \frac{1}{\omega C})^2]}}$$

where: $E = F \times h_{\text{eff}}$
R_s = aerial radiation resistance
L = inductance of the aerial
C = capacitance of the aerial
$\omega = 2\pi f$, in which f is the frequency at which the strength of the electromagnetic field varies.

The use of thicker rods for a dipole aerial also introduces another effect, namely that current then flows through the ends of the rods (the same thing applies to tubes, as these are closed at the ends, usually with metal plugs). In consequence the capacitance of thick dipoles is higher than otherwise; in the example given above it would not be $5C$ farads, but slightly more. In this case X_L is no longer equal to X_C, but is greater; in other words the aerial will then have a different resonance frequency. This, in turn, means that a smaller voltage is obtained from the aerial, seeing that its electrical length will no longer be $\frac{1}{2}\lambda$.

To compensate for such an increase in capacitance we would have to make the actual length of the two rods something less than $\lambda/4$. In relation to aerials, therefore, we make a distinction between physical length and electrical length; in the foregoing, where mention is made of length, the electrical length is meant in every case. Where the rods are of extremely small diameter the electrical and physical lengths are the same and the effects at the ends of the rods are then absent; the difference between the two concepts of length increases with the thickness of the rods in the sense that the physical length then becomes smaller than the electrical length.

The physical length of a dipole can be determined by multiplying the electrical equivalent ($\lambda/2$) by a factor which in the following will be denoted by the letter k. This factor k, which is dependent upon both the diameter of the rods and the wavelength of the radio waves which the aerial is to intercept, is usually stated as the quotient λ/d; in Fig. 36 this is shown plotted as a graph.

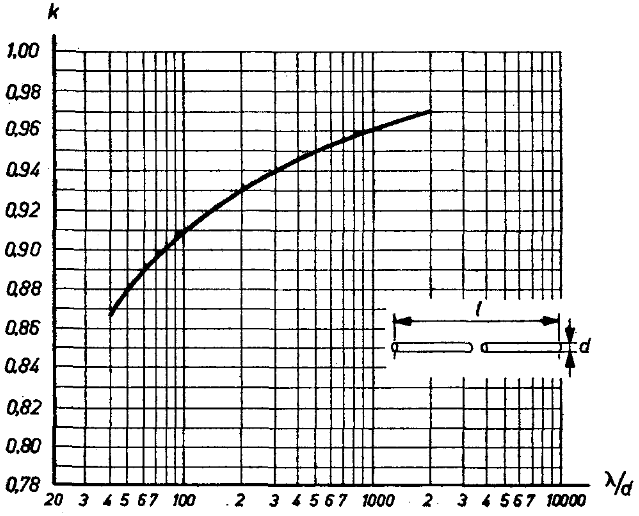


Fig. 36

Example

What would be the length of a dipole aerial suitable for the reception of a carrier wave of 100 Mc/s frequency, given a rod thickness of 10 mm ($\frac{3}{8}$")?

The wavelength of the carrier is $\lambda = c/f = \dfrac{300\,000\,000}{100\,000\,000} = 3$ metres.

The electrical length of the aerial is then $l = \lambda/2 = 1.5$ m and the quotient λ/d is $\dfrac{3}{0.010} = 300$. This gives us a factor k of 0.94 (see Fig. 36), so the physical length of the aerial is k times the electrical length or $0.94 \times 1.5 = 1.41$ metres.

The radiation pattern of dipole aerials

In order to satisfy the requirement of maximum sensitivity to the wanted signals and absence of sensitivity to all others, the aerial must be given a certain directional characteristic; in other words electromagnetic waves coming from any other direction than the required one, even though the wavelength may be the same, should induce in the aerial a smaller voltage than the desired signal, or none at all. Let us first see how a dipole aerial reacts to signals arriving from different directions.

To do this a dipole is placed on open ground and is connected to a signal generator. The dipole being tested is erected some distance from the other, 10 to 20 metres above the ground, this height being chosen in order to be able to carry out measurements as far as possible in a homogeneous field and so avoid introducing such factors as absorption, reflections etc which tend to interfere with the measurement. A meter is connected to the receiving aerial to indicate the voltage induced in it, the set-up being as shown in Fig. 37. The signal generator is then tuned to a wavelength that is equal to twice the electrical length of the receiving aerial. If the aerial is now rotated on its vertical axis (the members of the dipole thus rotating in the horizontal plane), it will be seen that the meter reading varies with the position of the aerial relative to the transmitting aerial. When the two aerials are parallel to each other the meter gives a maximum reading, i.e. the maximum amount of voltage is then being induced in the aerial. The absolute magnitude of this induced voltage, which is of course dependent on the field strength at

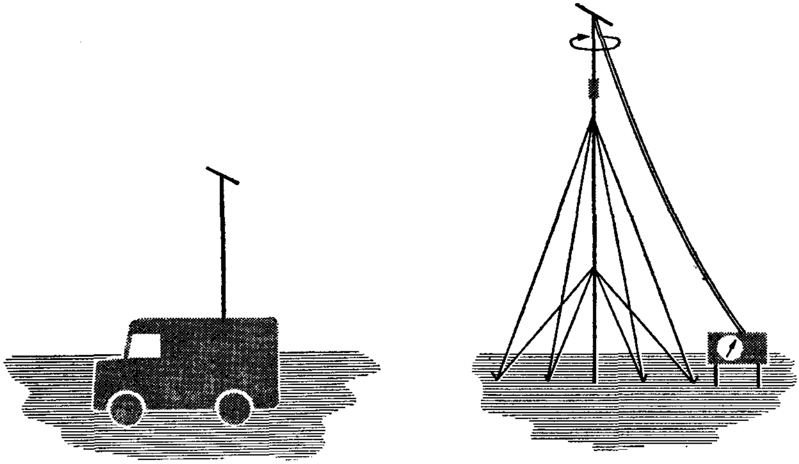


Fig. 37

the receiving aerial as well as on its effective height, is of no direct consequence, as it serves merely for comparison of the values obtained for the various positions of the aerial relative to the transmitter. Let us assume, for example, that the meter indicates 56 degrees on the scale when the two aerials are parallel to each other. When the receiving aerial is turned through an angle of 30° of a circle we may then find a reading of, say, 50. Rotation through a further 30°, making 60° in all from the original position, might then give a reading of only 28. Proceeding thus through the whole 360° we obtain a set of values something like the following:

Degrees of rotation	Meter reading	Degrees of rotation	Meter reading
0	56	180	56
30	50	210	50
60	28	240	28
90	0	270	0
120	28	300	28
150	50	330	50
		360	56

Similar values are usually supplied with the aerial by the makers, but are normally shown plotted in the form of a chart, of which Fig. 38 is an example constructed from the values in the above table. This chart then demonstrates the directivity of the aerial and is known as a radiation pattern.

It is found in practice, however, that simple dipoles of the kind under discussion may well yield different individual values of the voltage as actually measured, but the overall ratios are nevertheless constant; the radiation pattern is therefore the same in each case, namely a figure-of-eight.

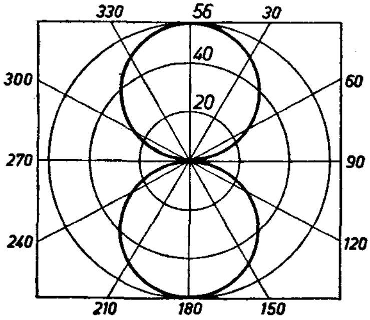


Fig. 38

For the purposes of such measurements the aerial, as mentioned, is rotated in the horizontal plane; the pattern is accordingly referred to as the horizontal radiation pattern.

Apart from this horizontal sensitivity to direction, however, the dipole has a certain sensitivity in the vertical sense and this can be similarly measured by rotating the receiving aerial in the vertical plane relative to the transmitting aerial. Aerial manufacturers accordingly often provide both the horizontal and vertical radiation patterns, as the latter can be useful for preventing interference (see also Chapter III).

Directivity factor

This is the ratio of the voltage obtainable from the aerial in respect of a certain angle of rotation, to the maximum voltage which the aerial is capable of delivering (i.e. when parallel to the transmitting aerial). For a signal arriving from the direction *A* at the aerial, the radiation pattern of which is shown in Fig. 39, this factor is 0.795.

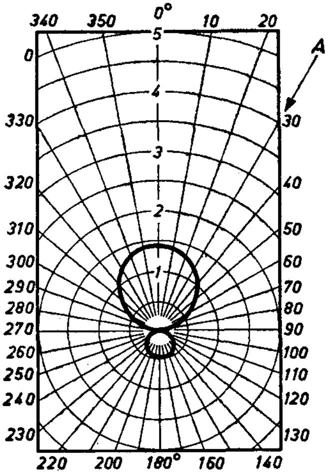


Fig. 39

The front-to-back ratio of an aerial

This is the term used to designate the ratio of the voltage obtained from the aerial as induced by a signal arriving from the main direction (0° in

Fig. 40), to the average voltage obtained in directions lying between 90° and 270°.

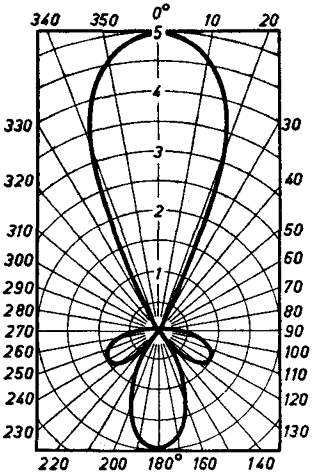


Fig. 40

As it is often very difficult to determine this average in respect of the rear "lobe" of the pattern, the procedure usually adopted is to take the average voltage induced by a signal actually transmitted from the opposite direction (180° in Fig. 40), as well as the maximum voltage obtained within the rear lobe. The front-to-back ratio of the simple dipole under consideration is seen from Fig. 38 to be 1 : 1. In the case of the radiation pattern shown in Fig. 40 the front-to-back ratio is:

$$5 : \tfrac{1}{2}\,(2 + 1) = 5 : 1.5 \text{ or } 3.33.$$

It is here assumed that the front-to-back ratio is the same at all frequencies, but measurements will in fact show that it is dependent on the frequency of the incoming signal. Fig. 41 shows this ratio, which in the following will be denoted by V/A, of an aerial as a function of the frequency; from this it is clearly seen that the ratio does vary with the frequency.

The question now arises as to what front-to-back ratio should be attributed to a frequency range extending from f_0 to f_b. For an aerial intended for the reception of signals in the F.M. band the frequencies concerned will be 87.5 — 100 Mc/s. The problem is even more critical in the case of the wide-band aerials used for television, since f_0 and f_b then cover a still wider range.

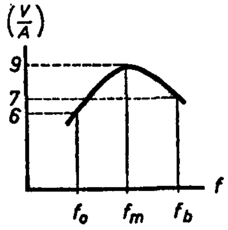


Fig. 41

As a rule, aerial manufacturers publish figures for the average front-to-back ratios of their aerials; let us see then, how this average is arrived at in reference to Fig. 41. It is seen from the figure that the ratio V/A at the lowest frequencies to be received (f_0) is 6, with 7 for the highest frequencies (f_b). In the middle of the band we find a value of 9. The average is obtained from the formula:

$$V/A = \frac{(V/A)_0 + 2(V/A)_m + (V/A)_b}{4}.$$

The average front-to-back ratio of the aerial to which Fig. 41 relates is therefore:

$$V/A = \frac{6 + 2 \times 9 + 7}{4} = 7.8.$$

For the benefit of those of our readers who are not familiar with the above formula we give below the manner of its derivation.

In the first place the average front-to-back ratio is found from measurements at frequencies f_0 and f_m (Fig. 41). This average is:

$$\frac{(V/A)_0 + (V/A)_m}{2}.$$

The average is then similarly obtained of the values for frequencies f_m and f_b:

$$\frac{(V/A)_m + (V/A)_b}{2}.$$

Lastly the average of these two terms is taken, viz:

$$\frac{\dfrac{(V/A)_0 + (V/A)_m}{2} + \dfrac{(V/A)_m + (V/A)_b}{2}}{2} = \frac{(V/A)_0 + 2(V/A)_m + (V/A)_b}{4}.$$

The front-to-back ratio of an aerial as given by the manufacturers will usually be found to be in decibels (dB). Now, in the numerical example above, a value of 7.8 was obtained; this corresponds to 17 dB. It should be noted here that the decibel is also a ratio, in that 1 dB = 20 log V/A (provided that the front-to-back ratio is in each case in respect of the same load resistance).

The aperture of an aerial

Another value often included in the manufacturers' published data is the aperture of the aerial. This refers to the angle through which the aerial can be rotated before the voltage induced in it drops by more than 70 % (3 dB) in strength. The aperture (θ) of the aerial the radiation pattern of which is shown in Fig. 42 is 2 × 24° = 48°. The smaller the aperture the greater the directional effect of the aerial.

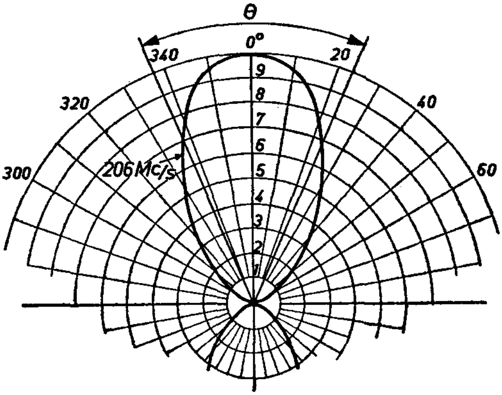


Fig. 42

The folded dipole

So far we have dealt only with the straight or extended type of dipole; there is, however, a variation of this, the folded dipole, an example of which is shown in Fig. 43. Let us first see what the aerial resistance is in this case. If we again assume a simple half-wave dipole made of extremely thin rods, the electrical length of which will then be equal to the physical length, the aerial resistance will be 73 Ω. Now, if we connect another, equally thin, rod in parallel with the dipole, the current will be divided between the dipole and the auxiliary rod in parallel with it. The equivalent circuit diagram of an aerial of this kind is given in Fig. 44. Here the dipole itself is represented by an equivalent network consisting of $L_1 — C_1 — R_{a1} — R_{a2} — C_2 — L_2$, whilst the extra rod is replaced by $C_3 — L_3 — L_4 — C_4$. If we assume that $(L_1 + L_2) = (L_3 + L_4)$ and that $(C_1 + C_2) = (C_3 + C_4)$, Fig. 44 can be replaced by Fig. 45; it should be borne in mind that the inductances $(L_3 + L_4)$ and $(L_1 + L_2)$ are inductively coupled. These equivalent circuit diagrams are not strictly correct, in so far that the inductances and capacitances of the rods are distributed along the rods and are not concentrated as in the two figures.

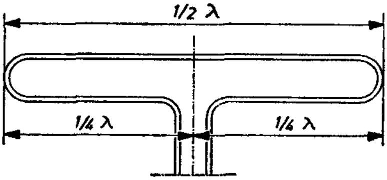


Fig. 43

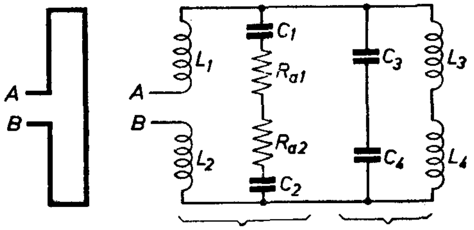


Fig. 44

It is seen from Fig. 45 that the aerial resistance R_a (73 Ω) occurs only across a part (in this case half) of the auto-transformer comprising $(L_1 + L_2 + L_3 + L_4)$, so that the aerial resistance between points A an B is equal to $4 \times R_a$ or $4 \times 73 \cong 300\ \Omega$.

Hence the aerial resistance of a folded dipole of extremely thin rods is four times greater than that of the corresponding straight dipole.

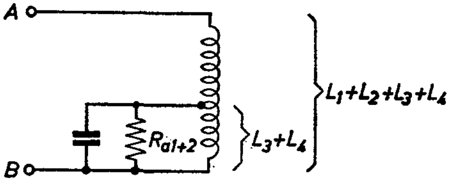


Fig. 45

The other properties as derived from the radiation pattern, i.e. the front-to-back ratio and the aperture, are virtually the same as for the straight dipole.

Now the above remarks are based on the assumption that the thicknesses of both the dipole and the auxiliary rod are the same and that the two rods are, in effect, extremely thin. In practice, however, the rods have a finite thickness which is often not the same for both the dipole and the auxiliary rod. In Fig. 46a we illustrate a folded dipole in which the parallel rod is thicker than the dipole itself ($d_2 > d_1$). The inductance and resistance of the thick part are less than in the case of the dipole, whereas the capacitance of the former is greater.

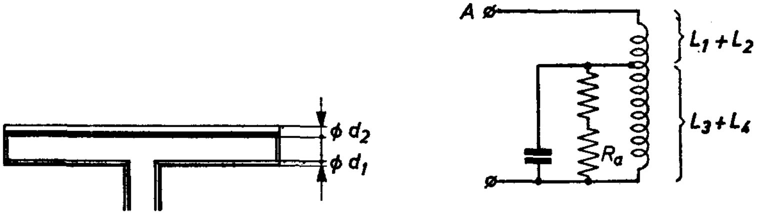


Fig. 46

The equivalent electrical diagram is shown in fig. 46b. Here $(L_1 + L_2)$ is greater than $(L_3 + L_4)$, so the resistance R_a is as it were stepped up, since R_{AB} (the resistance between terminals A and B) is given by:

$$\left(\frac{L_1 + L_2 + L_3 + L_4}{L_3 + L_4}\right) R_a.$$

Hence $R_{AB} > R_a$.

If $$\frac{L_1 + L_2 + L_3 + L_4}{L_3 + L_4} = 3, \text{ then } R_{AB} = 9R_a.$$

If the thickness of the dipole is greater than that of the auxiliary rod, the above conditions are reversed:

$$\begin{array}{ll} d_2 > d_1 & R_{AB} > 4R_a > 300\,\Omega. \\ d_2 = d_1 & R_{AB} = 4R_a \cong 300\,\Omega. \\ d_2 < d_1 & R_{AB} < 4R_a < 300\,\Omega. \end{array}$$

Now let us consider the question of the amount of power that the folded dipole is capable of receiving. If the aerial is positioned parallel to the transmitting aerial (the longitudinal axis of the rods then lies in the direction of the electric field vector F of the electromagnetic field), the voltage induced in it is equal to:

$$E = F \times h_{eff}.$$

For a folded dipole $h_{eff} = \frac{2\lambda}{\pi}$, so:

$$E = F \times \frac{2\lambda}{\pi}.$$

The power received is therefore:

$$P = \frac{E^2}{R_{AB}} = h^2_{eff} \times \frac{F^2}{R_{AB}} = \frac{4\lambda^2 F^2}{\pi^2 R_{AB}},$$

where $R_{AB} = 4R_a$ $(d_1 = d_2)$, or:

$$P = \frac{\lambda^2}{\pi^2 R_a} \times F^2.$$

This means that the power received by the folded dipole is the same as for the straight dipole, for in the latter case:

$$P = \frac{E^2}{R_a} = h^2_{eff} \times \frac{1}{R_a} \times F^2 = \frac{\lambda^2}{\pi^2 R_a} \times F^2.$$

(h_{eff} being $\frac{\lambda}{\pi}$ for the straight dipole).

To determine the aerial resistance of a folded dipole use is often made of a chart of the kind shown in Fig. 47, which gives the quotient D/λ (D = distance between centres of the dipole and the auxiliary rod), plotted against factor k. This is the factor by which the resistance R_a (of a single dipole of the same diameter) must be multiplied, using d_2/d_1 as parameter.

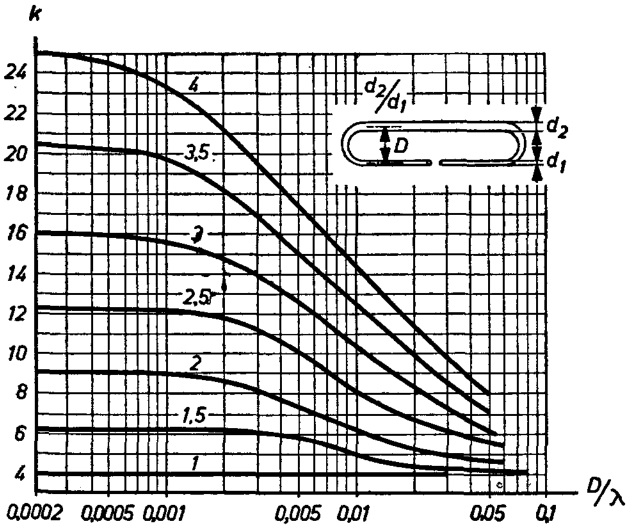


Fig. 47

Example.

Determine the aerial resistance of a folded dipole, given that the diameter of the rod used for the single dipole (d_1) is 6 mm, the diameter of the auxiliary rod is 12 mm and their centre distance $D = 9$ cm. The aerial is assumed to be suitable for a wavelength of 3 metres. The parameter $\frac{d_2}{d_1}$ in this case is $\frac{12}{6} = 2$. Further, the quotient $\frac{D}{\lambda} = \frac{0.09}{3} = 0.03$. From the family of curves in Fig. 47 it is seen that the aerial resistance is five times as great as that of a single dipole 6 mm in diameter. This latter resistance can be determined from Fig. 32.

For the aerial in question $\frac{\lambda}{d_1} = \frac{3}{0.006} = 500$, so R_a is 60 Ω approx. and the aerial resistance of the dipole $5 \times 60 \cong 300\ \Omega$.

Summarising, the more important features of the folded dipole are as follows.

1. The effective aerial height is $\frac{2\lambda}{\pi}$ and is thus twice as much as for the single dipole.
2. Generally, speaking, the aerial resistance is much higher than that of a single dipole (if the rods are infinitely thin, $R_a \backsimeq 300\ \Omega$). This type of aerial is therefore much more easily matched to the receiver than a single dipole.
3. Variation of the thickness of the auxiliary rod in relation to that of the dipole itself results in changes in the aerial resistance.
4. The bandwidth of the folded dipole is generally greater than that of a corresponding single dipole.
5. The directivity of the folded dipole is almost identical with that of the single dipole (the radiation pattern is the same).
6. The folded dipole is more robust.

Dipole aerials of the kind so far discussed all reveal the same radiation pattern (figure of eight), i.e. the sensitivity is the same at both front and rear. At the same time, just as much sensitivity at the back as at the front is not usually required and, in many cases, results in interference; it is only necessary to recall the reflections which can be such a nuisance in television. This tendency can be greatly reduced by employing an aerial having a small aperture and a high front-to-back ratio; these features can be obtained by means of auxiliary accessories which have the same effect as mirrors and lenses in the electrical sense.

The effect of a reflector

If a separate rod is placed behind an aerial as viewed from the transmitter, this works in the same way as a mirror. Such rods, known as reflectors, are not connected electrically to the aerial itself; that is to say, no current passes to them from the dipole or vice versa. This situation is illustrated in Fig. 48, in which the arrow indicates the direction of arrival of the radio waves. Now, it has already been explained that the aerial intercepts a certain amount of energy from the electromagnetic field in which it is situated. Assuming that the aerial and the receiver are correctly matched, half this amount of energy is passed to the receiver and the other half is absorbed by the aerial resistance, i.e. it is re-radiated by the aerial. What is the position, then, when a reflector is used?

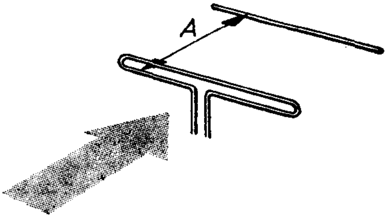
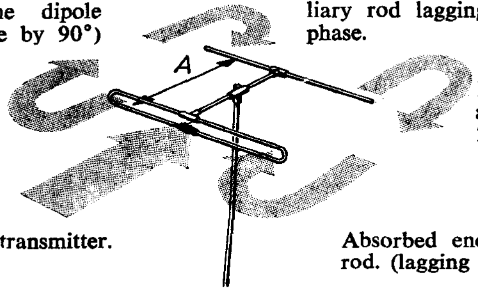


Fig. 48

The reflector also takes energy from the induction field, but this consists largely of energy that has been re-radiated by the dipole itself (I^2R_a), since the reflector is in the "shadow" of the dipole. This electrical energy cannot be channelled off in the usual way because the reflector is not in electrical contact with the aerial proper, with the result that almost all the energy absorbed by the reflector is radiated once again. The dipole thus receives not only the energy which it absorbs direct from the electromagnetic field, but also energy from the field that is re-radiated by the reflector. Now, if the distance *A* between the dipole and the reflector is so chosen that the electrical field strengths of the two fields (i.e. the *F* vectors of the fields) at the aerial system are in phase, the two fields reinforce each other and a voltage is induced in the dipole which is appreciably higher than it would be without the reflector (see Fig. 49).



Half the absorbed energy radiated by the dipole (lagging in phase by 90°)

Energy absorbed by auxiliary rod lagging 180° in phase.

Energy radiated by auxiliary rod lagging 270° in phase.

Waves from transmitter.

Absorbed energy from auxiliary rod. (lagging 360° in phase)

Fig. 49

In general, the characteristics of a dipole which are influenced by a reflector are:

a. The effective height, which is thereby increased

b. The bandwidth

c. The aerial resistance

d. The radiation pattern.

Before proceeding further, let us see for a moment what is meant by the term "relative power gain" of an aerial. This is defined as the factor indicating how much more, or less, is the energy passed to the receiver by the aerial than that which would be supplied to the same receiver by a folded half-wave dipole. As a formula this may be stated as:

$$G = \frac{\text{power delivered by a multi-component aerial}}{\text{power delivered by a folded half-wave dipole}}.$$

This power is generally given in decibels ($G = 10 \log \frac{P_1}{P_2}$).

P_1 = power delivered by the aerial
P_2 = power delivered by the folded half-wave dipole.

Where the load resistance of the two aerials is the same: $G = 20 \log \frac{E_1}{E_2}$, in which E_1 and E_2 represent the voltages induced in the additional components of the aerial.

In the first place the properties of a dipole with reflector are determined by the strength of the electromagnetic field produced at the dipole. This is in turn dependent amongst other things on the phase difference between the radiation fields of the transmitter and of the reflector as governed by:

a. the distance between reflector and dipole
b. the length of the reflector.

Generally speaking, the reflector will be about 5% longer than the dipole itself.

Fig. 50 shows the quotient A/λ (i.e. the distance between dipole and reflector in terms of the wavelength), plotted against the relative power gain of the aerial and the aerial resistance R_a. If we take the wavelength of the radiation field of the transmitter to be 3 metres and the spacing between the dipole and the reflector as 60 cm, then $A/\lambda = 60/300 = 0.2$.

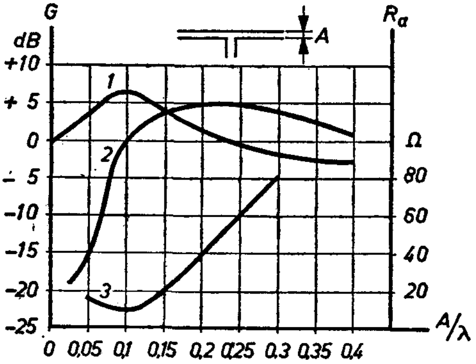


Fig. 50

Curve 2 in the chart then gives the aerial power gain in the case where the transmitted electromagnetic waves arrive first at the dipole and then at the reflector. This is known as the "forward gain" of the aerial. Curve 1, on the other hand, relates to the conditions whereby the radio waves reach the reflector before arriving at the dipole. Curve 3 relates to the aerial resistance. It will be seen from the chart that with a value of 0.1 for $\frac{A}{\lambda}$ the forward gain is zero (curve 2), whereas the gain in respect of the opposite direction is more than 5 dB.

The figure also shows that the radiation resistance of the simple, straight, dipole has now dropped to 15 Ω; for a folded dipole with rods of the same thickness this would have to be multiplied by 4. Where the auxiliary rod is so placed that the dipole lies between it and the transmitter it functions in the same way as a mirror, but if it is placed between the transmitting and receiving aerials it behaves as a lens; in this latter case it is called a director.

For a distance $A = 0.15\ \lambda$ the power gain is the same for signals arriving from either direction ($\frac{V}{A} = 1$), being 4 dB in each case. The aerial resistance is then 20 Ω (single dipole). For $A = 0.23\ \lambda$ the forward gain is about 5 dB, as against zero gain for signals coming from the opposite direction, in which case the auxiliary rod acts as a reflector.

Its follows from the above considerations that the aerial resistance of a single dipole, which is normally 60 to 70 Ω is reduced to a mere 15 Ω by

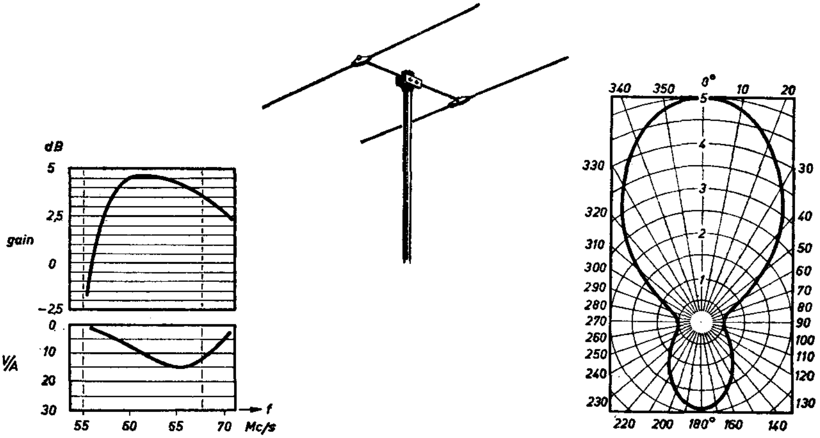


Fig. 51

the addition of a reflector at a distance $A = 0.1\lambda$ from it. Consequently, the aerial resistance no longer matches the resistance of the down-lead and the receiver, with the usual results of mismatching (loss of power and possibility of reflections). Fig. 51 gives data relating to a folded dipole with reflector designed for the reception of frequencies in the 55-70 Mc/s band. The first point to note is that the radiation diagram of this aerial is appreciably modified by the presence of the reflector; compare Fig. 51 with Fig. 38.

The main thing is that the front-to-back ratio is very much higher than otherwise and that the aperture is much reduced. Further, it is evident that both the front-to-back ratio and the aerial power gain are now very dependent on the frequency of the incoming signal.

The Yagi aerial

Should it be found that an aerial equipped with both reflector and director does not provide a satisfactory front-to-back ratio and sufficient sensitivity (gain), one or more components (directors) can be added at suitable distances from one another in front of the aerial proper. Aerials of this kind are known as Yagi aerials after the inventor, who introduced them as long ago as 1926. Yagi aerials are widely employed in places where rather more power gain than usual is required because the field strength in the area is low, or where a special radiation pattern is needed to eliminate reflections or local interference. At the same time, this kind of aerial is not without its disadvantages; the aerial resistance and the bandwidth are both reduced by the additional components, although it is possible to compensate this effect wholly or at any rate in part by using rods of different thickness and by varying their spacing.

It may be noted here that an aerial of this type may be found indispensable at relatively short distances from the transmitter for the reception of frequencies in Band IV, in view of the comparatively small effective height of half-wave dipole aerials at high frequencies; to make reception in this band possible aerials comprising some 20 components are by no means a rarity.

Another way out of this problem of ensuring high aerial gain consists in using two aerials in parallel. Fig. 52 illustrates two folded dipoles,

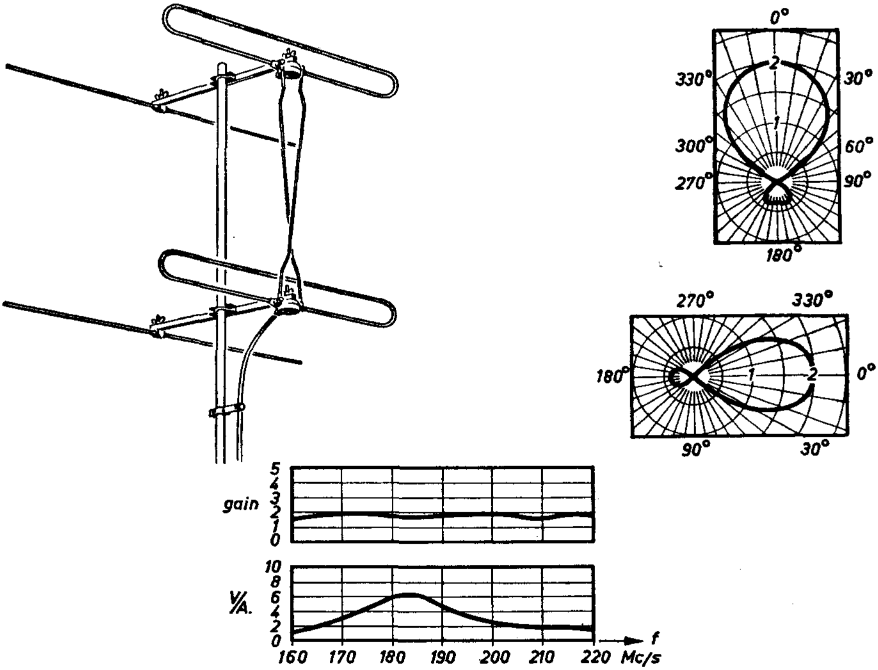


Fig. 52

each with a reflector, connected in this way. The vertical distance between the two aerials is approximately $\frac{\lambda}{2}$, where λ is the average wavelength in the band of frequencies to be received. Fig. 52 further shows the gain that may be expected, as well as the front-to-back ratio plotted against frequency.

Fig. 53 depicts an aerial of the type employed for reception over very long distances. Intended for vertical polarisation, this aerial is an array of two systems each comprising 10 components (8 directors, a folded dipole and a reflector), connected in parallel. The power gain obtainable from such an aerial would be 12 dB, the bandwidth 14 Mc/s and the aperture 24°.

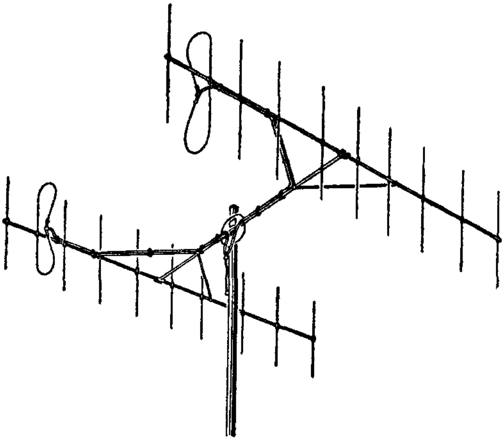


Fig. 53

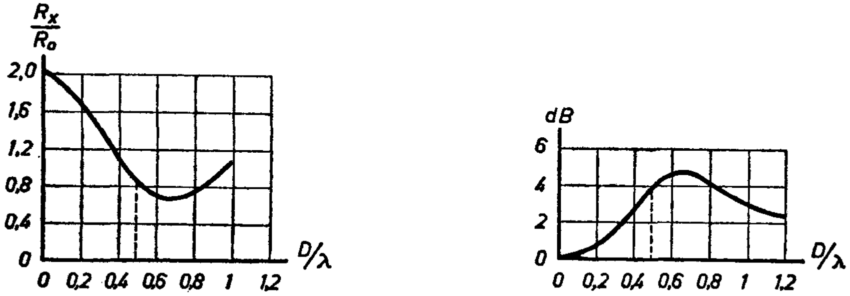


Fig. 54

It is generally found that the vertical distance between two individual aerials (horizontal distance with vertical polarisation) has a very marked effect on the aerial resistance and the gain that can be obtained from the whole array; to illustrate this point the ratio R_x/R_0 and the gain in dB as a function of $\frac{D}{\lambda}$ are shown plotted in Fig. 54 for two aerials in parallel.

The distance between the two units is D metres. It will be seen that where $D = \frac{\lambda}{2}$ the power gain is 4 dB and also that the aerial resistance is 0.8 times the value in respect of a single aerial (R_0). If R_0 is, say, 300 Ω, then $R_x = 0.8 \times 300 = 240\,\Omega$. Lastly, various data relating to different varieties of Yagi aerials are give in the appendix.

The "V" reflector (corner reflector)

As pointed out, the directivity of a Yagi aerial can be increased by adding components before and behind the primary element. The same effect can be obtained, however, by placing a reflecting screen behind the dipole. The reflector may be either paraboloid in section or V-shaped. An aerial of this kind is illustrated in Fig. 55. The reflector is usually made of gauze, of not too wide a mesh (less than 0.1 λ) and it is mostly some 5% longer than the dipole itself. The gain to be obtained by using such a reflector can be anything up to 10 dB and the V/A ratio, too, is

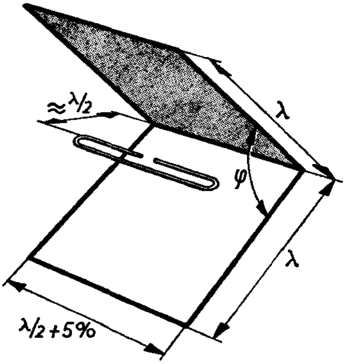


Fig. 55

very high. The aerial resistance at $\varphi = 90°$ is for practical purposes 150 Ω.

The helical aerial

The helical aerial, which is being more and more widely used for reception in Bands IV and V, ensures a very high aerial power gain. Dependent on the number of turns in the coil, this is from 4 to 20 dB.

This type of aerial (see Fig. 56) consists of wire, which should not be too thin, wound in the form of a helix on a rod of insulating material for rigidity, this being especially necessary if the coil is any great length.

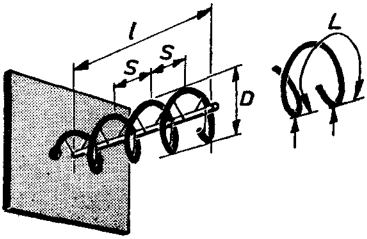


Fig. 56

The band of frequencies that can be received and also of course the aerial resistance, depend largely on the diameter *D* of the coil, the pitch and the length of wire per turn.

On the other hand the radiation pattern, aperture and aerial power gain are governed by the number of turns. The following relationship is found to exist between the pitch (*S*), diameter (*D*) and length per turn (*L*) (see Fig. 57):

$$L = \frac{\pi D}{\cos \alpha} \qquad S = L \sin \alpha.$$

For most aerials α varies from 12° to 18°, 14° being a fairly common value. In the case of wide-band aerials *L* is usually made equal to λ (the wavelength for which the aerial is intended).

Substitution in the wave formula gives:

$$\lambda = \frac{\pi D}{\cos \alpha} \text{ or } D = \frac{\cos \alpha}{\pi} \lambda = \lambda \frac{\cos 14}{\pi} = 0.31\,\lambda.$$

$$S = \lambda \sin \alpha = \lambda \sin 14 = 0.24\,\lambda.$$

To ensure the highest possible front-to-back ratio a metal screen is usually placed behind the spiral, consisting of fine gauze or sheet metal and about 0.85 λ in length (see Fig. 56). The distance from the first turn

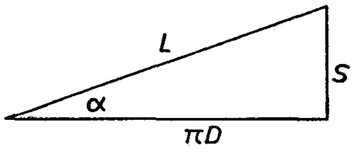


Fig. 57

to the screen is generally of the order of 0.1 λ. If the screen is earthed, the aerial can be connected to the receiver with a coaxial cable, in which case it is usual to employ an impedance matching transformer, seeing that the aerial resistance of helical aerials is roughly 120 Ω, which is unsuitable for coaxial cables. The question of matching, however, is discussed in more detail in Chapter IV.

By way of an example we give below the calculation relating to reception of channel 37 in the CCIR 625-line system.

This channel covers frequencies of 598 tot 606 Mc/s, the average frequency being $\frac{598 + 606}{2} = 602$ Mc/s, or a wavelength of 50 cm.

Now $D = 0.31\,\lambda = 15.5$ cm and $S = 0.24\,\lambda = 12$ cm.

The size of the aerial screen is therefore $\cong 0.85\,\lambda = 43$ cm. This screen is to be a metal plate 43 × 43 cm; the distance from the screen to the first turn of the aerial is $\cong 0.1\,\lambda = 5$ cm. Aluminium wire 5 mm in diameter is chosen for the coil, which is to be supported on paper laminate or bamboo. The usual material for the spacers would be perspex.

The curve in Fig. 58 gives the number of turns plotted against the aerial gain. As a final detail it many be noted that this aerial can be used for either vertical or horizontal polarisation.

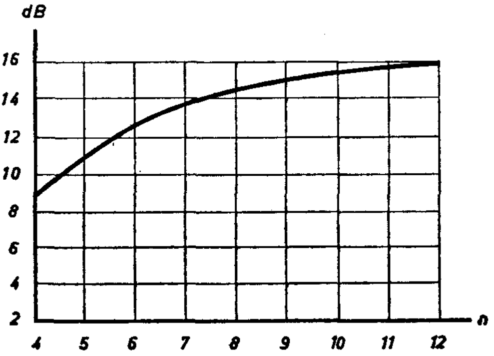


Fig. 58

CHAPTER III

THE CHOICE AND INSTALLATION OF THE AERIAL

The first two chapters of this book deal with the various kinds of aerials and their respective characteristics. We shall now consider the more practical aspect, that is, the factors which govern the choice of aerial to be used, the mountings and accessoiries and also the problems that may be encountered in the work of installation.

As the ultimate object of an aerial is to provide the radio-frequency voltage that will ensure the satisfactory functioning of the receiver, this is the main point to be borne in mind throughout. Next in order of importance is the avoidance of interfering signals; these are likely to be of different kinds, the more common of which are due to the following:

a) Other, unwanted, signals
b) Reflections
c) Local interference by motor cars, motor cycles, vacuum cleaners and so on
d) Inexpert installation of the aerial and its down-lead.

The first question that arises is of course: What kind of aerial should be used? Will a folded dipole be adequate, or should it be a Yagi type aerial, i.e. with or without reflectors or directors and, if the latter are required, how many?

In the first place the choice of aerial depends on the local field strength or, in other words, the reguired aerial gain, also taking into account the signal-to-noise ratio. The following table gives some idea of picture quality in relation to the signal-to-noise ratio.

Signal-to-noise ratio	Picture quality
100	Picture free from noise
50	"Drizzle" in picture
25	"Snow" in picture
10	Very poor
1	Picture obliterated

In Bands IV and V in particular, this ratio must be given very careful consideration, since the effective aerial height is directly proportional to the wavelength of the incoming signal. Thus the effective height for a signal of wavelength $\lambda = 1.5$ metres (Band III) is three times greater than in the case of a signal of 0.5 metres in Band IV.

It may be taken as a general rule that the greater the distance from the transmitter, the weaker the field strength and therefore the greater the gain required from the aerial, thus implying an aerial with a number of auxiliary components. Especially in large cities and hilly country the field strength tends to vary considerably between points a relatively short distance apart as a result of absorption and reflections. In connection with the erection of an aerial, then, its precise location is one of the most important aspects of the whole matter. If there is any doubt at all as to the best place for it the actual field strength should be measured, particularly if the distance from the transmitter exceeds the distance to the optical horizon, or even within the optical range if the aerial cannot be erected on the roof but has to be on an upper floor or in the loft.

For the purposes of measurement of the field strength in doubtful cases the effective height of the aerial can be calculated from:

$$h_{\text{eff}} = \frac{2E_0}{F}$$

where E_0 is the input voltage required for the receiver to ensure a good noise-free picture. For multi-component aerials the following approximate formula can be used:

$$h_{\text{eff}} = \frac{\lambda}{\pi}\,G,$$

in which G is the aerial power gain. This gain is roughly equal to the square root of the number of components of the aerial, so this gives the number of components required and hence also the type of aerial.

Example

An aerial is required suitable for the CCIR 625-line channel 9 (202-209 Mc/s). The receiver input is to be better than 180 μV for satisfactory reception. It is known that the field strength on the spot is 200 μV/m.

The voltage to be induced in the aerial is thus $2 \times 180\,\mu\text{V} = 360\,\mu\text{V}$ or more (correct matching and no cable losses). Now $E = h_{\text{eff}} \times F$, i.e.

$$360 \times 10^{-6} = h_{\text{eff}} \times 200 \times 10^{-6},$$

or:

$$h_{\text{eff}} = \frac{360}{200} = 1.8 \text{ m.}$$

The average frequency in the band is $\frac{202 + 209}{2} = 205.5$ Mc/s which is equivalent to a wavelength of 1.46 metres.

On the basis of the above formula:

$$1.8 = \frac{1.46}{\pi} G,$$

so $$G = 3.87.$$

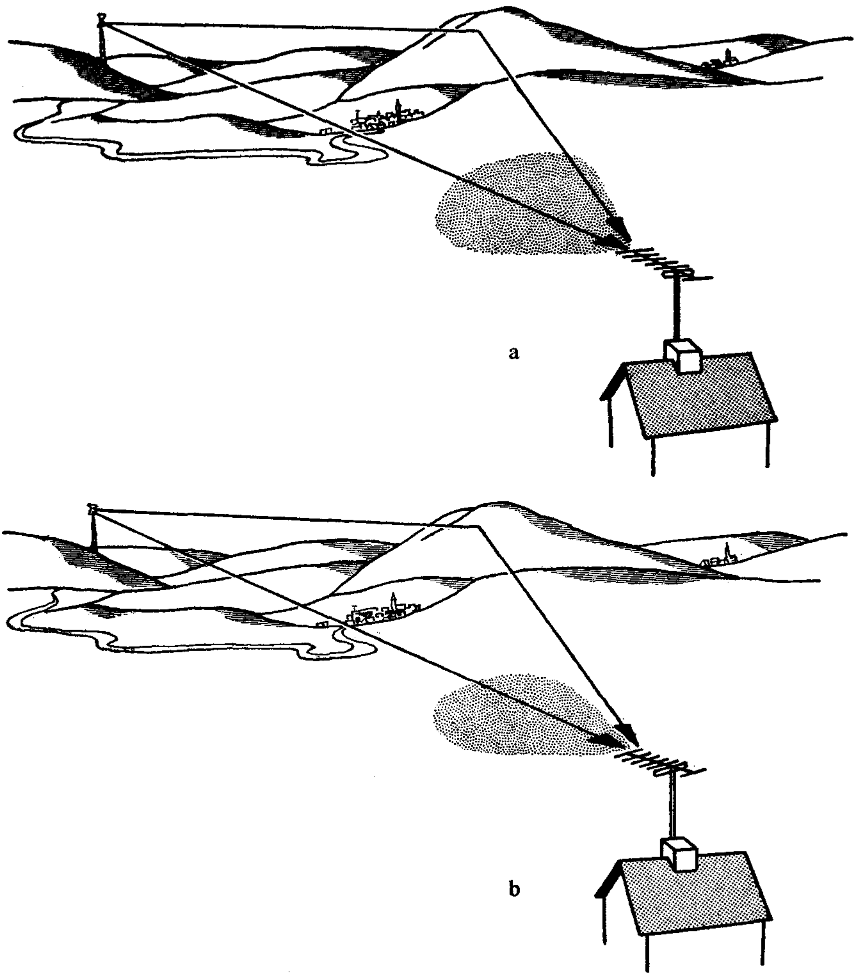


Fig. 59

An aerial to give a power gain of 3.87 would accordingly have 15 components.

The matter of the aerial gain having been settled, the next thing to do is to see whether any interference may be expected and, if so, what kind of interference and how to avoid it.

In the first place there may be reflections, resulting in multiple images; these have already been discussed in Chapter I, but there is still the question of eliminating them, or at least reducing them to a minimum. As pointed out, the greater the number of directors incorporated in an aerial the narrower the radiation pattern (smaller aperture) and, once the aerial has been set to the direction of maximum response, it will generally be found that a slight correction in one direction or the other is sufficient to reduce any reflections to negligible proportions. As will be seen from Fig. 59, however, this also has the effect of reducing the strength of the required signal.

Such adjustments are made with the aerial connected to the receiver, which should be tuned to the desired transmitter, preferably with the aid of the transmitted test pattern as this has the advantage that it gives a stationary image and contains numerous straight lines and different contrast values.

It may be found, however, that the required transmission can be received only as a reflection; the reason for this will be the presence of a large obstacle between the transmitting and receiving aerials, such as is frequently encountered in mountainous regions. This situation is depicted in Fig. 60. In such cases the aerial is set for maximum response from the reflection.

An entirely different form of interference is produced by electric sparks (car or motorcycle ignition systems), or the current collectors of trains or trams. This kind of interference can be reduced in different ways:

a. care in the selection of the location of the aerial

b. setting the aerial at an angle from horizontal (utilising the vertical radiation pattern of the aerial)

c. a combination of a. and b.

Any possible effects of interference on the down-lead to the receiver are disregarded for the moment, as these are discussed under the heading of the cable itself.

If a great deal of interference is noticed, i.e. due to heavy road traffic or in countries where the suppression of motor car interference is not impulsory, the optimum alignment of the aerial will have to be found by experiment, in connection with which the following hints may be found useful.

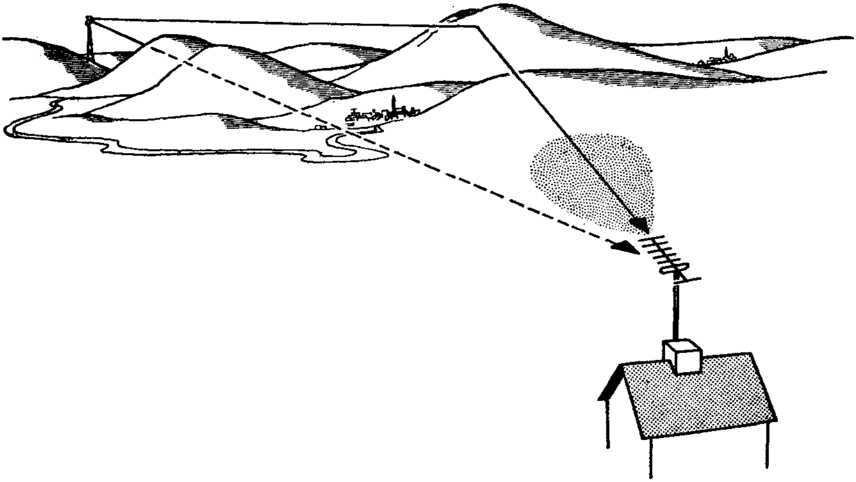


Fig. 60

In the first instance, the procedure to be followed depends largely on the nature of the building on which the aerial is to be erected. If it is of reinforced concrete the building itself will to some extent act as a screen between the source of interference in the street and the aerial, in which case the aerial is preferably located at the point shown in Fig. 61, i.e. as remote as possible from the street responsible for the interference.

On the other hand, if the roof is tiled or covered with bitumenised material, all interference signals will pass through it and here use must be made of the vertical sensitivity of the aerial by positioning it in the manner shown in Fig. 62, as close as possible to the street to ensure minimum sensitivity to interference produced by the traffic. It may be added here that in such cases care should be taken in the matter of choice and mounting of the down-lead.

Electrical appliances either inside the building itself or anywhere else in the vicinity are another possible source of interference, e.g. medical (diathermy) equipment etc. Before this can be dealt with it is necessary to

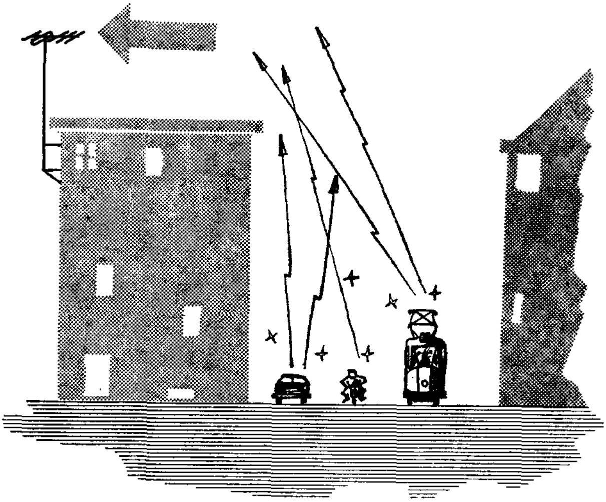


Fig. 61

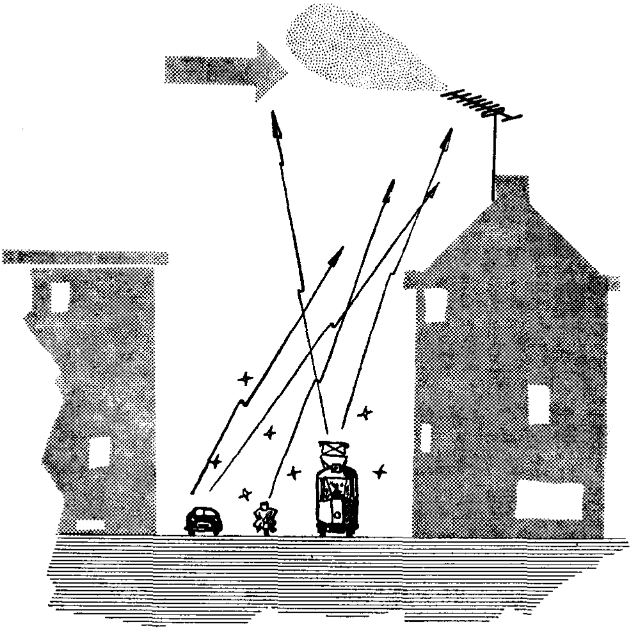


Fig. 62

ascertain whether the interfering signals are being propagated over the lighting mains or radiated in space. In the first instance a suppressor would have to be included in the mains lead of the offending appliance; in the second it may be found necessary to fit screens to those components which are responsible for the radiation. No fixed rules can be laid down in this respect, so each case must considered on its own merits.

The mast

Requirements imposed on the mast intended to carry the aerial are of a purely physical nature, relating only to rigidity and resistance to corrosion; a possible further point might be that the mast shall not be too heavy.

First let us consider the various forces that are likely to operate on the mast. There may be one or more aerials, each possibly comprising a number of components (folded dipole, reflector and one or more directors).

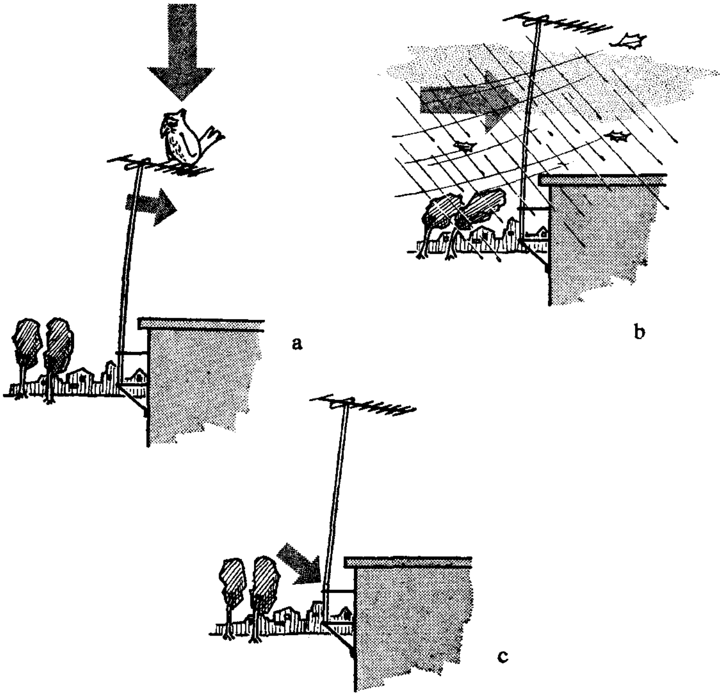


Fig. 63

This does not represent the total possible weight, however, as it may be increased considerably from time to time by birds alighting on the aerial; both the aerial and the mast should therefore be strong enough to withstand the extra weight. As will be seen from Fig. 63 the mast is subjected to a bending stress.

In the second place the whole structure should be able to withstand sudden strong gusts of wind, which represent lateral forces acting on the mast. If such forces reach their maximum the mast may quite possible become permanently bent (Fig. 63c).

Then again, the mast should be resistant to corrosion; the destructive effect of corrosion can generally be traced to two main causes, namely the atmosphere and combustion gases from chimneys. The atmosphere contains moisture and salt (the latter especially in coastal areas, where the salt may even be deposited on both the aerial and the mast). The action of combustion gases is rather more destructive, as these gases usually include sulphur dioxide which, in conjunction with the moisture in the atmosphere, produces sulphuric acid (H_2SO_4); this acid has a strong affinity for water and is extremely corrosive.

The first choice will always be a metal mast, except perhaps in wooded areas, where a good pine mast may be available; bamboo can also be used. Wooden masts should always be treated with creosote or some other wood preservative to prevent rotting and a metal cap should also be provided at the top to keep the end grain dry. Bamboo tends to split after two or three years in the open, unless steps are taken to avoid this, e.g. by binding it at intervals with copper wire and coating the whole with a layer of varnish.

Metal masts are usually of aluminium or one its alloys such as duralumin, the advantages of this metal being:

1. Lightness
2. A less bulky structure and therefore less vibration due to the wind; hence less risk of kinking or breaking.
3. Greater resistance to corrosion.

Even so, it is goed practice to give the metal a coat of zinc chromate paint if there are any factories in the neighbourhood where chemicals are used, or near the coast.

Duralumin masts should be at least 35 mm ($1\frac{1}{4}$ to $1\frac{1}{2}''$) in diameter, whatever the height.

Three-quarter inch gas piping is sometimes employed, but this is of course much heavier. It should always be carefully cleaned and then coated with anti-corrosive paint (e.g.red lead) or it should be galvanised, as it corrodes very easily.

Note

If piping is to be used for the mast it is very advisable to close the ends with cork or rubber plugs, not only to keep out the rain, but also to avoid humming which may occur as a result of vibrations set up by the wind.

Guy lines

Guy lines are not usually needed if the mast is not longer than some 10 to 12 feet, provided that it will not have to carry a very heavy aerial and is securely mounted on a chimney stack or wall.

On the other hand if the brickwork does not appear to be very strong or if very high winds are likely, as in coastal areas, it may be desirable to provide the additional support. Masts of 15 to 20 feet or more should always be guyed; 3 or 4 lines are ample.

The best types of wire to use for the guy lines are as follows.

a. Galvanised iron wire. In spite of its coating of zinc this wire does rust fairly quickly and, if used, should be inspected once a year. According to the load on the whole structure the wire should be 2 to 3 mm thick (30 - 20 S.W.G.). The breaking strain will be about 30 kg/mm^2 and the elongation about 40 %.

b. Telephone wire (phosphor bronze 20/10 mm).
This wire is very resistant to corrosion, but it has a marked tendency to stretch, necessitating re-tensioning of the lines after a few weeks. The thickness would be of the same order of size as that recommended for iron wire.

Note

From the point of view of working, telephone wire has the disadvantage that it must not be handled with pliers, as this inevitably scores the wire. In frosty weather such scratches cause the wire to break. For the same reason the eyes at the ends of the guy lines should be made larger than usual in order to avoid kinking and scoring.

c. Stranded steel wire with polyvinylchloride (P.V.C.) covering.

This type of wire is now used more than any other for such purposes. It is flexible and therefore easily manipulated, and the P.V.C. covering prevents corrosion.

Note

In the relatively rare event that the aerial is to be mounted on a thatched roof it should be borne in mind that thatching is often impregnated with substances to reduce the risk of fire. As these substances attack P.V.C., however, care should be taken that guy lines of this material do not come in direct contact with the roofing.

At points where this may be unavoidable rubber sleeving should be placed over the wire.

d. P.V.C. wire.

This material is not affected by humidity or chimney gases, but it stretches appreciably (20 to 30 %) and the breaking strain is not very high (6 to 7 kg/mm^2). Because of this it is used only where the tension can be checked from time to time or, alternatively, in conjunction with other, more stable, wire.

The stay tighteners

Stay tighteners are use for giving the guy lines the necessary tension, especially in the case of large installations. The advantage to be gained from the use of tighteners is that the lines need not be loosened from their anchorage when adjustments become necessary. The most suitable types of tightener are depicted in Fig. 64. The type shown in Fig. 64a

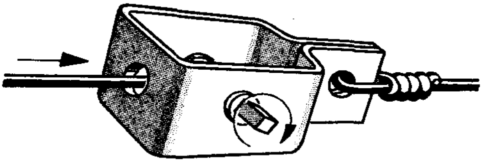


Fig. 64 a

is the kind that is widely used for wire mesh fencing; it consists of a galvanised iron housing containing a spindle on which a ratchet is mounted to permit of rotation in one direction only. It is suitable only for steel or steel-cored wire stays in view of the small radius to which the wire is wound on the spindle.

Fig. 64 b illustrates the double-ended, screw type of tightener; it is suitable for use with any kind of wire, including telephone wire.

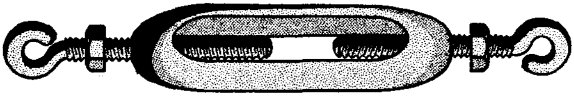


Fig. 64b

In general, tighteners fitted with lock nuts are prefeable as the nut prevents any loosening, but, if lock-nuts are not provided the device can be fairly effectively locked by passing the end of the wire through it a number of times.

Fastening material

The aerial is usually mounted on the mast with screws, which should preferably be of iron, either galvanised or cadmium plated to prevent rusting; even so, it is advisable to give all screws a coat of paint after fixing. When it is remembered that the aerial more often than not is mounted just above the chimney pots, it will be seen that all these precautions to combat rusting are not merely refinements. As already pointed out, flue gases are a source of sulphur dioxide which in turn produces sulphuric acid in conjunction with any moisture present, and the acid is likely to destroy metal fastenings in a very short time.

Another reason for avoiding corrosion is that the acid and the metal together constitute, as it were, an electric cell which may cause crackling noises in the receiver.

Plain iron brackets and cleats used as mountings for the mast should be carefully cleaned with emery cloth or by shot-blasting and then given a coat of anti-corrosive paint (red lead etc); otherwise they should be galvanised.

Erecting the mast

There are various ways of mounting aerials and we shall now examine one of two of the more usual methods.

a. *Mounting on a chimney stack*

If the mast is to be mounted on a chimney stack the first step is to make quite certain that the stack is robust enough to hold it, i.e. that its physical dimensions are adequate to withstand he forces that the aerial will bring to bear on it; thus it should not be too narrow or too short. Secondly, it is wise to ascertain the condition of the stack. If it is too badly cracked it is better to put the aerial somewhere else than run the risk of both aerial and stack falling to the ground. Fig. 65 shows an aerial erected on a chimney stack. If this method is used make quite sure that it will not weaken the masonry. The use of rag bolts belongs to the past and steel wires round the stack should never be used without corner plates to protect the mortar from damage.

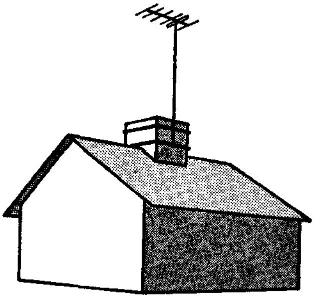
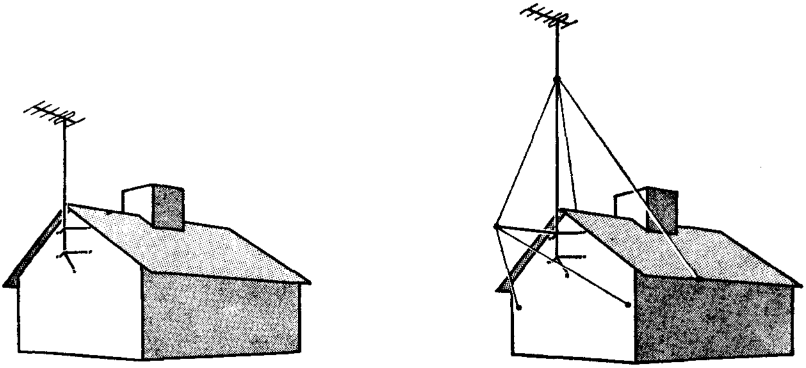


Fig. 65

The arrangement shown in Fig. 65 should be adopted only where the straps can be mounted at least 18″ apart.

Guy lines can of course be used if desired and are indispensable if the mast is to carry more than one aerial.

Should the chimney stack appear to be in no condition to hold the aerial, or if the landlord will not allow it to be used for this purpose, the mast can always be mounted on the wall. The supporting brackets must be very securely mounted, for example by means of $\frac{3}{8}$″ expanding bolts, since they not only have to withstand the lateral forces operating on the mast, but must bear the weight of the entire structure. An example of an aerial mounted on the wall of a house is shown in Fig. 66. Guy lines are essential in this case and attention is drawn to the manner in which the third wire is fixed. It should be added that the expanding bolts should never be inserted in the cement between the bricks, but in the bricks themselves; otherwise movements of the mast will cause them to work loose. Wall mounting is not practicable if the available wall is only of half-brick thickness.


a Fig. 66 b

On flat roofs the mast can be supported freely in a special base; a home-made base is suitable if the proprietory article in unobtainable. If roofing felt has been used no nails or screws should be used, as this inevitably results in leaks. The base is placed on a wooden board or beam, or even on a piece of rubber to isolate it from the felt, although according to various authorities this is not strictly necessary. The mast

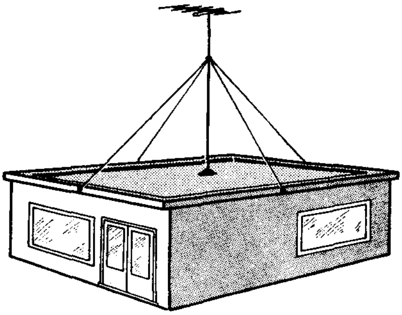


Fig. 67

is held in position by four guy lines in the manner shown in Fig. 67. For tiled roofs we have seen a specially recessed tile into which the mast can be inserted; here, too, 3 or 4 guy lines are necessary (Fig. 68).

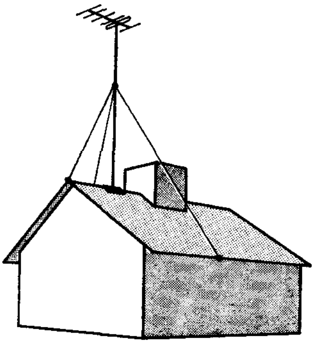


Fig. 68

Mounting the aerial

The aerial or aerials having been duly checked over, they can be mounted on the mast and, if guy lines are to be used, these are fixed in position. A suitable flange (see Fig. 69) should be used for this purpose.

It then only remains to attach the down-lead to the aerial and clip it to the mast, after which the whole structure can be placed in position and guyed. This should need no further explanation.

The down-lead and methods of fixing are discussed in the next chapter.

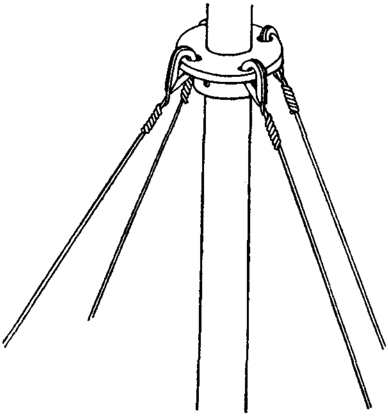


Fig. 69

CHAPTER IV

CONNECTING THE AERIAL TO THE RECEIVER

The aerial as discussed in the preceding chapters is connected to the input of the receiver by means of a down-lead, or line, the function of which is therefore to pass to the receiver the electrical energy induced in the aerial. A line is here understood to be a system of two conductors in accordance with the following:

a. Constant spacing between the conductors throughout the whole length

b. Conductors of the same thickness throughout

c. The same kind of dielectric over the whole length.

The approximate equivalent electrical diagram of a line of this kind, as depicted in Fig. 70 a, consists of a large number of inductances with extremely small capacitances between them (Fig. 70 b). Now, when a d.c. voltage (V) is applied to the line — which for the moment is assumed to be infinitely long — a current flows in it which successively charges the capacitances C_1, C_2, C_3. This implies that the voltage is propagated through the line at a certain velocity. If we assume also that the capacitors within a length of the line equal to 1 metre are charged in a period of t seconds, the total charge will be:

a

Fig. 70

b

$$Q = C \times V = I \times t \tag{1}$$

where C = capacitance of 1 m of the line,

I = current flowing in the line to charge the capacitors in a length of 1 m.

Further:

$$V = L \times \frac{I}{t} \text{(Faraday's law)},$$

or:

$$V \times t = L \times I;$$

$$t = \frac{L \times I}{V} \qquad (2)$$

(L = inductance of 1 metre of the line).

Substituting formula (2) in (1) we obtain:

$$C \times V = I \times \frac{L \times I}{V},$$

or:

$$Z^2 = \frac{V^2}{I^2} = \frac{L}{C},$$

so

$$Z = \frac{V}{I} = \sqrt{\frac{L}{C}} \qquad (3)$$

It follows, then, that the current entering the infinitely long line and successively charging all the capacitors is equal to that which flows through an impedance $Z = \sqrt{\frac{L}{C}}$ Ω.

This impedance is known as the characteristic impedance of the line. (In the above, the purely d.c. resistance is disregarded).

The characteristic impedance of a cable is thus dependent on the inductance and the capacitance, in other words on the construction of the line (the spacing of the two conductors, their diameter, the type of metal of which they are made and the dielectric between them). By way of an example let us calculate the characteristic impedance of the flat twin type of cable shown in Fig. 70a.

The inductance of such cable is:

$$L = 4 \times 10^{-9} \times \mu \times l \times \ln \frac{2D}{d} \text{ henry}, \qquad (4)$$

where μ = permeability of the conductors
l = length of the cable in cm
D = centre distance of the two conductors
d = diameter of conductors.

The capacitance of this cable will be:

$$C = \frac{l}{9 \times 10^{11}} \times \frac{\varepsilon}{4\, ln \frac{2D}{d}} \text{ farad,} \tag{5}$$

where ε = relative permittivity of the material between the conductors
l = length of the cable in cm.

The characteristic impedance of flat twin cable can now be calculated by substitution of the values of L and C in formula (3):

$$Z = 120 \sqrt{\frac{\mu}{\varepsilon}} \times ln \frac{2D}{d} = 276 \sqrt{\frac{\mu}{\varepsilon}} \times \log \frac{2D}{d} \tag{6}$$

Note

The formulas given above apply only so long as D is much greater than d; if it is not, the capacitance as calculated will be too low. To give a few examples:

D/d	Discrepancy
20	0.5%
5	4%
2.5	20%
2	40%

In the case of coaxial cables (see Fig. 71) the values in question are:

$$L = 2 \times 10^{-9} \times l \times \mu \times ln \frac{D}{d} \text{ henry,} \tag{7}$$

$$C = \frac{l}{9 \times 10^{11}} \times \varepsilon \times \frac{1}{2\, ln \frac{D}{d}} \text{ farad,} \tag{8}$$

so the characteristic impedance of the cable is:

$$Z = 138 \sqrt{\frac{\mu}{\varepsilon}} \times \log \frac{D}{d}\ \Omega \tag{9}$$

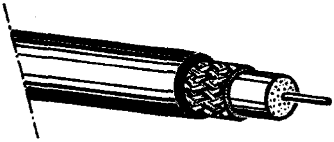


Fig. 71

It will be seen from the above that there is a certain relationship between the voltage applied to an infinitely long line and the current flowing in the line, this being defined as $Z\sqrt{\frac{L}{C}}$. But what is the position in regard to a short line?

Fig. 72 illustrates a short line connected to a voltage source the internal resistance of which is R, this being equal to the characteristic impedance of the line.

Immediately the circuit is closed a current passes into the line through the resistance R. This accordingly charges the capacitors C_1, C_2, C_3 etc in succession, and both current and voltage are thus propagated through the line. The current is:

$$I = \frac{V}{R + \sqrt{\frac{L}{C}}} = \frac{V}{2R} \quad (R = \sqrt{\frac{L}{C}}).$$

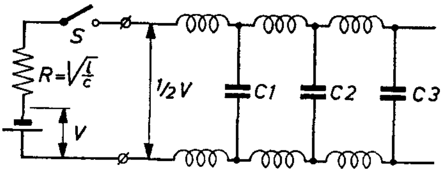


Fig. 72

So far, everything is the same as in the long line. However, when the current and voltage arrive at the end of the line a characteristic difference is seen, for the current is then zero (as the line is open). Nevertheless two reasons can be given to show that a current (at the voltage source) for the time being continues to flow in the line.

a. The input end of the cable is charged to a voltage of $\frac{1}{2}V$. Across the resistance R there is another $\frac{1}{2}V$, so that, in the first instance the current flowing in the resistance remains the same:

$$(I = \frac{V - \frac{1}{2}V}{R} = \frac{V}{2R}).$$

b. The magnetic field that is built up cannot change suddenly.

This means that a concentration of charges occurs at the extremity, which constantly drains away in the inverse direction, thus charging the numerous capacitors up to twice the original charge; the voltage across these capacitors therefore rises from $\frac{1}{2}V$ to V volts, the effect being as though another voltage were applied to the open end of the line. Fig. 73 illustrates a number of successive conditions appertaining to the voltage and current; Fig. 73a shows the situation at the moment that both current and voltage reach the end of the line. (This occurs in t sec after the circuit has been closed). An instant later the conditions are as depicted in Fig. 73b. In the direction from the open end of the line the voltage across the line has built up to V volts. The current, on the other hand, has dropped to 0 amperes in the same interval. Two t seconds after the switch has been closed we have the conditions shown in Fig. 73c, when the voltage across the line is V volts and no current is flowing. At this moment, then, equilibrium is established.

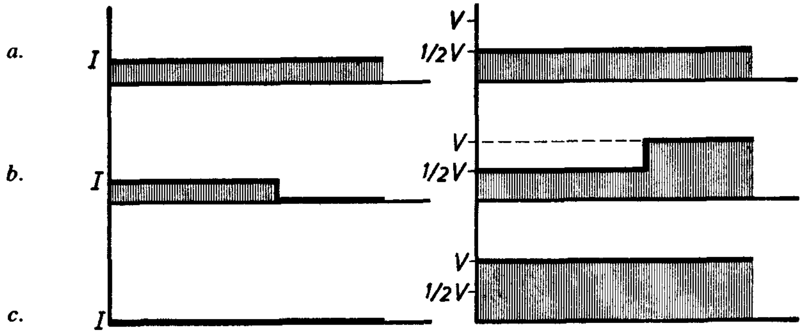


Fig. 73

An important conclusion can be drawn from the above, namely that in an open transmission line the current is reflected with negative polarity and the voltage with positive polarity from the open end of the line.

Now, what takes place when the d.c. source of supply is replaced by a source of a.c. voltage? When the circuit is closed current flows in the line via resistance R, and both current and voltage are propagated to the end of the line, producing the condition shown in Fig. 74a. When the end of the line is reached the voltage is reflected with positive polarity as before, and the current with negative polarity, just as if a second

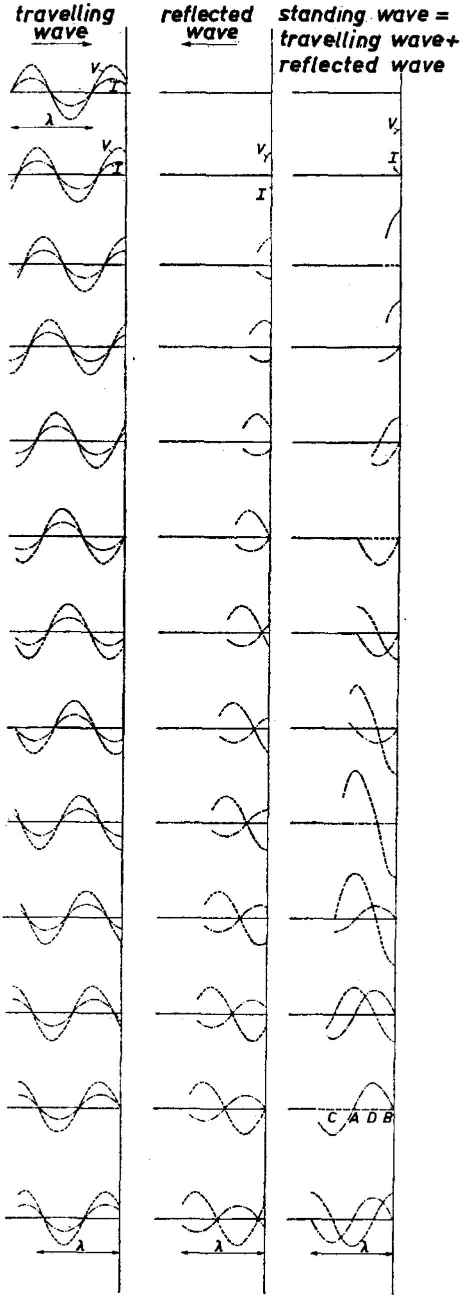

travelling wave
reflected wave
standing wave = travelling wave+ reflected wave
V
I
λ
V
I
V
I
V
I
C
A
D
B
λ
λ
λ

Fig. 74

source of alternating current were connected to the far end, propagating a current in the opposite direction. The voltage from this hypothetical source is then in phase with the original voltage, but the current is opposed in phase to the original current. Fig. 74b to m depicts a number of successive phases of the current and voltage along the line. Now, if the instantaneous values of the direct and reflected current and voltage are added up, it is found that they are zero, and remain so, at certain points in the line, whereas they vary from 0 to I amperes (volts) at other definite points ($V/2$ = amplitude of the voltage delivered by the source, the internal resistance of which is $R = \sqrt{\frac{L}{C}}$, and half the amplitude of the current passing into the line from the source). The points where the current and voltage remain zero are known respectively as current and voltage nodes; similarly the points where they both vary between minimum and maximum values are called antinodes.

It will be seen from Fig. 74 that the shortest distance between two successive antinodes is equal to half the wavelength of the alternating voltage delivered by the source.

Let us now see with the aid of numerical examples what happens when the line is terminated with a resistance which is:

a. the same as
b. greater than } the characteristic impedance of the line.
c. less than

a. Given a source of supply delivering 30 V the internal resistance of which is 75 Ω, connected to a line having a characteristic impedance of 75 Ω and terminated with a resistance R_0 = 75 Ω, a current will flow in the line when the circuit is closed, equal to:

$$I = \frac{30}{75 + 75} = 0.2 \text{ A},$$

the voltage across the line being:

$$0.2 \times 75 = 15 \text{ V}. \quad \text{(See Fig. 75).}$$

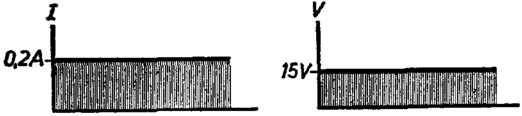


Fig. 75

If the resistance R_0 were connected direct to the voltage source the current flowing through it would also be 0.2 A and the voltage between its terminals would also be 15 V, so, when the current and voltage reach the resistance at the extremity of the line the current flowing in the resistance is also 0.2 A and the voltage 15 V. In other words the current carried by the line is entirely absorbed by the resistance.

From this it may be concluded that a short line terminated with a resistance equal in value to the characteristic impedance of the line behaves in the same way as an infinitely long line from the point of view of the voltage source; reflections of current and voltage do not occur.

b. Let us now suppose that the line is loaded with a resistance of 300 Ω instead of 75 Ω.

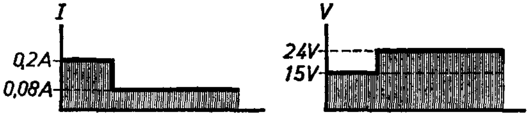


Fig. 76

When the circuit is closed a current of 0.2 A again flows in the line and the voltage is once more 15 V. These conditions prevail until both current and voltage arrive at the resistance R_0. With the resistance connected direct to the voltage source the current in the resistance will now be $I = \dfrac{30}{300 + 75} = 0.08$ A and the voltage $0.08 \times 300 = 24$ V.

In this case the resistance absorbs power to the extent of $24 \times 0.08 = 1.92$ watts.

The voltage source thus imparts to the line $0.2 \times 15 = 3$ W, of which 1.92 W is dissipated by the resistance; this means that $3 - 1.92 = 1.08$ W is reflected, i.e. returned to the aerial. At the end of the line the current will then be 0.2 A, but as R_0 accounts for 0.08 A, a current of $0.2 - 0.08 = 0.12$ A, inverted in phase, is reflected. The voltage across the line is 15 V, and that at the resistance would be 24 V if this were connected direct to the source. Hence $24 - 15 = 9$ V is reflected in phase with the original voltage, thus increasing it to 24 V. See Fig. 76.

To sum up, the generator delivers 3 W to the line; when this reaches the resistance R_0, 1.92 W is absorbed by this resistance and 1.08 W is returned to the source (current 0.12 A and voltage 9 V). This last-mentioned (reflected) power is absorbed by the internal resistance of the source (75 Ω).

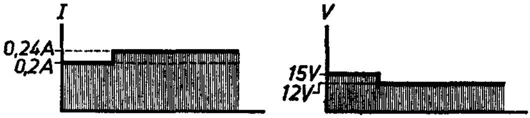


Fig. 77

c. Resistance less than the characteristic impedance of the line.

Once again current and voltage are supplied to the line ($I = 0.2$ A, $V = 15$ V, equivalent to 3 W. If the resistance, say, of 50 Ω were connected direct to the source, a current of $\frac{30}{75 + 50} = 0.24$ A would flow through it and the voltage across it would be $0.24 \times 50 = 12$ V. Hence a current of 0.24 — 0.2 = 0.04 A positive is reflected, as well as a voltage of 15 — 12 = 3 V negative: See Fig. 77.

The above conditions are set out for comparison in the following table

Open line	Voltage reflected positive Current reflected negative	$V_{\text{refl}} = V/2$ $I_{\text{refl}} = I$
Terminating resistance greater than characteristic impedance	Voltage reflected positive Current reflected negative	$V_{\text{refl}} < V/2$ $I_{\text{refl}} < I$
Terminating resistance equal to characteristic impedance	Voltage not reflected Current not reflected	$V_{\text{refl}} = 0$ $I_{\text{refl}} = 0$
Terminating resistance less than characteristic impedance	Voltage reflected negative Current reflected positive	$V_{\text{refl}} < V/2$ $I_{\text{refl}} < I$
End of line short circuited	Voltage reflected negative Current reflected positive	$V_{\text{refl}} = V/2$ $I_{\text{refl}} = I$

In this matter of the matching it has been assumed throughout that the internal resistance of the voltage source is equal to the characteristic impedance of the line; in other words that the source and the line are matched. This implies that any power returned to the source as a result of mismatching at the end of the line is fully absorbed by the source. If the internal resistance of the source and the characteristic impedance of the line are not the same, some of the reflected power is absorbed by the internal resistance and the rest is passed back to the line.

To return to the question of the line as a means of connecting the receiver to the aerial, it can now be said that the line must be matched at both ends, i.e. to both the aerial and the receiver. The following four contingencies then arise:

a. Line to aerial mismatched
   Line to receiver matched
b. Line to aerial matched
   Line to receiver mismatched
c. Line to aerial mismatched
   Line to receiver mismatched
d. Line to aerial matched
   Line to receiver matched.

Let us assume that in a) above a folded dipole (300 Ω) is connected to a 75 Ω line, the receiver input being also 75 Ω. The electrical energy in this case is only partly transferred to the line, since the aerial is loaded with 75 Ω whereas the maximum transfer of energy would occur at 300 Ω. Hence there is a loss of sensitivity in the aerial system ($2\frac{1}{2}$ times).

In case b) we shall assume that the 300 Ω dipole is connected to a 300 Ω line, the receiver input again being 75 Ω. Here the characteristic impedance of the line is greater than the terminating resistance; some of the energy delivered by the line is then taken by the receiver input and the rest is returned to the aerial, where it is absorbed by the aerial resistance; this residual energy is then re-radiated by the aerial and is likely to interfere with other receivers in the vicinity (multiple images). Thus the immediate result of such a mismatch is loss of sensitivity at the aerial and interference with your neighbours' reception (if the reflected signal is strong enough).

The example given in c) is an extreme case, which would arise if a folded dipole (300 Ω) were connected through a 75 Ω line to a receiver input of 300 Ω. In this case only a part of the aerial power is passed to the line; a part of this again is absorbed by the input impedance of the receiver, and a part is reflected. The reflected power, in turn, is only partially absorbed by the aerial resistance and is therefore re-radiated, the rest being returned to the line (reflection in consequence of the mismatching of the aerial and line). This latter signal accordingly reaches the receiver later than the original signal and, apart from the loss of power, double images may be produced. If the incoming signal is strong, it is, in fact, very likely that there would be several images in decreasing order of intensity.

In d) above, the line is correctly terminated at both ends, so the power delivered to the line by the aerial is fully utilised by the receiver input. In other words the transfer of power is at a maximum and any multiple images that may be produced cannot possibly be due to mismatching.

For convenience, the above contingencies are shown in tabular form below.

Matching		Results
Aerial/line	Line/receiver	
Correct	Correct	Maximum energy transfer. No multiple images.
Incorrect	Correct	Energy transfer less than optimum. No multiple images.
Correct	Incorrect	Energy transfer less than optimum. No multiple images, but possible interference with other receivers.
Incorrect	Incorrect	Energy transfer less than optimum; multiple images; possible interference with other receivers.

Attenuation

Our arguments have so far been based on the assumption that the down-lead is free from losses and, as far as the lower frequencies are concerned, this is indeed the case. At the higher frequencies employed for FM and TV transmissions, however, line losses cannot be disregarded. The amount of the loss is in the first place determined by the a.c. resistance of the conductors and this depends not only on the material of which the conductors are made, as well as their dimensions, but also on the frequency of the alternating current. This a.c. resistance is given by the formula:

$$R_{hf} = \frac{l \times \sqrt{(\rho \times f)}}{5030 \; \pi \; d} \; \Omega,$$

where l = length of conductor in cm
ρ = resistivity of the metal
f = frequency of the a.c. signal
d = diameter of the wire in cm.

It is also found that the dielectric losses increase with the frequency, i.e. the higher the frequency the greater the dielectric losses and also the loss of power.

For example if N_1 watts are delivered to a line and N_2 represents the power available at the other end, $(N_1 - N_2)$ watts are converted to heat and are thus lost.

The attenuation in a line is defined as $10 \log \frac{N_1}{N_2}$ per 100 metres length and is expressed in decibels. From the above it will be clear that the attenuation of a line must always be stated in respect of the frequency at which it occurs. In order to give some idea of the different kinds of cable used for aerial down-leads, a few of the more common types, together with their properties, are described in the following.

a. *Flat twin cable* (Fig. 78a).

This consists of two conductors moulded parallel to each other some distance apart in plastics material (polythene). There are two grades, one of which has transparent insulation, the other being black (polythene mixed with other substances). It is a disadvantage of the transparent kind that exposure to sunlight affects the polythene in such a way as to increase the losses. Also, in frosty weather, the insulation becomes very rigid and tends to craze; moisture then enters the minute fissures and considerably increases the attenuation. This type of cable is therefore used mainly for indoor work. The black polythene cable suffers in this way to a much lesser extent and is therefore suitable for outdoor use; it is also fairly cheap.

For general purposes the attenuation per 100 metres can be taken as 4 dB at 50 c/s, 7.5 dB at 200 Mc/s and 14.4 dB at 500 Mc/s. The cable is obtainable with a characteristic impedance of 75 Ω, 150 Ω, 240 Ω or 300 Ω.

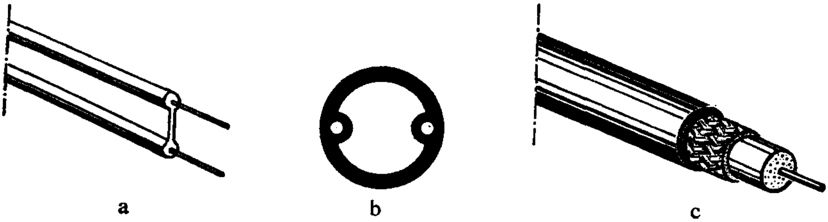


Fig. 78

b. *Tubular twin cable (see fig. 78b).*

This type of cable consists of tubular polythene with the conductors arranged more or less in the manner shown in the sketch. The great advantage is that the characteristic impedance and the attenuation are affected to a much lesser extent than otherwise, this being a great asset at frequencies in Bands IV and V. On the other hand, this type of cable is not so easy to install and it is rather more expensive. Some useful details are as follows:
Colour of polythene: black or white.
Characteristic impedance: 240 Ω.

Attenuation at 50 Mc/s : 4 dB
100 Mc/s : 6 dB
200 Mc/s : 8 dB
800 Mc/s : 16 dB

Note: The upper end of the cable must be plugged to exclude rain water.

c. *Balanced screened cable*

Screened cable is used mainly for outside connections. The conductors, which are parallel to each other and individually insulated, are jointly screened with braided copper wire which in turn is protected from the atmosphere by a covering of p.v.c. It is not flexible and the attenuation is high:

100 Mc/s : 12 dB
200 Mc/s : 18 dB

The characteristic impedance is 240 Ω.

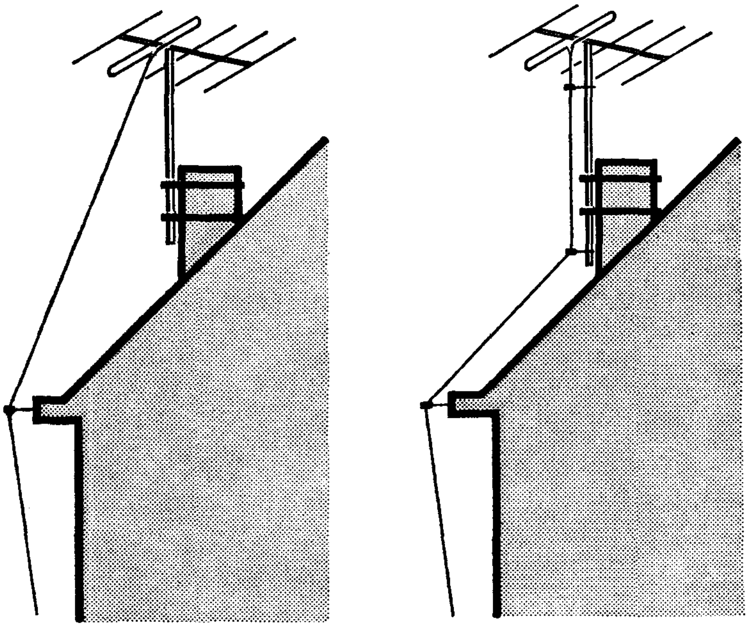
d. *Coaxial cable* (Fig. 78c)

In this type of cable a central conductor is insulated with p.v.c. from an outer metal sleeve which constitutes the other conductor; hence the dielectric is p.v.c. The outer sleeve (conductor) is earthed and the connection between the aerial and the receiver is therefore asymmetrical. This cable is expensive and is generally used only in cases where interference is expected.

The attenuation is considerably higher than that of the parallel type of flex:

50 Mc/s : 6.2 dB
100 Mc/s : 11 dB
200 Mc/s : 15 dB
800 Mc/s : 30.5 dB

The characteristic impedance is 72 Ω.



a Fig. 79 b

Connecting the receiver to the aerial

The down-lead may be regarded as being in two parts, namely the inside and the outside sections. If ordinary flat twin wire is used for the exterior section it can be connected direct to the dipole (provided the aerial resistance is equal to the characteristic impedance of the line). It is then carried down over the roof, care being taken to watch the following points.

The joint at the aerial must not be placed under stress as a result of bending of the mast (see Fig. 79a); in other words the lead must be secured to the mast itself before it is carried down to the receiver, in the manner shown in Fig. 79b. The lead should be supported at intervals on insulators in order to keep it away from the roof and wall; various types of insulators are illustrated in Fig. 80. In the process of fixing the lead the wire should be twisted at a pitch of 1 turn per foot; this has the advantage that it makes the wire more rigid and at the same time ensures a better distribution of the capacitances to the surroundings.

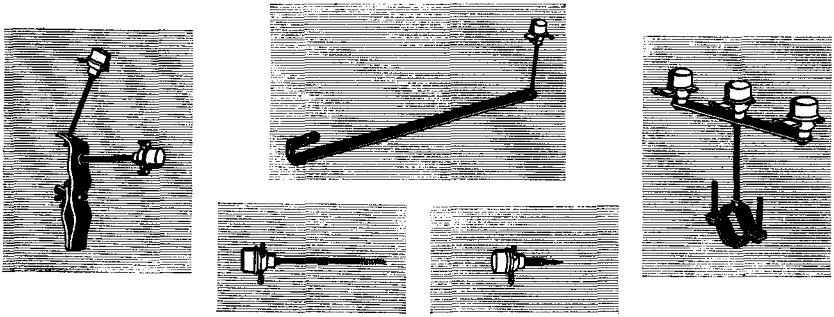


Fig. 80

The lead can be brought into the room in the manner shown in Fig. 81 to prevent rain from entering. Fig. 82 illustrates a method of leading in a polythene down-lead.

Note: The lead-in hole is often drilled through the window frame obliquely in order to keep out moisture.

In this chapter we have dealt only with balanced down-leads (flat twin wire), as these are the most frequently encountered in practice. Asymmetrical (coaxial) down-leads, as used in cases where strong interfering fields are met with or where more than one receiver is to be connected to the aerial, are discussed in Chapter VI.

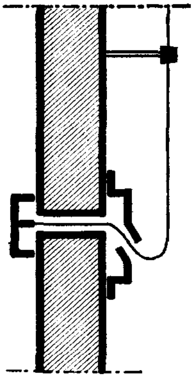


Fig. 81

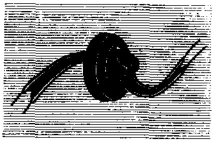


Fig. 82

CHAPTER V

ATTENUATORS

In some localities, particularly close to a powerful transmitter, the field strength may be so great as to supply too high a voltage to the input of the receiver, resulting in overloading. This is manifested as wide horizontal lines across the screen, appearing in the rhythm of the sound. In the first place efforts will be made to cure this by using a simple aerial which provides no signal gain, such as a dipole with reflector only, or even an indoor aerial. This does not always give the desired result, however, especially if numerous reflections are encountered, in which case it is better to use an aerial with a small aperture, such as a Yagi giving a certain amount of gain. The ultimate solution to the problem, then, consists in installing an attenuator between the aerial and the receiver.

Attenuators should meet the following requirements:

a. They should be capable of reducing the incoming signal to the required extent.
b. They should not affect the impedance of the down-lead, i.e. the input and output impedance of the attenuator should be the same.

It may be noted that attenuators have been designed that will transform the impedance as well; the input impedance might then be 75 Ω and the output impedance, say, 300 Ω.

We shall first consider those attenuators the input and output of which are the same.

The symmetrical T-attenuator (Fig. 83).

If we denote the ratio of the input voltage to the output voltage (V_i/V_u), i.e. the degree of attenuation, by the letter *a*, the values of the resistors R_1 and R_2 can be calculated with the aid of the formulas:

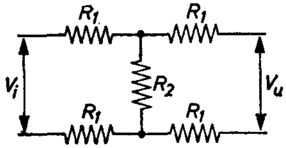


Fig. 83

$$R_1 = \frac{Z}{2}\,\frac{(a - 1)}{(a + 1)} \qquad R_2 = 2Z\,\frac{a}{(a^2 - 1)}$$

both of which are derived quite simply from Kirchoff's laws.

Attenuation is generally given in decibels and it is written as

$$20 \log \frac{V_i}{V_u}$$

For easy reference the theoretical values of R_1 and R_2 in respect of various degrees of attenuation are given in the following table; these values relate to a line having a characteristic impedance of 300 Ω.

V_i/V_u		R_1	R_2
dB	*a*	Ω	Ω
0	1	0	∞
3.5	1.5	30	720
6	2	50	400
7.9	2.5	64	285
9.5	3	75	225
12	4	90	160
14	5	100	125
15.6	6	107	103

The self-inductance of the resistors used should be as small as possible, for which reason the cracked-carbon type of resistor is the most suitable ($\frac{1}{4}$ or $\frac{1}{8}$ W). Further, the dimensioning of the components should be such that R_2 is not too high, in order to avoid stray capacitances.

The symmetrical π-attenuator (Fig. 84).

In this case R_1 and R_2 are calculated from:

$$R_1 = \frac{Z}{4}\left(\frac{a^2 - 1}{a}\right), \qquad R_2 = Z\,\frac{a + 1}{a - 1}.$$

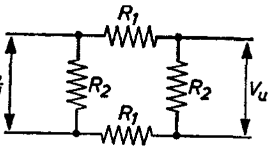


Fig. 84

Values for the resistors are given below for various values of a to suit a 300 Ω line.

V_i/V_u		R_1	R_2
dB	a	Ω	Ω
3.5	1.5	62.5	1500
6	2	112.5	900
9.5	3	200	600
12	4	281	500
14	5	360	450

The asymmetrical T-attenuator (Fig. 85)

This type of attenuator is suitable for use with coaxial down-leads. The resistance values are given by:

$$R_1 = Z\,\frac{a-1}{a+1}, \qquad R_2 = 2Z\,\frac{a}{a^2-1}.$$

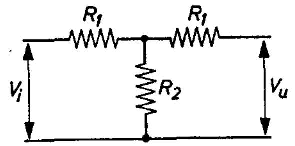


Fig. 85

Example

The signal is to be attenuated by a factor 4 for an installation impedance of $Z = 75\ \Omega$.

$$R_1 = 75 \times \frac{4-1}{4+1} = 45\ \Omega,$$

$$R_2 = 2 \times 75 \times \frac{4}{16-1} = 40\ \Omega.$$

The asymmetrical π-attenuator (Fig. 86).

The resistance values R_1 and R_2 are given by:

$$R_1 = \frac{Z(a^2-1)}{2a} \quad \text{and} \quad R_2 = \frac{Z(a+1)}{a-1}$$

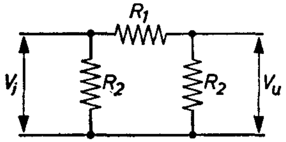


Fig. 86

Example

The signal is to be attenuated by a factor of 4 for an installation impedance of $Z = 75\ \Omega$.

$$R_1 = \tfrac{1}{2} \times 75 \times \frac{16 - 1}{4} = 141\ \Omega$$

$$R_2 = 75 \times \frac{4 + 1}{4 - 1} = 125\ \Omega$$

Attenuation with change of impedance

Networks for this purpose not only reduce the signal strength, but also modify the impedance of the line. Usually a change to the extent of a factor of 4 is required, either higher or lower. Fig. 87a depicts a network of this kind intended for use with a symmetrical system and Fig. 87b a network for an asymmetrical system. The resistances R_{p1}, R_s and R_{p2} cannot be evaluated by means of simple formulas and have to be calculated to suit each individual case. For convenience, values of

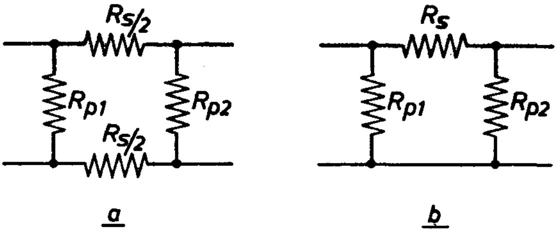


Fig. 87

R_{p1}, R_s and R_{p2} suitable for a balanced π-network with $Z_{in} = 300\ \Omega$ and $Z_{out} = 75\ \Omega$ are given in the following table.

V_i/V_u		R_{p1}	$\frac{1}{2}R_s$	R_{p2}
dB	a	Ω	Ω	Ω
18	8	4000	70	86.5
20	10	1200	90	85.6
23	15	608	138	83.4
26	20	486	185	81.5

CHAPTER VI

SEVERAL RECEIVERS CONNECTED TO THE SAME AERIAL

The central aerial system

Difficulties are likely to arise where a large number of receivers are to be installed at relatively short distances from one another, as for example, in blocks of flats, in hotels or at exhibitions.

The primary requirement is that the receivers should not interfere one with the other, which implies that the necessary aerials should not be too close together; separation of only five to six times the wavelength will result in interfering fields.

Secondly, if a forest of aerials is placed on the roof the latter is quite likely to suffer damage, if only from the amount of walking about on it that will take place.

Then again, a large number of aerials on a roof, especially if these are of many different varieties, can hardly be called decorative.

For these reasons distribution systems have been devised which necessitate the use of only one aerial mast. Fig. 88 illustrates a method of distribution whereby the aerial is connected to an amplifier *V*, the purpose of which is to amplify the incoming signal; such amplification

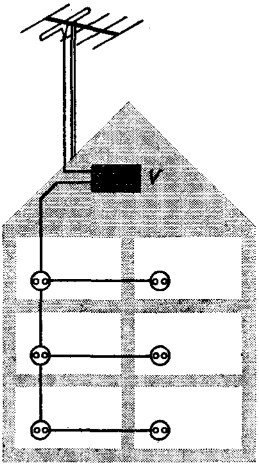


Fig. 88

is usually necessary, seeing that the aerial power is divided up among the various receivers, but also because the whole installation introduces additional attenuation.

A distribution network is inserted between the amplifier and the various coaxial feeders, to match these feeders with the amplifier.

Let us first take the case of an installation where the local signal strength is such that no amplifier is needed. This might be an exhibition or showroom in which a number of receivers are demonstrated at the same time. The signal is then passed to the distribution network by coaxial cable (see Fig. 89), i.e. the installation is asymmetrical, which means that an adapter may have to be inserted in the aerial or the receiver.

The resistors R in the distribution network are now obtained from:

$$Z_1 = R + \frac{R + Z_2}{n}$$

where Z_1 = characteristic impedance of the down-lead
Z_2 = characteristic impedance of the distribution line
n = number of receivers.

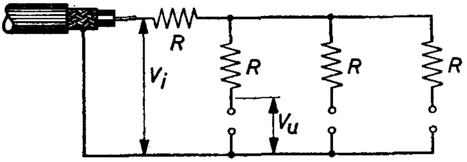


Fig. 89

It follows from this formula that, if Z_1 is the same as Z_2, the formula can be re-written as:

$$Z_1 = R + \frac{R + Z_1}{n},$$

or:

$$R = Z_1 \frac{n - 1}{n + 1}. \tag{1}$$

The next point is the amount of attenuation of the signal; this is given by the ratio V_u/V_i (see Fig. 89).

Now $$\frac{V_u}{V_i} = \frac{Z}{Z + R(n + 1)}.$$

Substitution of $R = Z\frac{n-1}{n+1}$ then gives:

$$\frac{V_u}{V_i} = \frac{1}{n}.$$

Example

If three receivers are to be connected to the same aerial and $Z = 72\ \Omega$, the value of R is found from formula (1):

$$R = 72\ \frac{3-1}{3+1} = 36\ \Omega.$$

Disregarding losses in the lines and distribution network, the signal is attenuated by a factor of 3.

It will now be clear that such an arrangement will work properly only provided that:

a. the aerial signal is strong enough

b. the number of receivers working on the common aerial is not too great

c. all the receivers remain connected (otherwise mismatching will occur, and possibly reflections).

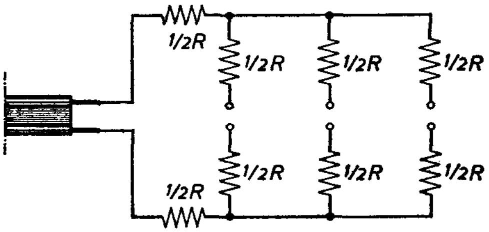


Fig. 90

Fig. 90 illustrates a distribution system of this kind, but this time on the symmetrical principle.

So far we have dealt only with star-connected distribution systems, but other arrangements can be employed, based on the polygonal method of connection, an example of which is shown in Fig. 91.

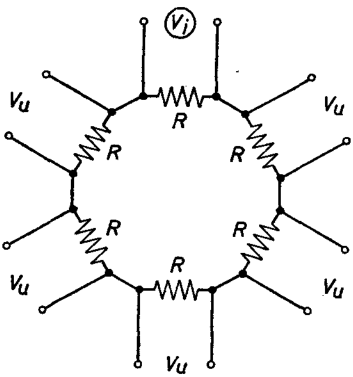


Fig. 91

Here the value of resistor R is calculated from:

$$R = Z\frac{n + 1}{n - 1}.$$

This system has the disadvantage, however, that the value of R is high with only a limited number of receivers, this being undesirable from the point of view of stray capacitances etc. A distribution system of this kind can be employed only where the receivers to be operated from it are not too many in number and are all tuned to the same programme. Should it be found that the receivers interfere with one another, it will be necessary to use an attenuator. If the incoming signal is too weak another aerial can always be installed in parallel with the original one, and a suitable method of doing this is shown in Fig. 92.

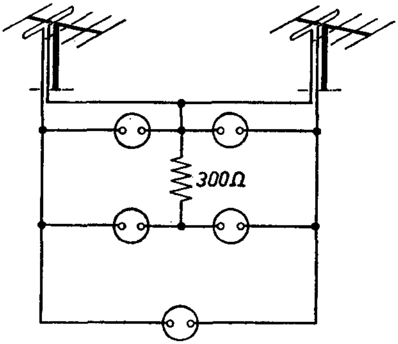


Fig. 92

This concludes our remarks concerning relatively simple distribution systems for use at no great distance from the transmitter (high field strength) and to serve only a few receivers. We shall now consider a more extensive installation, but, before taking the arrangement as a whole, we shall mention one or two details. In the first place there will be the question of the wiring. Generally speaking, the cables will have to be hidden and, in newly constructed blocks of flats or in hotels, for example, the cables can be installed along with the power and lighting wiring. This necessitates the following:

1. A situation plan of the building or buildings
2. Plans showing the rooms to be connected up.

From these a wiring drawing can be prepared giving the location of the cables, amplifiers, aerials, distribution boxes, grouping and so on. The quantity of wire required can also be derived from the drawing; this should be of the coaxial type.

In the detailing of the project the following points must also be taken into consideration:

a. The minimum signal strength required for the most remote receiver from the point of view of the signal-to-noise ratio (This is usually 500 μV).
b. The maximum number of receivers to be supplied from the system
c. The aerial voltage
d. The overall attenuation of the system.

The total attenuation can be broken down under the following headings:

1. The down-lead. The attenuation is about 1.5 dB per 10 m (at 200 Mc/s)
2. The distribution boxes. This depends upon the particular equipment; various values are given below.

Distribution box	Attenuation
Distribution 1 to	
2	4 dB
3	7 dB
4	9 dB

3. The load. Each receiver represents a load on the cable and so introduces additional losses, usually about 1 dB per receiver.

By way of an example let us now work out a system for fourteen receivers, say for a small block of flats.

Several different circuits can be employed, but we shall first consider the one shown in Fig. 93. Here the down-lead branches through a 3-way distribution box into two groups of 5 and one group of 4 outlet sockets.

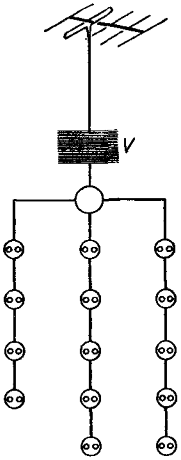


Fig. 93

Assuming the down lead to be 30 metres in length, the losses per branch of 5 sockets will be:

30 m cable	4.5 dB
1 distr. box	7 dB
5 sockets	5 dB
Total	16.5 dB

If the aerial voltage is 1500 μV and the required input voltage per receiver is 500 μV, the aerial voltage will be three times the input voltage, or a factor of $20 \log 3 = 9.5$ dB.

Hence the aerial amplifier should be capable of amplifying the aerial signal to the extent of $16.5\text{-}9.5 = 7.0$ dB, or a factor of 2.

Alternatively the circuit shown in Fig. 94 might be used. In this case the attenuation is:

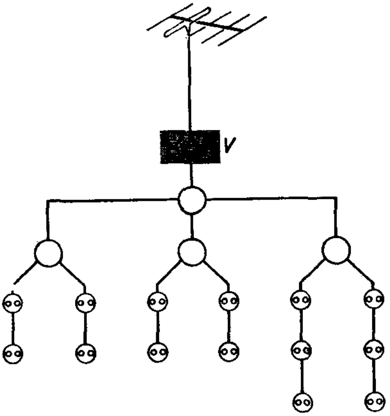


Fig. 94

1 3-way box	7 dB
1 2-way „	4 dB
3 outlet sockets	3 dB
20 m cable	3 dB
	17 dB.

An amplifier capable of amplifying the aerial signal 2 or 3 times would thus be required.

A collective aerial system for more than one TV channel

Fig. 95 shows the theoretical circuit of a multichannel system. As some transmitters may be at greater distances from the receiving aerial than others it is necessary to ascertain whether or not an aerial amplifier will have to be included. This consideration should be based on a minimum aerial signal of 100 μV in every case in order to avoid too low a signal-to-noise ratio; the noise at the input of the receiver is of course the sum of the aerial noise — which is amplified in proportion with the aerial signal — and the amplifier noise. If we denote the signal-to-noise ratio at the aerial amplifier by S/r, the ratio at the output of the amplifier will be

$\frac{nS}{nr + r_e}$, where r_e is the noise produced in the amplifier itself. The amplifier amplifies both the aerial signal and the aerial noise n times.

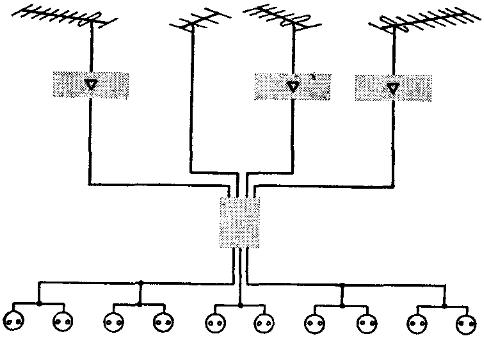


Fig. 95

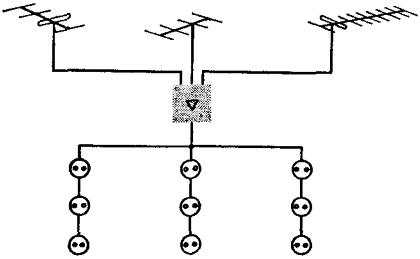


Fig. 96

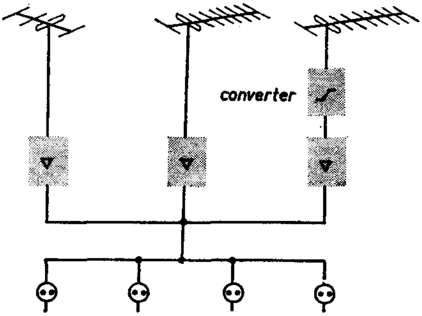


Fig. 97

Figs. 96 and 97 depict suitable layouts for the distribution of signals from 3 transmitters. The installation of Fig. 97 is also suitable for the reception of a transmitter in band IV. The respective channel has therefore to be transformed to a free channel in band I.

Needless to say, suppliers of such aerial systems all have their own ideas as to the details, but, broadly speaking, these will be on the same lines as those given above.

The aerial amplifier

In our discussion of collective aerial systems mention has been made of the need to amplify the aerial before passing it to the distribution system. Such amplifiers generally need not provide much more amplification than about 2 to 4 times. What is important, however, is that the response curve should as flat as possible over a wide band of frequencies and that the amplifier noise should be low. A conventional type of circuit will be found in Fig. 98. The low-noise double triode ECC84 has been chosen for this circuit which, as is usual for this type of amplifier, operates on the cascode principle. The input to the amplifier valve B_1 is asymmetrical and is damped with a resistor R_1; the grid-to-cathode capacitance of B_1 serves for tuning the secondary winding of the input transformer and the same direct current passes through both the triodes, this being determined by R_2 for B_1 and R_3 for B_2.

It will be seen from the circuit diagram that the anode load for B_1 is in effect the internal resistance of triode B_2, which is roughly equal to the reciprocal of the mutual conductance of this valve ($R_{iB1} = \frac{1}{S}$). It can be shown that the amplification obtainable from a valve is equal to the product of the mutual conductance and the anode load, so that in the present case the gain provided by the triode B_1 is $S \times \frac{1}{S}$.

Triode B_2 is controlled by the voltage across the input resistor on this triode; this voltage is amplified by B_2 and is then passed via the output transformer to the outgoing coaxial cable. As the grid of B_2 is earthed, the voltage across the anode circuit of B_2 cannot be fed back to the input, and the circuit is therefore quite stable.

The input impedance of this circuit as a whole is equal to that of an earthed cathode circuit, whilst the stability is equivalent to that of a circuit with earthed grid.

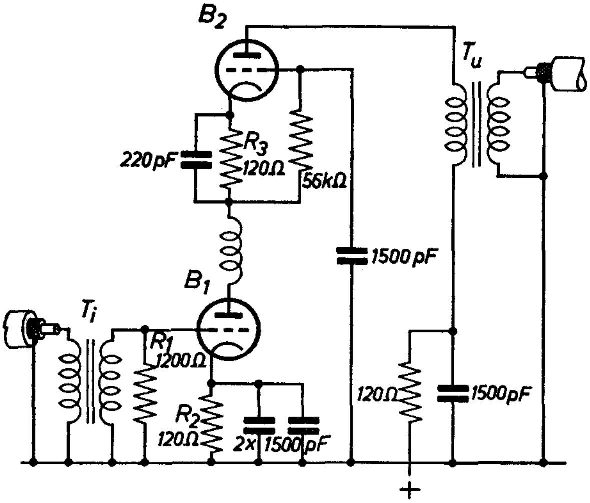


Fig. 98

Even though two triodes are employed, the noise is not in excess of that of a single triode for the following reason.

For the biasing resistance for B_2 we use the internal resistance of B_1. Hence the noise current in B_2, being to a large extent fed back, is only small. When current feedback is employed the gain is reduced by $\frac{1}{1 + S \times R_k}$, where R_k is the non-decoupled biasing resistor on triode B_2. In the present case $R_k = R_1$ of B_1, so the gain due to B_2 is $\frac{1}{1 + S \times R_{iB1}}$ less; using the PCC84 valve this is roughly equal to a factor of 7.

This does not apply to the aerial signal, as this occurs between the grid and the cathode of B_2.

APPENDIX

Relationship between V_1/V_2 and 20 log (V_1/V_2) (dB):

V_1/V_2	dB	V_1/V_2	dB
1	0	15	23.5
2	6	16	24.0
3	9.5	17	24.6
4	12	18	25.1
5	14	19	25.6
6	15.6	20	26.0
7	17	30	29.5
8	18	40	32
9	19	50	34
10	20	60	35.6
11	20.8	70	37
12	21.5	80	38
13	22.2	90	39
14	23.0	100	40

DATA RELATING TO YAGI AERIALS

1. Folded dipole aerial with reflector

length of dipole aerial	k × $\lambda/2$
length of reflector	1,05 k × $\lambda/2$
distance between dipole and reflector	0.23 λ
aerial resistance	240 Ω
aerial gain	5 dB

2. Folded dipole aerial with reflector and director

length of dipole aerial	$k \times \lambda/2$
length of reflector	$1.05\ k \times \lambda/2$
length of director	$0.95\ k \times \lambda/2$
distance between dipole and reflector	$0.23\ \lambda$
distance between dipole and director	$0.1\ \lambda$
aerial resistance	$100\ \Omega$
aerial gain	7 dB

3. Folded dipole aerial with reflector and two directors

length of dipole aerial	$k \times \lambda/2$
length of reflector	$1.05\ k \times \lambda/2$
length of 1st director	$0.95\ k \times \lambda/2$
length of 2nd director	$0.93\ k \times \lambda/2$
distance between dipole and reflector	$0.23\ \lambda$
distance between dipole and 1st director	$0.1\ \lambda$
distance between 1st and 2nd director	$0.1\ \lambda$
aerial resistance	$16\ \Omega$
aerial gain	11 dB

SURVEY OF TELEVISION SYSTEMS

System	C.C.I.R. 625 - Line	British	French	O.I.R.*)	R.T.M.A. **)
Number of lines	625	405	819	625	525
Bandwidth Mc/s	5	3	10.4	6	4
Channelwidth Mc/s	7	5	14	8	6
Frame freq.	25	25	25	25	30
Picture modulation	negative	positive	positive	negative	negative
Sound modulation	FM	AM	AM	FM	FM
Channel symbol	E	B	F	ER	A

*) Employed in E. European countries (U.S.S.R., E. Germany, Poland, Czechoslovakia etc).

**) Employed in the U.S.A. and most of the countries in the Western Hemisphere where the mains frequency is 60 c/s.

TV TRANSMITTERS IN CHRONOLOGICAL ORDER

Transmitters	Channel	Transmitters	Channel	Transmitters	Channel
Antilles (Neth.)		*Bermuda*		Hawai (cont.)	
Curaçao	EA8	Kindley Air		Honolulu	A 4
		Force Base	A 10	Wailuku	A 3
		Pembroke	A 10	Hilo	A 9
Australia				Wailuku	A 12
Sydney	E 9	*Cyprus*		Kala	A 7
Melbourne	E 7	Nicosia	E 2	Hilo	A 13
Sydney	E 2				
Melbourne	E 2	*Egypt*		*Iracq*	
Sydney	E 7			Baghdad	E 8
Melbourne	E 9	Alexandrie	E 6		
Brisbane	E 9	Batra	E 8	*Iran*	
Adelaide	E 9	Cairo	E 7	Tehran	A 5
Adelaide	E 7	Mansoura	E 5	Abadan	A 2
Perth	E 7	Cairo	E 5	Tehran	A 8
Brisbane	E 2				
				Ireland	
				Dublin	B 8
		Gibraltar		*New Zealand*	
Brisbane	E 7	Gibraltar	E 6	Auckland	E 2
Adelaide	E 2			Christchurch	E 3
Perth	E 2	*Greenland*		Wellington	E 1
Hobart	E 6	Air Force			
Hobart	E 2	Base Thule	A 6	*Nicaragua*	
Bendigo	E 8	Fjord		Managua	A 8
Yallourn	E 10	Sondrestrom	A 8		
Shepparton	E 6			*Nigeria*	
Illawara	E 4	*Hawai*		Ibadan	G 4
Azores		Honolulu	A 9	Abagon	E 3
Lajos Field	A 8	Honolulu	A 2	Enoegoe	E 2

TV TRANSMITTERS IN CHRONOLOGICAL ORDER

Transmitters	Channel
Norway	
Oslo	E 6
Bergen	E 9
Kongsberg	E 4
Stavanger	E 8
Trondheim	E 2
Panama	
Panama	A 8
Panama	A 10
Panama	A 4
Philippines	
Manila	A 3
Clark Field	A 8
Manila	A 9
Manila	A 7
Manila	A 13
Manila	A
Rhodesia	
Salisbury	E 4
Bulawayo	E 3
Kitwe	E 6
Sweden	
Stockholm	E 4
Göteborg	E 9
Norrköping	E 5
Malmö	E10
Nässjö	E10
Halmstad	E 7
Hälsingborg	E 9
Skövde	E 3
Motala	E 7
Linköping	E 9
Gävle	E 9
Örebro	E 2
Sweden (cont.)	
Västeras	E 2
Sundsvall	E 5
Bollnäs	E 6
Hörby	E 2
Borlänge	E10
Emmaboda	E 8
Boras	E 6
Varberg	E10
Uddevalla	E 2
Västervik	E 6
Visby	E 9
Östersund	E 4
Uppsala	E 6
Trolhätten	E 7
Solleftea	E 7
Karlstad	E 5
Karlstrona	E 9
Lycksele	E 8
Ornskolvick	E 6
Sunne	E 7
Vännas	E 2
Skelleftea	E 6
Ange	E 8
Bickefors	E 8
Svog	E 3
Mora	E 8
Växjo	E 5
Harnosand	E10
Täsjo	E 9
Haparanda	E 8
Pajala	E 7
Boden	E 4
Arvidsjaur	E 5
Gällivare	E 9
Kiruna	E 6
Thailand	
Bangkok	A 4
Bangkok	A 7
Turkey	
Istanbul	E 4
United Kingdom	
Sutton Coldfield	B 4
Holme Moss	B 2
Kirk O'Shotts	B 3
Wenvoe	B 5
Divis	B 1
Pontop Pike	B 5
Douglas	B 5
Rowridge	B 3
Meldrum	B 4
Les Platons	B 4
North Hessary Tor	B 2
Crystal Palace	B 1
Sandale	B 4
Blaen Plwyf	B 3
Inverness (Rosemarkie)	B 2
Norwich (Tacolneston)	B 3
Londonderry	B 2
Kirkwall (Orkney Islands)	B 5
Wick (Thrumster)	B 1
Peterborough	B 5
Croydon	B 9
Lichfield	B 8
Winter Hill	B 9
Emley Moor	B10
Black Hill	B10
St. Hilary	B10
Chillerton Down	B11
Burnhope	B 8
Mendlesham	B11
Belfast (Black Mountain)	B 9
Dover	B10
Caradon Hill	B12
Stockland Hill	B 9
Caldbeck	B11
Durris	B 9
Mounteagle	B12
Llandrindod Wells	B 1
Selkirk	B13

TV CHANNELS AND THEIR FREQUENCIES

hannel	Vision carrier (Mc/s)	Sound carrier (Mc/s)	Channel	Vision carrier (Mc/s)	Sound carrier (Mc/s)	Channel	Vision carrier (Mc/s)	Sound carrier (Mc/s)
T.M.A. system (A								
			A29	561.25	565.75	A57	729.25	733.75
A 2	55.25	59.75	A30	567.25	571.75	A58	735.25	739.75
A 3	61.25	65.75	A31	573.25	577.75	A59	741.25	745.75
A 4	67.25	71.75	A32	579.25	583.75	A60	747.25	751.75
A 5	77.25	81.75	A33	585.25	589.75	A61	753.25	757.75
A 6	83.25	87.75	A34	591.25	595.75	A62	759.25	763.75
A 7	175.25	179.75	A35	597.25	601.75	A63	765.25	769.75
A 8	181.25	185.75	A36	603.25	607.75	A64	771.25	775.75
A 9	187.25	191.75	A37	609.25	613.75	A65	777.25	781.75
A10	193.25	197.75	A38	615.25	619.75	A66	783.25	787.75
A11	199.25	203.75	A39	621.25	625.75	A67	789.25	793.75
A12	205.25	209.75	A40	627.25	631.75	A68	795.25	799.75
A13	211.25	215.75	A41	633.25	637.75	A69	801.25	805.75
A14	471.25	475.75	A42	639.25	643.75	A70	807.25	811.75
A15	477.25	481.75	A43	645.25	649.75	A71	813.25	817.75
A16	483.25	487.75	A44	651.25	655.75	A72	819.25	823.75
A17	489.25	493.75	A45	657.25	661.75	A73	825.25	829.75
A18	495.25	499.75	A46	663.25	667.75	A74	831.25	835.75
A19	501.25	505.75	A47	669.25	673.75	A75	837.25	841.75
A20	507.25	511.75	A48	675.25	679.75	A76	843.25	847.75
A21	513.25	517.75	A49	681.25	685.75	A77	849.25	853.75
A22	519.25	523.75	A50	687.25	691.75	A78	855.25	859.75
A23	525.25	529.75	A51	693.25	697.75	A79	861.25	865.75
A24	531.25	535.75	A52	699.25	703.75	A80	867.25	871.75
A25	537.25	541.75	A53	705.25	709.75	A81	873.25	877.75
A26	543.25	547.75	A54	711.25	715.75	A82	879.25	883.75
A27	549.25	553.75	A55	717.25	721.75	A83	885.25	889.75
A28	555.25	559.75	A56	723.25	727.75			

hannel	Vision carrier (Mc/s)	Sound carrier (Mc/s)	Channel	Vision carrier (Mc/s)	Sound carrier (Mc/s)	Channel	Vision carrier (Mc/s)	Sound carrier (Mc/s)
ritish system (B)			C.C.I.R. system (E)			The frequency band 470 to 960 Mc/s is divided into 61 channels each 8 Mc/s wide numbered from 21 to 81 in accordance with the following table, taking from the Final Acts of the European Broadcasting Conference (Stockholm).		
B 1	45.00	41.50	E 2	48.25	53.75			
B 2	51.75	48.25	E 2a	49.75	55.25			
B 3	56.75	53.25	E 3	55.25	60.75			
B 4	61.75	58.25	E 4	62.25	67.75			
B 5	66.75	63.25	E 5	175.25	180.75			
B 6	179.75	176.25	E 6	182.25	187.75			
B 7	184.75	181.25	E 7	189.25	194.75			
B 8	189.75	186.25	E 7a	192.25	197.75	E21	470.-	478.-
B 9	194.75	191.25	E 8	196.25	201.75	E22	478.-	486.-
B10	199.75	196.25	E 8a	201.25	206.75	E23	486.-	494.-
B11	204.75	201.25	E 9	203.25	208.75	E24	494.-	502.-
B12	209.75	206.25	E10	210.25	215.75	E25	502.-	510.-
B13	214.75	211.25	E11	217.25	222.75	E26	510.-	518.-

Channel	Vision carrier (Mc/s)	Sound carrier (Mc/s)
C.C.I.R. system (E) (cont.)		
E27	518.-	526.-
E28	526.-	534.-
E29	534.-	542.-
E30	542.-	550.-
E31	550.-	558.-
E32	558.-	566.-
E33	566.-	574.-
E34	574.-	582.-
E35	582.-	590.-
E36	590.-	598.-
E37	598.-	606.-
E38	606.-	614.-
E39	614.-	622.-
E40	622.-	630.-
E41	630.-	638.-
E42	638.-	646.-
E43	646.-	654.-
E44	654.-	662.-
E45	662.-	670.-
E46	670.-	678.-
E47	678.-	686.-
E48	686.-	694.-
E49	694.-	702.-
E50	702.-	710.-
E51	710.-	718.-
E52	718.-	726.-
E53	726.-	734.-
E54	734.-	742.-
E55	742.-	750.-
E56	750.-	758.-
E57	758.-	766.-
E58	766.-	774.-
E59	774.-	782.-
E60	782.-	790.-
E61	790.-	798.-
E62	798.-	806.-
E63	806.-	814.-
E64	814.-	822.-
E65	822.-	830.-
E66	830.-	838.-
E67	838.-	846.-
E68	846.-	854.-
E69	854.-	862.-
E70	862.-	870.-
E71	870.-	878.-
E72	878.-	886.-
E73	886.-	894.-
E74	894.-	902.-
E75	902.-	910.-
E76	910.-	918.-
E77	918.-	926.-
E78	926.-	934.-
E79	934.-	942.-
E80	942.-	950.-
E81	950.-	958.-

Australia, revised numbering of TV channels (E)

E 0	45 - 52
E 1	56 - 63
E 2	64 - 70
E 3	85 - 92
E 4	94 - 101
E 5	101 - 108
E 5A	137 - 144
E 6	174 - 181
E 7	181 - 188
E 8	188 - 195
E 9	195 - 202
E10	208 - 215
E11	215 - 222

Channel	Vision carrier (Mc/s)	Sound carrier (Mc/s)
E10	210.25	215.75

New Zealand, classification of channels different from the C.C.I.R. system(E)

E 1	45.25	50.75
E 2	55.25	60.75
E 3	62.25	67.75
E 4	175.25	180.75
E 5	182.25	187.75
E 6	189.25	194.75
E 7	196.25	201.75
E 8	203.25	208.75
E 9	210.25	215.75

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