



# Feedback



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# Antenna Systems Demonstrator Volume 1 Instructor's Manual ASD512-1



**Feedback**

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## Notes

**PREFACE**

**THE HEALTH AND SAFETY AT WORK ACT 1974**

We are required under the Health and Safety at Work Act 1974, to make available to users of this equipment certain information regarding its safe use.

The equipment, when used in normal or prescribed applications within the parameters set for its mechanical and electrical performance, should not cause any danger or hazard to health or safety if normal engineering practices are observed and they are used in accordance with the instructions supplied.

If, in specific cases, circumstances exist in which a potential hazard may be brought about by careless or improper use, these will be pointed out and the necessary precautions emphasised.

While we provide the fullest possible user information relating to the proper use of this equipment, if there is any doubt whatsoever about any aspect, the user should contact the Product Safety Officer at Feedback Instruments Limited, Crowborough.

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We are required by European Directives to indicate on our equipment panels certain areas and warnings that require attention by the user. These have been indicated in the specified way by yellow labels with black printing, the meaning of any labels that may be fixed to the instrument are shown below:



CAUTION -  
RISK OF  
DANGER



CAUTION -  
RISK OF  
ELECTRIC SHOCK



CAUTION -  
ELECTROSTATIC  
SENSITIVE DEVICE

Refer to accompanying documents

**PRODUCT IMPROVEMENTS**

We maintain a policy of continuous product improvement by incorporating the latest developments and components into our equipment, even up to the time of dispatch.

All major changes are incorporated into up-dated editions of our manuals and this manual was believed to be correct at the time of printing. However, some product changes which do not affect the instructional capability of the equipment, may not be included until it is necessary to incorporate other significant changes.

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Where components are of a 'Safety Critical' nature, i.e. all components involved with the supply or carrying of voltages at supply potential or higher, these must be replaced with components of equal international safety approval in order to maintain full equipment safety.

In order to maintain compliance with international directives, all replacement components should be identical to those originally supplied.

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- |                        |                            |
|------------------------|----------------------------|
| 1. Equipment type      | 2. Component value         |
| 3. Component reference | 4. Equipment serial number |

Components can often be replaced by alternatives available locally, however we cannot therefore guarantee continued performance either to published specification or compliance with international standards.

## PREFACE

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### DECLARATION CONCERNING ELECTROMAGNETIC COMPATIBILITY

Should this equipment be used outside the classroom, laboratory study area or similar such place for which it is designed and sold then Feedback Instruments Ltd hereby states that conformity with the protection requirements of the European Community Electromagnetic Compatibility Directive (89/336/EEC) may be invalidated and could lead to prosecution.

This equipment, when operated in accordance with the supplied documentation, does not cause electromagnetic disturbance outside its immediate electromagnetic environment.

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## FOREWORD

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This is one of two manuals which accompany the ASD512 Antenna Systems Demonstrator.

Volume 1 (this manual) is intended for use during the preparation of a lecture or discussion on the subject of antennas in which the ASD512 will be used for demonstration. It provides a non-mathematical explanation of the theory of antennas in terms relevant to the demonstrations performable with ASD512.

Volume 2 combines the functions of a handbook for the equipment and a handbook for use during demonstrations. It therefore includes instructions for checking, maintaining and setting up the equipment and for carrying out demonstrations. It also contains within the section on demonstrations brief reminders of the points which each demonstration is intended to convey to students.

### Acknowledgement

The ASD512 Antenna Systems Demonstrator is based on original ideas by H.V. Sims C.Eng FIEE FIERE, who has given Feedback Instruments Ltd considerable help in the development of the equipment and in the preparation of the two accompanying manuals.

Mr. Sims, who was formerly a BBC Antenna Engineer at Daventry and Head of Technical Projects & Services with the BBC Engineering Training Department has demonstrated and lectured on 'Antennas' to BBC Engineering Staff and at Universities, Technical Colleges and learned Societies for many years.

**FOREWORD**

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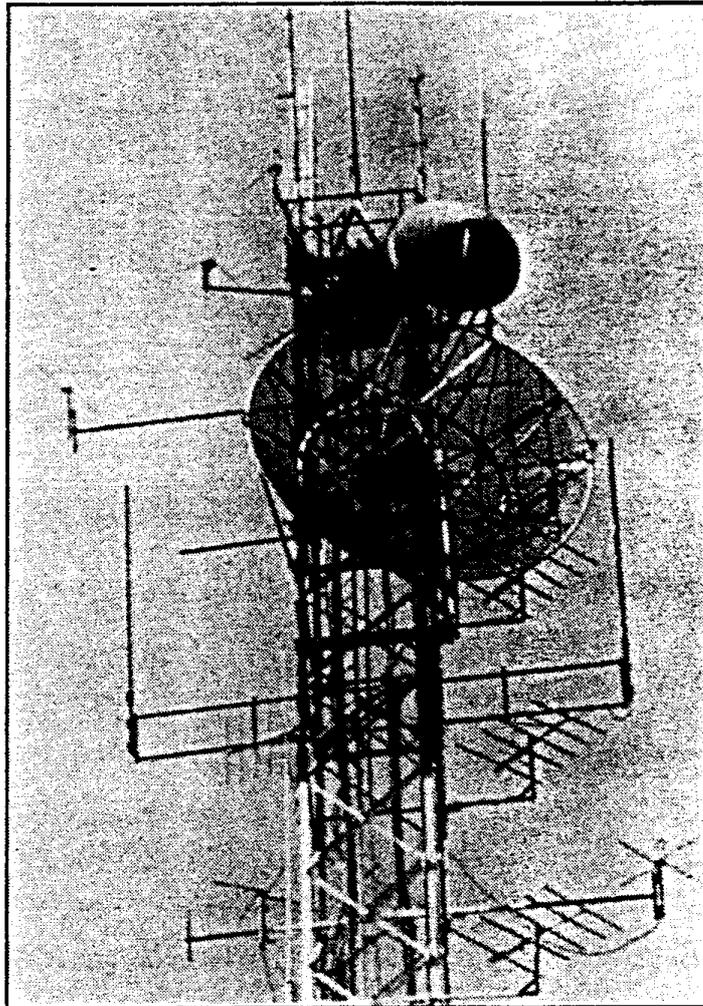
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*How many different types can you identify in this interesting collection of antennas?*

## INTRODUCTION

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### What is an antenna?

Radio communications are vital to modern life. Broadcasting, television, long-distance telephones, air traffic control, radar and many other familiar things would be impossible without radio.

Radio starts and ends with equipment like a transmitter and a receiver. These use the intervening space to pass information. Neither transmitter nor receiver can do this without a means of coupling it to that intervening space.

The antenna is the means for coupling the equipment to the space around it and consequently to the universe.

### The Antenna Systems Demonstrator ASD512

The ASD512 includes a kit of parts for constructing a wide variety of antennas in a convenient size for classroom demonstration; detectors of radiation and of voltage and current distribution within a conductor; a radio frequency generator for energising the antennas; and charging facilities for maintaining the batteries used in the detectors.

The purpose of the ASD512 is to provide practical demonstrations of basic concepts and of the fundamental antenna types. Although these are qualitative, i.e. measurement is not attempted, the two detectors enable the difference between static and radiating fields to be clearly shown, and the Voltage and Current Detector provides simultaneous indications of the strength of voltage and current, so that such phenomena as standing waves may be effectively explored. Further indication of current distributions is provided by lamp bulbs built into some of the simpler antennas.

A course of instruction based on the ASD512 should provide an excellent preparation for students who will be engaged in installation and maintenance of all types of antenna systems. It should also provide useful insight to those concerned in operating radio systems, or planning or negotiating for radio installations.

## **INTRODUCTION**

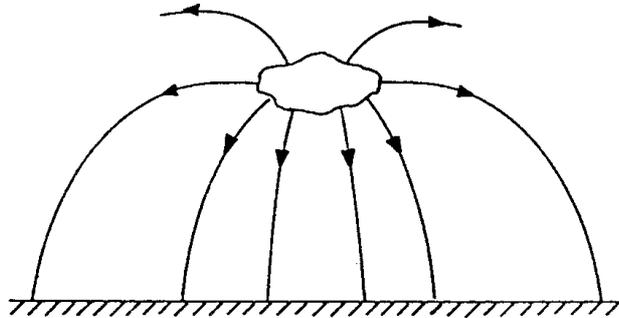
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## **NOTES**

### Fundamental ideas

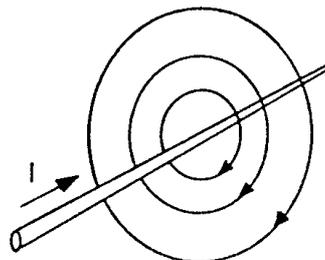
The concept of a 'field' is essential to the understanding of antennas. By 'field' is meant a region in space which is subject to an influence by something in that region. Two kinds of field which may be associated with an electrical conductor are an electric field and a magnetic field.

The electric field is the region surrounding a conductor which has a potential difference from another conductor or generally from its surroundings or along its length. It may be represented by lines of force. These are lines showing at any point the direction in which mechanical force would be exerted on an electric charge placed in the field. Electric 'fields' lines of force always leave the conductor at right angles, see fig 1.1.



*Fig 1.1 Lines of force associated with a charged conductor above the conducting earth.*

The magnetic field is the region surrounding a moving charge, such as an electric current along a wire. It may be represented by lines of magnetic force. These are lines indicating at every point the direction in which a small magnet placed in the field would align itself if free to move, again due to a mechanical force. The lines of force due to a current in a wire surround the wire, fig 1.2.



*Fig 1.2 Lines of force surrounding a current-carrying wire.*

Radio transmission makes use of electromagnetic waves. These are an electric field and a magnetic field combined in a special way which enables them to travel together. Light is one form of electromagnetic wave occupying a small portion of the spectrum (range of frequencies) of electromagnetic waves. Radio waves occupy a range of much lower frequencies. These waves are produced when an electric charge is moved rapidly backwards and forwards in a conductor, i.e when the conductor carries a high-frequency alternating current. The frequency of the wave is the same as the frequency of oscillation of the electric charges (i.e of the electric current). Its wavelength is related to that frequency by the equation.

$$c = f\lambda$$

where  $c$  is the velocity of light

$f$  is the frequency

and  $\lambda$  is the wavelength of the radiation

We shall find that the dimensions of an antenna relative to the wavelength  $\lambda$  largely determine its behaviour. In particular reference will frequently be made to lengths equal to fractions of a wavelength, such as a half-wavelength or a quarter-wavelength. As the ideas related to wavelength become more familiar it will be found convenient to refer to such lengths in the abbreviated form  $\frac{\lambda}{2}$ ,  $\frac{\lambda}{4}$  or as appropriate. The symbol  $\lambda$  will be reserved in this manual to mean 'wavelength' accordingly.

### Requirement for radiation

Although a different starting point is taken in the strict mathematical treatment of antennas, for practical purposes it can be said that radiation occurs because the electric and magnetic fields associated with the current can only move with the velocity of light. When a current flows the resulting magnetic field expands outwards and when the current reverses the field attempts to collapse and change polarity. If the current reverses very rapidly, as is the case with high frequency a.c, the field may not have collapsed completely before the new one starts expanding. The remaining field is carried ahead of the new field and is thus radiated. The rapid reversal of current can only be achieved by applying an appreciable potential difference across the conductor, so that an electric field exists as well. This electric field also will expand and collapse incompletely, leaving a radiated portion to move outwards.

This action is repeated with every reversal of the current, so that both magnetic and electric fields, alternating in polarity, continue to be detached and radiated together.

The radiation depends on the inability of the fields to collapse fully, so that if the conductor is small in comparison with a wavelength and the fields are concentrated around it, then hardly any radiation takes place at all. This would occur for instance with a small coil. Fig 1.3a shows such a coil tuned to resonance by a parallel capacitor.

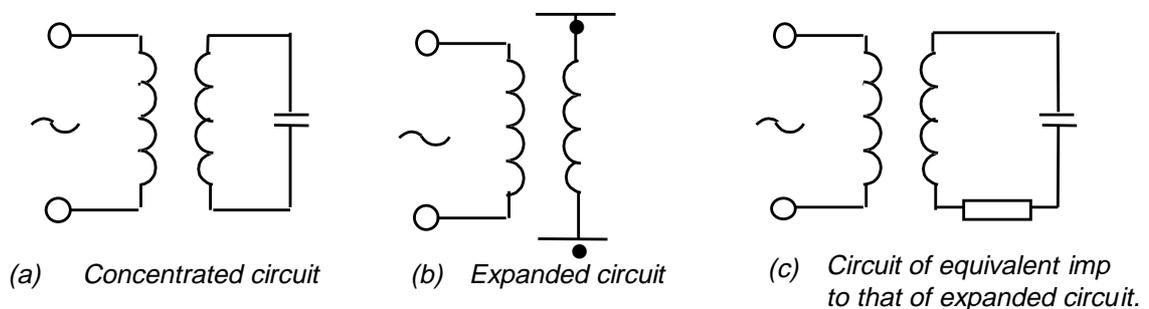


Fig 1.3

Almost no radiation takes place and no power is absorbed except by losses in the components. Suppose that we now expand the circuit as in fig 1.3b; the length of the wire might have to be altered to maintain resonance, but we still have the same circuit. A large proportion of power will now be lost by radiation, since the separated capacitor plates spread an electric field, and the connecting wires spread a magnetic field, over a large volume of neighbouring space. When a system is designed like this, so that it produces the widespread fields which encourage radiation, it is called an antenna.

The radiated wave travels outward at the speed of light and consists of a magnetic component field called  $H$ , and the electric component field called  $E$ . The two components are at right angles and the direction of motion is at right angles to both of them (fig 1.4). The wave is said to be 'polarised' in the direction of the electric field.

The conditions of fig 1.3a (little radiation from a small coil) and fig 1.3b (considerable radiation when the conductor is spread out) are the subject of Demonstration 1 to be found in Volume 2.

## REQUIREMENTS FOR RADIATION AND RECEPTION

## CHAPTER 1

**Radiation  
resistance**

The radiation of each new cycle of the expanding fields represents a loss of energy from the system. The energy has to be supplied by feeding power into its terminals. Any device which absorbs power when alternating current is passed through it may be represented by a series combination of reactance and resistance. In figs 1.3a and 1.3b both capacitive and inductive reactances can be seen, but no resistance is shown. But a reactance cannot absorb power, so to represent the load seen by the generator, resistance must be added, as in fig 1.3c. The value of this resistance  $R$ , must be such that the absorbed (and radiated) power is given by  $I^2R$ . Because this resistance represents the function of converting electrical power into radiation it is called the 'radiation resistance' of the antenna. (Note that there is no 'resistor' associated with radiation resistance, unless you choose to think of the antenna and the space around it as one).

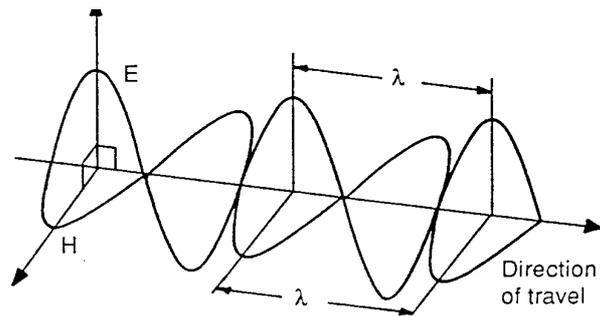


Fig 1.4

**Demonstration 1  
Extended circuit**

In this demonstration a coil of wire is first energised, and the intense electric field in its immediate vicinity is shown by lighting a fluorescent tube held in the field. The electric and magnetic fields can each be picked up by the radiation detector, but only when its receiving elements (which are a simple small antenna) are held close to the coil.

The wire of the coil is then stretched out. Because this greatly increases its ability to radiate, radiation can be detected at an appreciable distance.

**Demonstration 2  
Balanced currents  
in extended circuit**

Demonstration 2 is in a sense complementary to Demonstration 1, in that it shows the even with extended conductors no radiation takes place provided that the conductors are arranged

## REQUIREMENTS FOR RADIATION AND RECEPTION

## CHAPTER 1

in pairs and in such a manner that the fields are localised around the conductors. This is achieved by placing the conductors close together (in terms of wavelength), and ensuring that a current in one conductor is matched by an equal current in the opposite direction in the other conductor), and the potentials of adjacent parts of the two conductors are equal and opposite, fig 1.5.

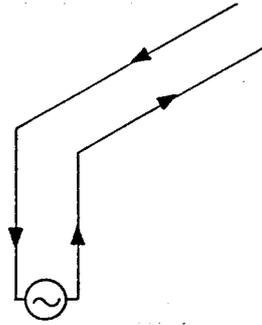


Fig 1.5

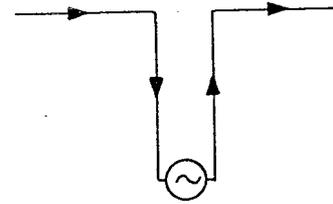


Fig 1.6

However, when the conductors are opened out, fig 1.6, and the open arms of the antenna thus formed carry currents in the same direction, appreciable radiation takes place. Two arms having a total length of a half-wavelength (actually very slightly less) at the operating frequency constitute a 'half-wave dipole'. This is a very effective simple antenna, useful on its own, or in conjunction with other antenna elements. It also serves as a useful reference standard against which other antennas can be compared.

The two halves of this demonstration together show that it is the production of expanded fields, stretching away from the conductors into the surrounding space, which encourages radiation. This demonstration also uses the voltage and current detector to show the non-uniform distribution of voltage and current on the conductors.

### Voltage and current detector

This detector provides indications, in the form of a variable-length illuminated column, of the electric and magnetic fields in the immediate vicinity of the rod conductors. The magnetic field is directly proportional to the current in the conductor.

It could be argued that 'voltage' is a term which has no meaning except in relation to a pair of adjacent terminals (i.e whose separation was small compared with a wavelength). However the expression 'voltage' is a convenient and short expression fairly widely used in relation to antennas to signify 'electric field strength'. This has some practical justification in that any

insulator used to support a part of an antenna associated with high electric field strength will have to be designed to withstand high voltage.

### Reception of an Electromagnetic wave

If a second circuit is placed close to the energised one, the latter's electric and/or magnetic fields can transfer energy to the second circuit. With this close coupling the field which causes the energy transfer is mostly the local field which collapses every half-cycle and is not radiated. This local field falls off very rapidly, in inverse proportion to the square of the distance. The region where the local field predominates is called the 'near zone'.

The proportion of the field which is radiated is only small compared to the local field, but as the second circuit is moved farther away, the radiated field becomes more important, since it decreases more slowly, only inversely proportional to the distance. Thus, moving away from the near zone, there is found first an 'intermediate zone' where the local and radiated fields are comparable, and then a 'far zone' in which the contribution from the local field is negligible. In the far zone it is more helpful to think of the second circuit as being coupled to space, and the energised circuit also being coupled to space, so that energy flows from the energised circuit, to space, and then to the second circuit, with no interaction between the circuits directly. The three different zones are indicated in fig 1.7.

Since our interest in an antenna is usually concerned with the far zone, which effectively starts about two wavelengths away, accurate measurements require a very large area to be clear around an antenna. It is important also to have the surroundings clear of any objects which can reflect waves into the clear area and upset the field patterns. This is difficult to achieve even at short wavelengths like 1cm where the 'far zone' is not so far away. If however accurate measurements are not necessary and it is required only to show in a general way how an antenna works, we need not be so fussy. For convenience therefore most of the observations of radiation with the ASD512 will be made in the intermediate zone, and it will not be necessary to clear an impossibly large space. Nevertheless care should be taken to conduct experiments reasonably far away from any obvious obstructions such as walls or pillars. Large metal objects especially should be well separated from the apparatus.

For use in the experiments two detectors are provided. One is the voltage and current detector, already mentioned. The other is designed to detect radiation. It must therefore be coupled to

REQUIREMENTS FOR RADIATION AND RECEPTION

CHAPTER 1

space by an antenna, which takes the form of a pair of simple rods.

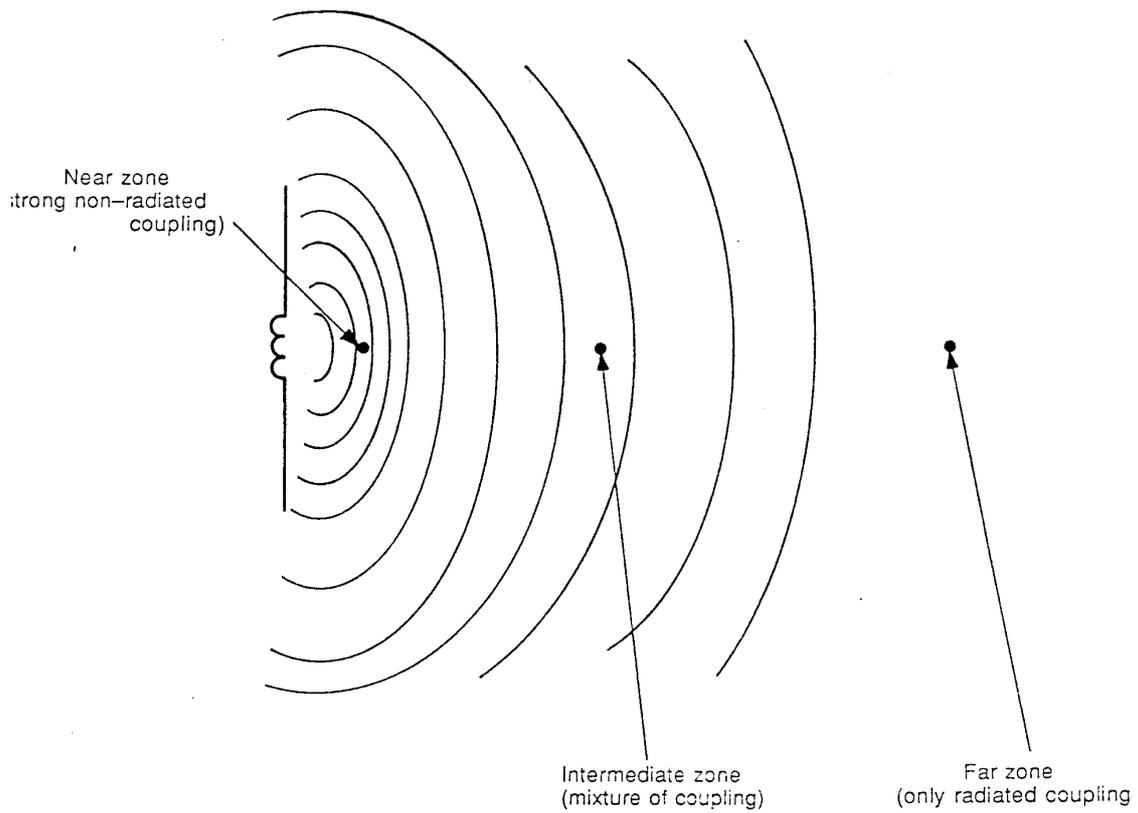


Fig 1.7

**NOTES**

Some form of connection is required between a transmitter and its antenna, or between a receiving antenna and the receiver, in order to convey power from one to the other. The simplest case is that in which the terminals of the transmitter or receiver are directly connected to the antenna terminals. This however is not always convenient, or may in many cases be impossible. A transmission line is then necessary to convey power. A transmission line connected to an antenna is often called a 'feeder'. This will comprise conductors extending between equipment and antenna; being an extended system of conductors it must be properly designed to avoid radiation since this would lose energy from the line rather than transmit it. The other important design factor is that it must be possible to put the required power into the input end of the line, and to extract the power from the far end of the line.

In Demonstration 2 it is shown that voltage between, and current in, an extended pair of conductors need not radiate if the voltage and currents are suitably balanced and the conductors are close together in terms of wavelengths. It is also shown that the voltage and current vary between different points along the transmission line. It is instructive to enquire why.

If a long pair of conductors has a voltage applied to one end, current will flow into the line, the amount of current being determined by the line itself in conjunction with the voltage. The ratio between the applied voltage and the resulting input current (for a line which is very long indeed) is called the 'characteristic impedance' of the line, for which the usual symbol is  $Z_0$ . (although  $Z_0$  is a complex impedance, for practically useful RF lines the reactance should be small and is often negligible).

If the line were infinitely long the input signal would travel along the line for ever. Practical lines always have an end. Consider what happens in the case of Demonstration 2, when the end is open-circuited. The wide variations in voltage and current between one part and another of the line are called 'standing waves'. These arise because the travelling wave is reflected when it reaches the end of the line. Both voltage and current waves travel together along the line until suddenly at the open circuit the current is reduced to zero. The effect is the same as if a reverse current had been injected into the line, which just cancelled out the original current at that point. This reverse current (which you can think of alternatively as just the original current bouncing back at the open circuit) and the voltage it causes both travel back down the line toward the transmitter. Now there are two waves on the feeder, the original one and the reflected one.

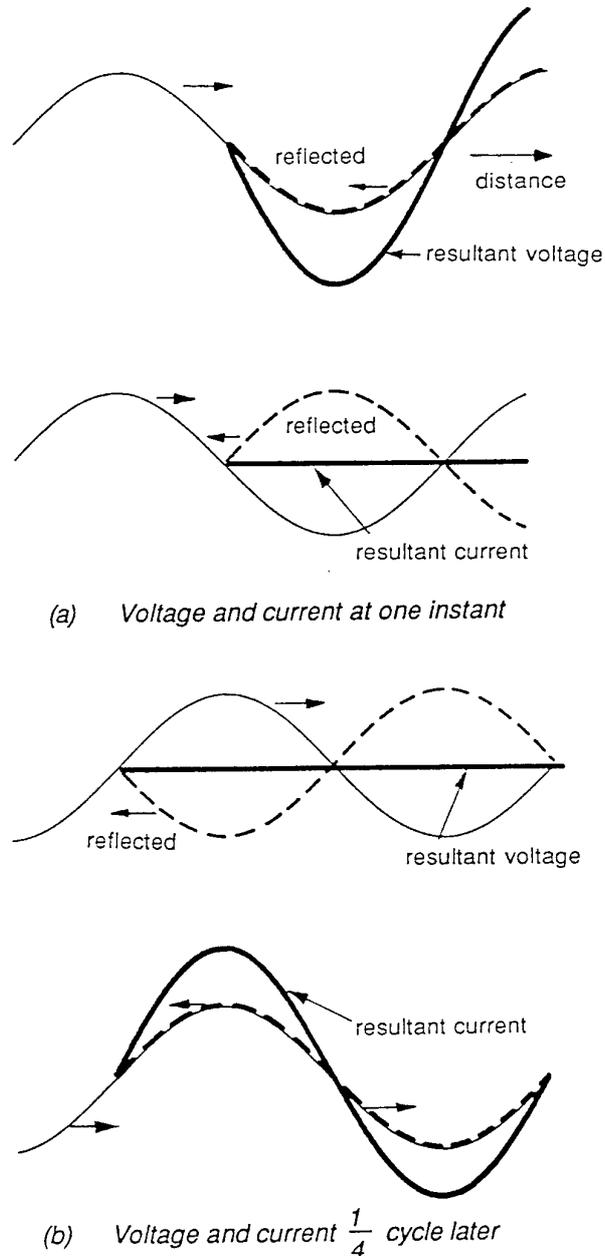


Fig 2.1

Fig 2.1 shows graphs of waves of voltage and current on the line in which the horizontal axis in each graph is distance along the line. These represent the values (a) at a particular time and (b) at a later time. In each case the figure shows in the upper graph the voltage and in the lower graph the current. A full-line curve shows the voltage and current wave advancing from left to right. The broken line shows the reflected wave travelling back from the open circuit from right to left. A further full line shows the resultant.

It may be noted that in a travelling wave the current and voltage are at a maximum together (in space and in time). The associated electric and magnetic fields are therefore in phase. This is characteristic of the transmission of electromagnetic energy, and may be compared with the case of radiation depicted in fig 1.4.

In contrast a standing wave (i.e the resultant current and voltage in the case of fig 2.1) has the current and voltage in quadrature, i.e when voltage is a maximum, current is a minimum, and vice versa. Again this is true both in time and in distance.

A standing wave may be thought of as the resultant of the two travelling waves, forward and reflected. The latter each carry energy in their own direction, but the resultant net energy transfer is zero.

If the right-hand end of the line had been terminated in a short-circuit instead of an open-circuit, there would again be a standing wave, a quadrature relationship between voltage and current, and no net energy transfer.

Suppose however that the line had been terminated in a resistance equal to the characteristic impedance. In this case the terminating resistance would have absorbed energy from the line at the maximum possible rate, leaving no energy to be reflected. In this case, with nothing reflected back to the input terminals, these terminals behave as if the line were infinitely long. All the input power is absorbed by the line, so far as the source is concerned. If the line is loss-free, all of this power is delivered to the terminating resistance at the far end.

## Losses

In practice not all the energy put into a feeder is transmitted to the far end. Losses occur for three principal reasons:

- Radiation from the feeder
- Resistance of conductors (called 'copper loss')
- Dielectric loss.

Radiation losses can be minimised by using balanced conductors with separation small in terms of wavelength, or screened feeders.

Copper loss is reduced by using thick wire.

Where the material insulating the feeder line is not air, appreciable dielectric loss can take place, especially in coaxial

cables where the two lines are not side by side but concentric. Feeders of this type have excellent mechanical and non-radiation properties but the dielectric loss at high frequencies can be large.

The longer a line is, the more of the signal is lost as it travels from one end to the other. With long feeders it becomes increasingly important to terminate the feeder correctly, for reasons which can be looked at in two simple ways, considering first the forward and reverse power separately, and second the standing waves which result from their combination.

For a given voltage applied to the source end of the line the forward power is determined by the characteristic impedance, independent of the load. The losses will be some fixed fraction of that power, the balance being delivered to the load end of the line. If the load does not absorb all that power, the result is reflected back toward the source. The same fixed fraction of that power is lost on the way back. The source therefore has to supply more power to make good losses than it would if the load were matched, while delivering less useful power to the load.

The reflected wave combines with the outgoing wave to make standing waves. Therefore if the current and voltage are examined in different parts of the line they will differ. Because of the square law relating current to power, the peaks of current will produce in the line much more power loss than is saved by the troughs of current a quarter-wavelength away. A similar argument applies to voltage.

### ***Demonstration 3 Balanced Feeder***

Demonstration 3 shows that power can be transmitted along a feeder. The power is dissipated in a resistor which is used as the termination. Although the resistor gets hot, showing that power is delivered to it, the distribution of voltage and current along the feeder is not exactly uniform: a small standing wave is superimposed on the travelling wave. This is because the termination differs from the characteristic impedance for the following reasons:

Resistance values at high frequency tend to differ from values measured at d.c or lower frequencies, and are difficult to measure.

Current flowing in the resistor and its leads creates a magnetic field, so that the termination inevitably possess inductance. The electric field is distorted by the termination adding capacitance also.

It will be seen in later chapters that when the nominally resistive termination is an antenna there are similar and sometimes more difficult problems in making correct terminations.

### Practical aspects

Two common types of feeder are the open pair of parallel wires and the coaxial cable. The open-wire feeder can provide very low losses under dry conditions, but is adversely affected by wet and by the proximity of lossy objects such as buildings or trees. Twisted insulated wires have been used, but are especially liable to variation in performance between wet and dry conditions.

Characteristic impedances depend on the geometry and on any dielectrics employed. Typically an open-wire feeder's characteristic impedance is in the region 200 to 600 ohms, depending on the ratio between separation and diameter of the conductors. Coaxial cables for low-power work and for reception are more usually 50 or 75 ohms. At the highest power such a low impedance requires inconveniently high current (e.g. 115A to transmit 1MW at 75 ohms), so that coaxial feeders of higher impedance are used. The impedance depends on the ratio of diameters of inner and outer conductors, so that a high-power coaxial feeder may have a large outer diameter, say 0.3m; to save material it may be skeletonised, both conductors being cylindrical arrays of wire. For a twisted feeder an impedance of 100 ohms is typical.

**NOTES**

We saw in Chapter 1 that when a system radiates, the power radiated appears to be dissipated in a resistance called the radiation resistance. We also saw that the current in different parts of an antenna varies. The radiation resistance is therefore always calculated from the maximum value of current, wherever this may occur.

However, it is not necessary always to choose the point of maximum current to feed power in to the antenna. If a point is chosen which is not a current maximum, the antenna may present an impedance which is a combination of reactance with some other value of resistance. This impedance is called the 'drive (or feed) point impedance'. The impedance must of course have a pair of adjacent terminals (the drive point) which may be connected to different parts of the antenna, or in some cases to ground (or an artificial 'ground plane') and an adjacent part of the antenna. (If the terminals were not adjacent, then any conductor linking them would become part of the antenna). One antenna may have different drive point impedances when driven at different points.

A knowledge of the drive point impedance is very important. Any equipment connected to the antenna will require to be adjusted to operate correctly with that impedance. In the case where a feeder is employed the drive point impedance must match the characteristic impedance of the feeder for efficient power transfer, as discussed in Chapter 2.

Two simple and much-used kinds of antenna illustrate the concept of drive point. Fig 3.1 shows a balanced antenna in free space (i.e very far from any other conductors). It is divided in the middle and the RF power source is connected to the two sides of the break. This is known as a Hertz antenna (or Hertz aerial, the word 'aerial' being a generally used alternative to 'antenna' from the early days of radio). Alternatively it may be referred to as a 'dipole' antenna.

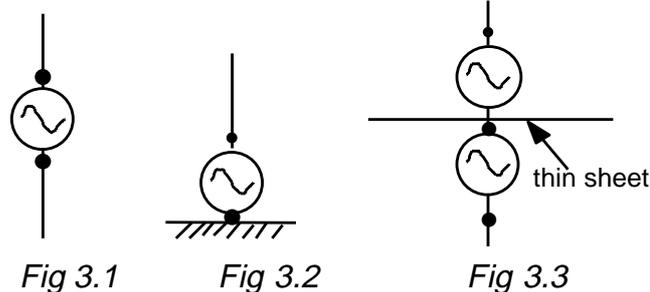
Fig 3.2 shows an antenna perpendicular and close to a flat conducting surface, such as ideal flat ground. This is referred to as a Marconi antenna. The RF source has one of its terminals connected to the bottom of the antenna and the other connected to ground. By analogy with the dipole, this type of antenna is sometimes referred to as a 'unipole' antenna.

The relationship between these two kinds of antenna can be seen by the following process. Suppose that in fig 3.2 the flat conducting surface is made into a thin conducting sheet; this will not affect the antenna's performance in any way. Then construct on the other side of the sheet a similar antenna extending in the

opposite direction, fig 3.3, with its own RF source which drives the second antenna in the opposite polarity.

The symmetry of the arrangement ensures that any current flowing in the sheet due to one antenna is exactly counterbalanced by an equal and opposite current due to the other. The sheet can therefore be removed without having any effect. This converts the pair of Marconi antennas into a single Hertz antenna fed by the two RF generators in series. (The effect of a conducting plane near an antenna is examined in more detail in the next chapter).

If all RF generators in figs 3.2, 3.3 are identical, the currents in each will also be identical, but evidently since two RF generators are in series in the arrangement equivalent to the Hertz antenna the latter requires twice as much voltage between its input terminals for the same current. Its drive point impedance is twice as great therefore, and it absorbs twice the power for the same current. (This is consistent with the conservation of energy since it has twice as much space to radiate energy into).



### Impedance changes due to variations of antenna length

Let us consider the drive point impedance of a Marconi antenna, fig 3.2, with various different lengths of conductor extended from the transmitter upwards.

If we start at zero length the impedance is infinite as no current can flow. When a very short length is connected a very high capacitive reactance is presented. The conductor will have inductance and capacitance both of which will be unevenly distributed as one end of the conductor is closer to the earth than the other. As the length of conductor is increased it begins to radiate and thus the impedance becomes slightly resistive due to radiation resistance as well as capacitive (fig 3.4a). The capacitive reactance also decreases as the conductor's capacitance increases and as the increased inductance cancels some out. At a length approaching a quarter-wave length the inductance completely cancels the capacitance and series

resonance takes place. The only opposition to current flow is the radiation resistance which has also increased. We now have the resonant condition. The radiation resistance and drive point impedance are now both equal to about 35 ohms. From the discussion related to fig 3.3 it will be deduced that the radiation resistance of the half-wave dipole is 70 ohms.

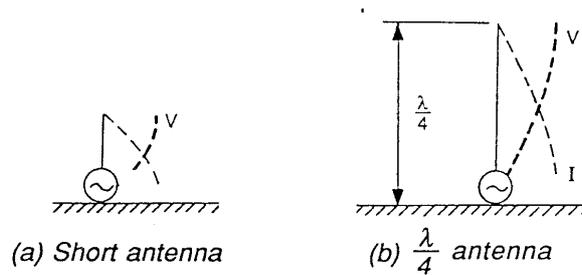


Fig 3.4

We shall find that as the length increases other resonances occur. These may be thought of as arising from the distributed capacitance and inductance along the conductor as indicated in fig 3.5. Just as in a feeder a current maximum (point of minimum impedance) is found a quarter-wavelength from an open-circuited end, so in the antenna, if it is increased beyond  $\frac{\lambda}{2}$ , a current maximum is found approximately  $\frac{\lambda}{4}$  from the top, fig 3.6. If the increase is small, the added wire behaves like an inductance in series with the low resistance of the top  $\frac{\lambda}{4}$  section; the capacitance added is not at this stage significant, although as the length increases it will progressively reduce the drive current. When the added length is  $\frac{\lambda}{4}$  (making a total height of  $\frac{\lambda}{2}$ ), the bottom  $\frac{\lambda}{4}$  section acts as a transformer once more converting a low impedance at one end to a high impedance at the other; this time the low impedance presented by the top  $\frac{\lambda}{4}$  is converted to a high impedance at the drive point, which behaves now like a parallel resonant circuit, fig 3.7.

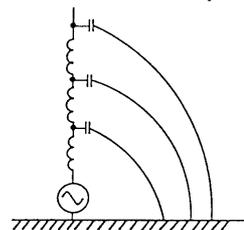


Fig 3.5

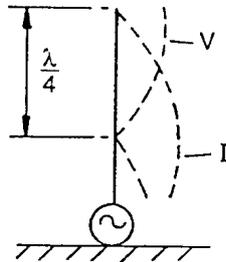


Fig 3.6

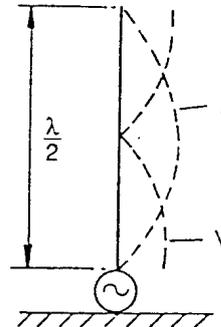


Fig 3.7

In a similar manner increasing the length further produces alternate 'series' and 'parallel' resonances. The drive point impedance  $Z_d$  may be expressed as a complex number

$$Z_d = R_d + jX_d$$

where  $R_d$  and  $X_d$  are the effective series resistance and reactance respectively. The variation of these quantities is plotted in fig 3.8 against the antenna height expressed in wavelengths ( $\lambda$  is the wavelength). The impedance transformation over  $\frac{\lambda}{4}$  of antenna length is analogous to that in a  $\frac{\lambda}{4}$  feeder, whose characteristic impedance  $\sqrt{\left(\frac{L}{C}\right)}$  determines the impedance ratio and the rate of change of reactance with frequency. In the antenna these properties are important for matching and in determining useful bandwidth.

The 'characteristic impedance' of an antenna is thus defined as

$$Z_o = \sqrt{(\text{maximum } R_d)(\text{radiation resistance})}$$

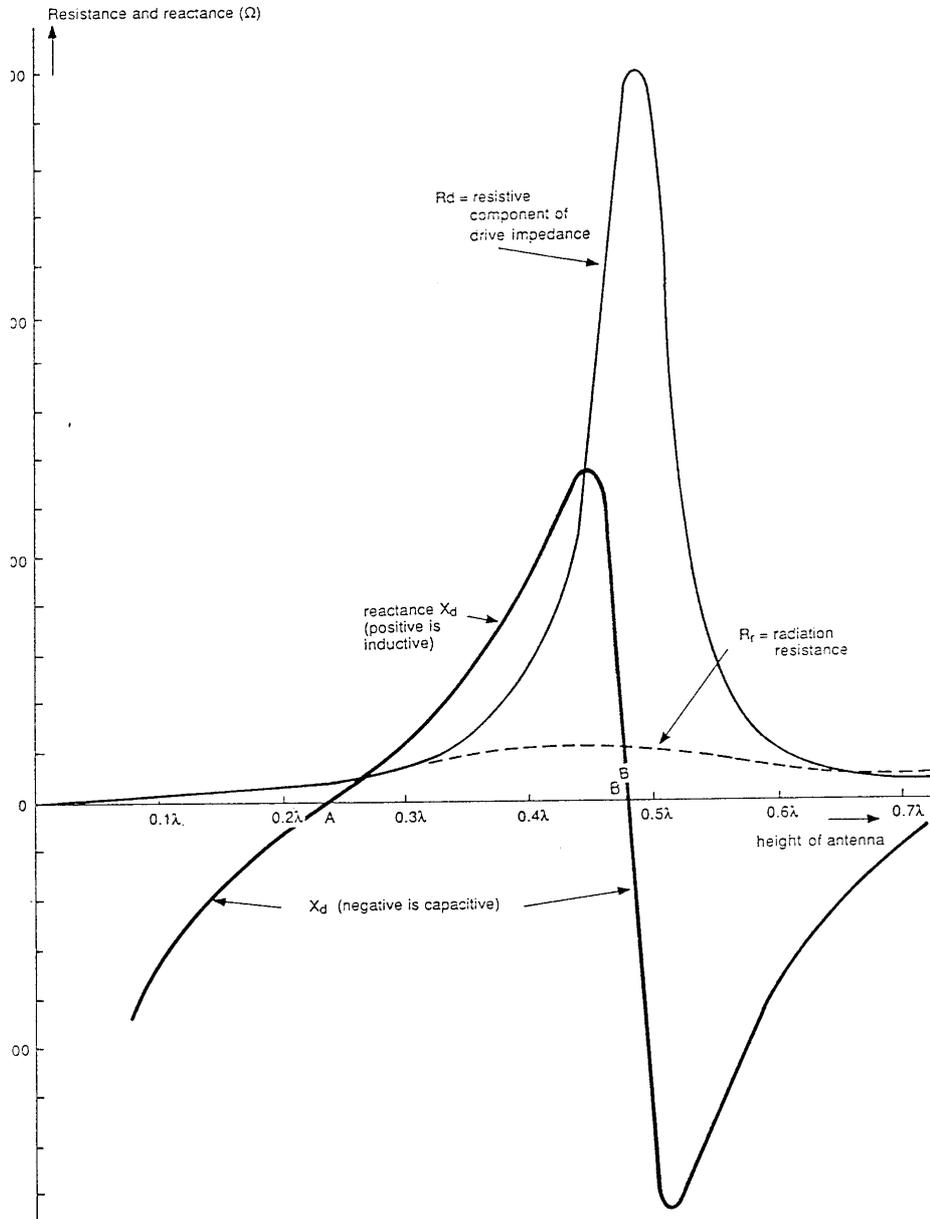


Fig 3.8 Variation of drive impedance with height of a vertical antenna extending from perfectly conducting earth. The value of  $Z_0$  is about  $360\Omega$  for a height of  $\frac{\lambda}{2}$

It can be altered by, for instance, thickening the conductor to decrease inductance per unit length and increase capacitance (although these values are not constant along the length), and is an important parameter in antenna design.

Various expressions have been derived for calculating  $Z_o$  for different shapes of conductor. For a vertical round wire just above a perfectly conducting ground the following expression may be used:

$$Z_o = (\ln \frac{h}{r} - 1)$$

where  $h$  = total height of wire

$r$  = radius of wire

The usual range of  $Z_o$  is between 230 and 650 ohms.

### Distinction between radiation, resistance and drive point impedance

It should be noted that once the length has increased beyond a quarter-wave, the point of maximum current is no longer the drive point. The radiation resistance is defined as  $\frac{W}{I_m^2}$  where  $W$

is the radiated power and  $I_m$  is the maximum current in the antenna. When the maximum current  $I_m$  flows at the drive point, the drive point series resistance  $R_d$  must be the same as the radiation resistance  $R_r$ . Once the quarter-wave length is exceeded this is no longer true. The distinction is shown on fig 3.8. Fig 3.9 gives a clearer graph of  $R_r$  against the antenna height in wavelengths.

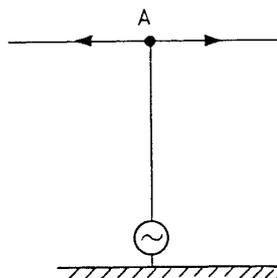


Fig 3.9

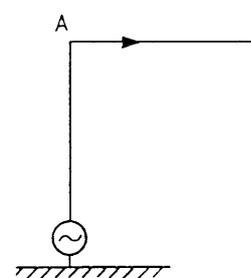


Fig 3.10

### ***Demonstration 4 End-fed vertical antennas***

It is not practicable without elaborate techniques and expensive equipment to measure the variations in drive point impedance just discussed. Demonstration 4 however clearly demonstrates the extreme cases of  $\frac{\lambda}{4}$  and  $\frac{\lambda}{2}$  end-fed vertical antennas. The voltage and current detector is used to show the distributions of current and voltage as indicated in figs 3.4b and 3.7c. In the latter it may be noted that the current, although a minimum at the drive point, does not fall to zero there. It differs in this respect from a half-wave length of feeder with open termination, because the antenna radiates and the feeder does not. In the antenna some current is necessary to support the loss of energy by radiation: in the feeder no energy (ideally) is lost.

The distribution of voltage and current in antennas is examined in most of the subsequent demonstrations, so that Demonstration 4 is to be regarded as an introduction to the topic. It also illustrates a practical form of radiator.

### **Physical and electrical lengths**

It has been mentioned that as the antenna is lengthened further resonances occur. Where the antenna is a thin straight wire these occur for lengths which are very nearly integral multiples of a quarter-wavelength. It is convenient to think of an antenna which is resonant as having an 'electrical length' which is exactly an integral number of quarter-wavelengths. There is then a difference between the physical and electrical lengths (which is small in the case of the thin straight wire).

The electrical length can be altered without altering the physical length by 'loading' the antenna with lumped capacitance or inductance. If we place a capacitance at the end of the radiator current can flow into it and thus the position of minimum current moves up so that the length has apparently increased. This can be done in several ways, fig 3.9 shows a section of wire added horizontally to the top of a radiator. The horizontal part will not radiate much because the two currents flowing away from the connection at point A are in opposite directions and the fields cancel. This is called a 'T' type antenna. In the arrangement of fig 3.10 the top section radiates, as the current flows in a single direction. This is called an inverted 'L' antenna. 'Top capacitance' can be added by a plate as in fig 3.11 or by radial spokes in fig 3.12. They all have the same general effect on the electrical length.

We can also effectively lengthen the radiator by adding some series inductance as in fig 3.13.

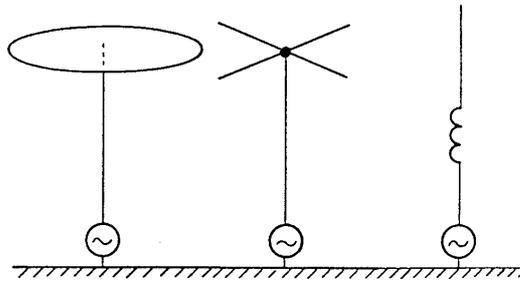


Fig 3.11

Fig 3.12

Fig 3.13

**Demonstration 5**  
**Altering the effective length of an antenna.**

These effects are practically demonstrated by the use of half- and quarter-wave rods with lamps inserted at intervals. For both lengths of rod it can be verified that the current maximum moves upwards when capacitance, in the form of a metal plate, is added at the top. The half-wave rod is also provided with an inductor which can effectively be removed by short-circuiting it. When the inductor is brought into effect an upward shift in the current maximum can again be observed.

**Demonstration 6**  
**Practical top-loaded antennas**

The T and inverted-L antennas are shown. The principal point of this demonstration, apart from extending Demonstration 5 into more practical forms of antenna, is to demonstrate the difference that the T antenna produces little or no horizontally polarised radiation, while the inverted-L produces a significant amount.

**Effect of electrical length adjustments**

When the electrical length is changed by any of the means discussed there will be a change in the drive point impedance and in the radiation resistance. Both effects can be beneficial in the usual cases where loading is used, namely when the height of the antenna is limited in relation to the wavelength. For instance when the antenna is short and therefore has an associated low radiation resistance, the current must be very large even at low power. This would mean that losses due to ground resistance and conductor resistance would be quite large and a significant amount of power would be lost. By raising the electrical height of the tower in the way that we have discussed, the drive point impedance can be raised and the fraction of power lost is smaller, even though the radiation resistance is

unchanged. For a very short antenna the radiation resistance will also be increased, giving a further benefit.

One other important factor which is influenced by the electrical length is the angular distribution of the radiation. In the case of a Marconi antenna such as we have been discussing the electrical height influences how much energy is radiated upwards. At heights up to a quarter-wave there is significant upwards radiation as in fig 3.14. At heights around a half-wavelength there is a significant reduction in upwards radiation. Strong horizontal radiation is commonly required, to reach receivers in the surrounding area. The choice of height to give optimum horizontal radiation is complicated by the effects of the imperfect conductivity of the ground. In practice heights of  $0.52\lambda$  to  $0.6\lambda$  are found useful. A reduction in upwards radiation is also useful because it can be reflected back by the ionosphere and at a distant point a combination of 'ground' wave and 'sky' wave with differing phases can cause 'fading' thus reducing the service area. The effect occurs mainly in the evening at medium frequencies. see figs 3.15 & 3.16

ANTENNA IMPEDANCES AND LENGTHS

CHAPTER 3

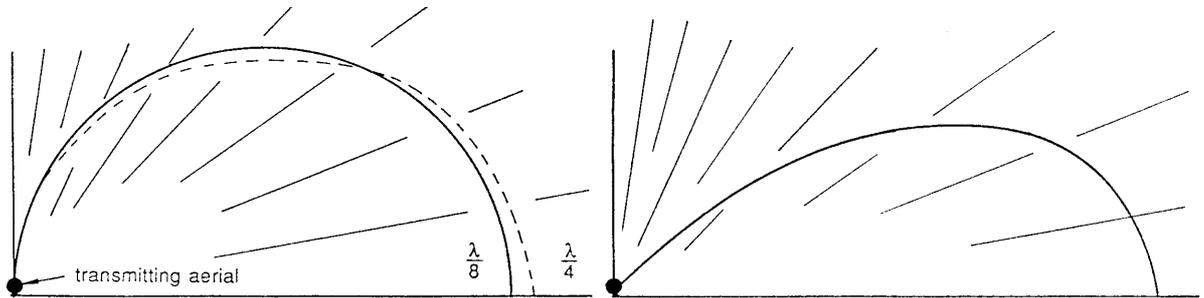


Fig 3.14

Vertical radiation patterns of  $\frac{\lambda}{8}$  and  $\frac{\lambda}{4}$  vertical antennas just above earth.

Fig 3.15

Vertical radiation pattern of  $\frac{\lambda}{2}$  vertical antenna just above earth.

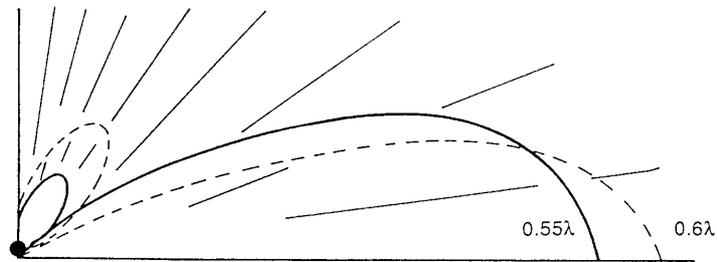


Fig 3.16

Vertical radiation patterns of  $0.55\lambda$  and  $0.6\lambda$  vertical antennas just above earth.

## ANTENNA IMPEDANCES AND LENGTHS

## CHAPTER 3

### Practical applications of Marconi antennas

Marconi antennas with and without loading find applications from low radio frequencies up to VHF. Increasing the height is most common at low frequencies where the wavelength is too long for a half-wave tower to be erected. At 200kHz, for example, a tower would have to be higher than 375 metres, which is clearly improbable. By using a 'T' as in fig 3.17, a much shorter antenna is possible. A multiple wire construction is used because particularly at low carrier frequencies the bandwidth of the antenna is insufficient for the sidebands used in AM radio. The multiple wire construction lowers both inductive and capacitive reactances of the antenna without altering the radiation resistance significantly. It thus lowers the ratio reactance/resistance (often called the 'Q') of the system, which increases the bandwidth.

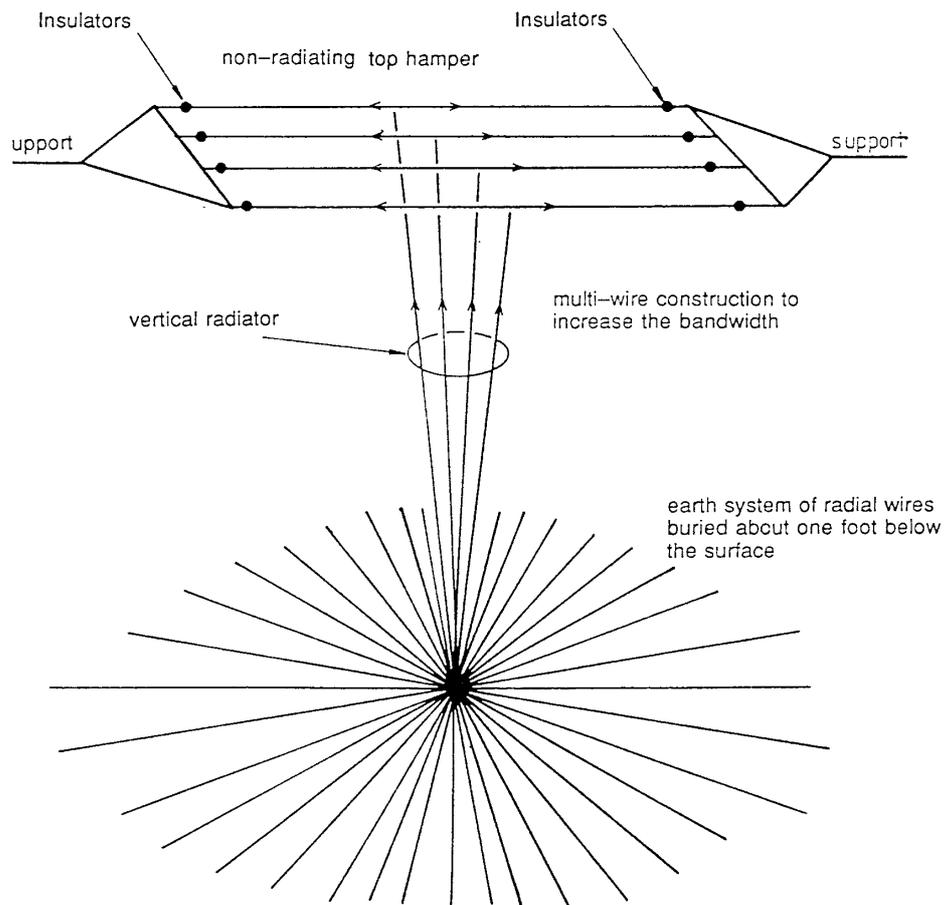


Fig 3.17

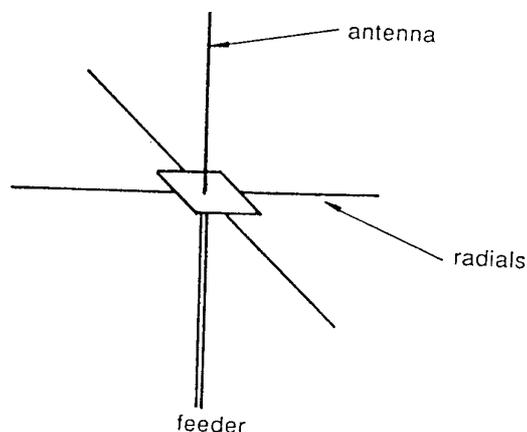
Apart from intended alterations of electrical length, allowance must also be made for the unintended effects of constructional features. Insulator capacitance is a particularly frequent factor which alters the behaviour of antennas.

As we also saw the currents involved at the base of short antennas can be very large and losses due to ground resistance can be large. A series of radial wires also shown in fig 3.17 just below the ground can improve this and it is important where soil conductivity is poor. They should be at least as long as the tower is high.

As the frequency increases from 0.5 — 1.5MHz the ground-wave becomes weaker until about 1.4MHz the service area is only 20 — 30km. The high-frequency end of the medium wave band is therefore generally used only for very local broadcasting. This is unaffected by sky waves, since the ionosphere does not reflect waves arriving nearly vertically; complicated anti-sky-wave antennas are therefore not justified in this frequency region.

Some foreign long-distance transmissions use sky-wave propagation to extend their night-time service area to several thousand kilometres, but reception is very variable and subject to fading. In this case antennas are used to radiate mainly upwards — the exact opposite to domestic usage. High power is also used, 1 megawatt not being at all uncommon.

At VHF where the antenna is small it is necessary to erect it above the ground, on a building for example, to improve coverage. A vertical quarter or 5/8 wave rod is used and to simulate a ground a few radial 'spokes' are used as in fig 3.18.



*Fig 3.18*

The simple Marconi antenna radiates equally in all horizontal directions. This is obvious from the symmetry of the antenna and the supposedly uniform ground surrounding it. If a graph were drawn in polar coordinates, showing the strength of radiation emitted in a given direction by the distance in that direction from the graph origin to a point on the graph, it would be a circle, fig 4.1. It was pointed out near the end of the last chapter that it does not however radiate uniformly in all vertical directions, and this was illustrated by graphs in polar coordinates. These graphs are commonly referred to as 'polar diagrams' and the distribution of radiation which they represent is called the 'radiation pattern'. Since they are so closely related in antenna work, either of these terms is occasionally used to mean the other or both, although it is an aid to clear thinking if the distinction is remembered.

A slightly simpler radiation pattern is produced by a dipole in free space (i.e a very long way from any other object such as the ground). Fig 4.2 shows a polar diagram in a plane containing the dipole. The dipole itself is superimposed on the polar diagram to show the relative directions. Fig 4.2 could represent any plane containing the dipole: once again symmetry causes the radiation pattern in any of these planes to be identical. If a polar diagram is plotted for radiation in the plane perpendicular to the dipole therefore, it is once again a circle, like fig 4.1. Figs 4.1 and 4.2 are plane diagrams and each represents a section of a three-dimensional radiation pattern. A three-dimensional polar diagram would of course be a three-dimensional object, and for the dipole it is doughnut-shaped, as depicted in fig 4.3. A polar diagram on paper can never be more than a partial representation of the complete radiation pattern.

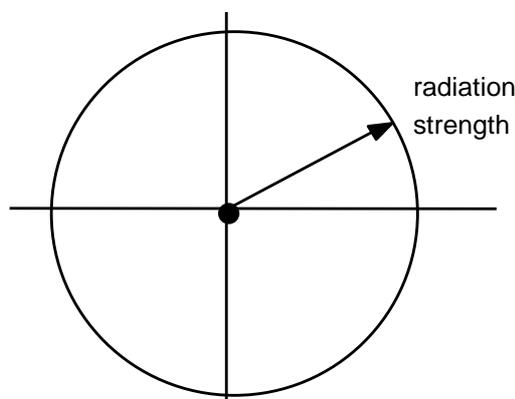


Fig 4.1

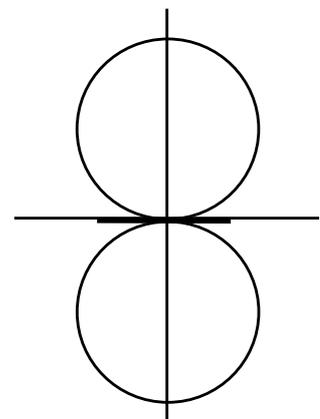


Fig 4.2

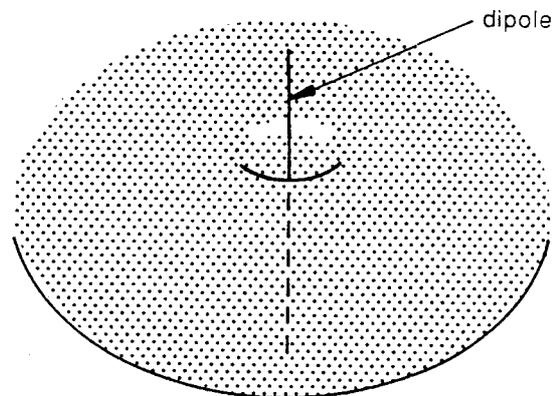


Fig 4.3

### Antenna gain

If a given amount of RF power is fed into an antenna system and is radiated, any reduction in the amount of power radiated in one direction must be accompanied by an increase in the power radiated in another, in order to balance input and output powers. One use of a directional antenna therefore is to concentrate as much of the available power as possible in a particular direction. This may be useful for point-to-point communication (i.e. between a particular transmitter and a particular receiver), or in long-distance broadcasting to a particular country or region, when all the receivers will lie within a small angle as seen from the transmitter. The effect may be likened to that of the reflector in a flashlamp, which provides a bright beam of light rather than weak general illumination. This attribute of a directional antenna, that it radiates more power in a chosen direction than a non-directional antenna, is called 'gain'.

It is usually specified in terms of a power ratio by comparison with a standard antenna. If no particular standard is mentioned, the reference is taken to be an isotropic radiator. This means an antenna which emits radiation uniformly in all directions. No practical antenna does this, but the theoretical concept is a valuable one.

The gain is then the ratio of the power received at a distant point in the direction of maximum radiation, to the average power which would be received if measurements were taken at all possible points at the same distance. The ratio is often expressed in decibels (db) and to save writing 'dB with respect to an isotropic radiator', the abbreviation 'dBi' is often used.

Gain is sometimes expressed in terms of dB compared with a half-wave dipole, but if so this should be clearly stated. A half-wave dipole has a forward power gain of 1.64 times or approximately 2.2dB, so that if an antenna had a gain of 10dB referred to a  $\frac{\lambda}{2}$  dipole its gain would be 12.2dBi.

Directional properties can exist and be useful also in receiving antennas. An antenna which emits radiation directionally will, when used for reception, be more sensitive than an omnidirectional antenna for signals coming from the favoured direction, thus enhancing the desired signal. It will also be less sensitive to signals from other directions, which in general will be interfering signals. The signal-to-noise ratio is thus doubly improved, by increasing the signal and reducing the received noise. A very common example of a directional receiving antenna is the television antenna, in which directivity not only increases the received signal, but helps to reduce 'ghost' pictures (received later than the main signal after reflection from some large object such as a building) and co-channel interference.

The gain of a receiving antenna is defined in much the same way as for a transmitting one. Gain is the ratio of powers delivered at the antenna terminals for a given radiation field strength, when the antenna is directed in the most sensitive direction relative to the field and when the average is taken for all possible relative directions. Again, for practical purposes comparison is often made with an antenna of known gain such as a dipole.

## DIRECTIONAL ANTENNAS AND RADIATION PATTERNS

## CHAPTER 4

**Demonstration 7**

This demonstration illustrates the simplest way of making a directional antenna, which is to combine two antenna elements in such a way that they assist one another in sending radiation in one direction or more, and (inevitably) counteract each other's radiation in other directions.

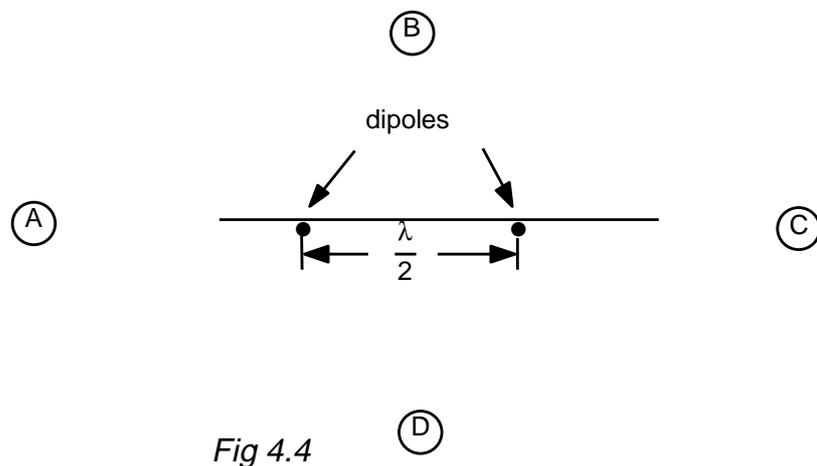


Fig 4.4

The antenna elements chosen are simply half-wave dipoles driven in phase, and separated by a distance of one half-wavelength, fig 4.4. Receiver A in the diagram receives energy from both antennas, but the signal from the far antenna has an extra half-wavelength to travel and therefore arrives with a phase lag of  $180^\circ$ . Provided that the power fed to both antennas is equal, the two signals will cancel and receiver 'A' will detect nothing. Receiver 'B' however also receives both signals, but is the same distance from both sources, therefore the signals arrive in phase and reinforce each other. Receiver 'B' detects twice the power that it would if only one antenna had been present. Receiver 'C', like 'A', detects no signal, and 'D' receives a strong signal like 'B'. Fig 4.5 shows the polar diagram.

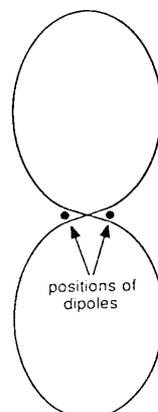


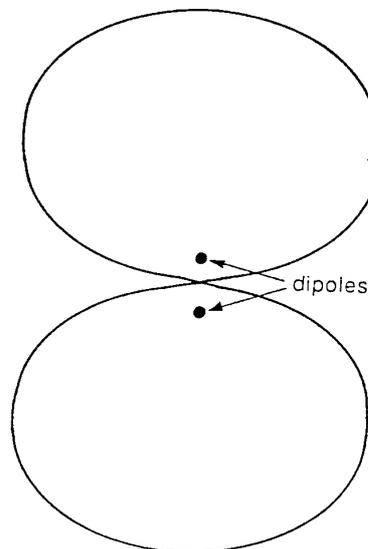
Fig 4.5

## DIRECTIONAL ANTENNAS AND RADIATION PATTERNS

## CHAPTER 4

Notice that in setting up this demonstration it is important to connect the dipoles with the correct polarity. The importance will become evident from what follows.

The demonstration continues by reversing the polarity of the feed to one of the dipoles. This is conveniently done by rotating its arms about the feed conductors which support them. The radiation pattern is now quite changed. Fig 4.6, shows the positions of the nulls and the maxima exchanged, because the signals at 'B' and 'D' now cancel one another, while the travel of one dipole's signal to the other takes just that time interval which brings the two dipoles' signals into phase as they travel along the line towards 'A' or 'C'.



*Fig 4.6*

Where, as in this simple case, there is a well defined plane containing the antenna elements, the antenna may be described as an 'end-fire' antenna when the maximum radiation is emitted in the plane, and a 'broadside' antenna when the direction for maximum radiation is at right angles to the plane.

## DIRECTIONAL ANTENNAS AND RADIATION PATTERNS

## CHAPTER 4

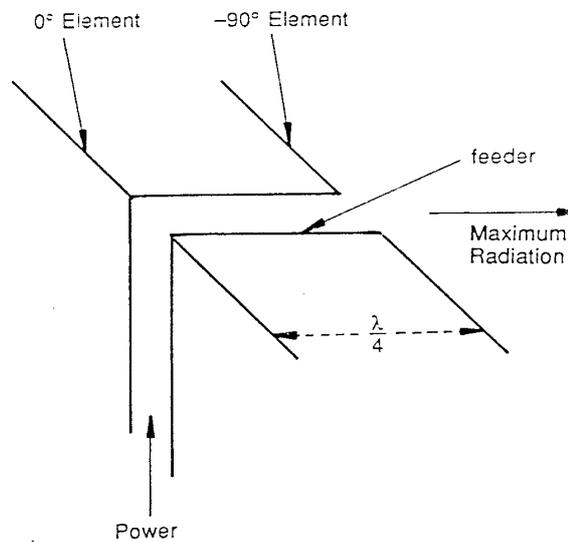


Fig 4.7

The antenna elements need not be driven in equal or opposite phase. If for instance they are fed at  $90^\circ$  relative phase, by giving one dipole an additional quarter-wavelength of feeder, fig 4.7, a pattern with a single maximum and a single null of radiation is formed, fig 4.8. This pattern is called a 'cardioid' (which simply means 'heart-like').

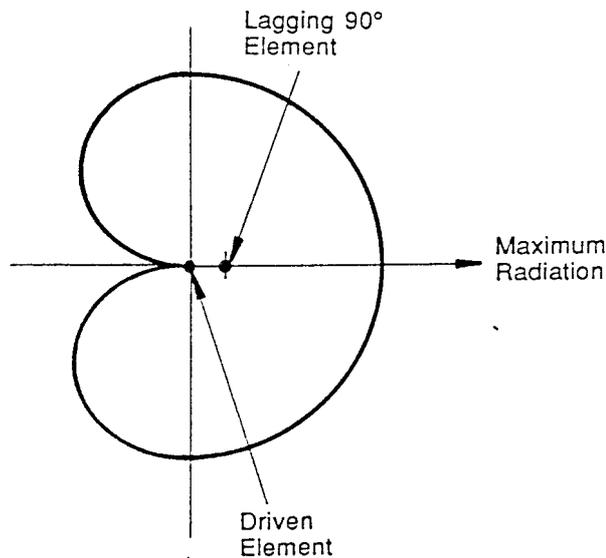


Fig 4.8

**Parasitic elements**

It is not always necessary to drive every element in an antenna. If one dipole is driven, and another dipole is placed in its neighbourhood, an emf is induced in the second dipole whose phase depends on the separation between the two dipoles. A current will flow in the second dipole, whose phase will depend both on the phase of the induced emf and on its distributed inductive and capacitive reactances (or equivalently, on its self-induced fields). Thus if the driven dipole is half-a-wavelength long, the separation is held constant and the length of the second dipole is adjusted from slightly less than half-a-wavelength to slightly more, the current in the second dipole can be made to vary in phase quite widely. Regarding it as being driven centrally by the induced voltage, that voltage will work into a capacitive reactance when it is shorter than  $\frac{\lambda}{2}$  and inductive when it is longer than  $\frac{\lambda}{2}$ .

The current set up in the second element gives rise to radiation, which modifies the radiation pattern provided by the driven dipole on its own.

Elements working in this way, that is elements which although not driven are energised by the field of other elements, and which modify the radiating properties of an antenna, are called 'parasitic elements'. They have the great advantages that they are cheaper and require less maintenance than elements to which feeders must be connected. These factors become important when large numbers of elements are used to produce highly directive antenna systems. An antenna comprising a number of more or less separate elements is often called an 'array'.

**Parasitic reflector and director**

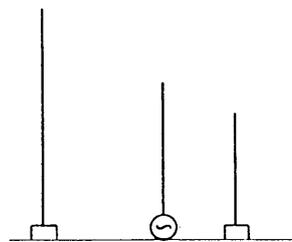
If a parasitic element is placed about one-quarter wavelength away from the driven element, and is slightly longer than the resonant length, the pair of elements will have a radiation pattern generally similar to that shown in fig 4.8, although the null is never very sharp in a parasitic system. In this case the parasitic element is called a reflector, since it appears to turn back radiation directed at itself.

Just as in Demonstration 7 the reversal of phase in one dipole exchanged the positions of nulls and maxima, so the maximum and null in a two-element parasitic array can be changed. Decreasing the length of the parasitic element to slightly less than the resonant length very nearly reverses the phase of the current in it, so that radiation from the driven element tends now

to be enhanced in the direction of the parasitic element, which is now called a 'director'. However a director is rarely used without a reflector, since the director's spacing is critical and it lowers the radiation resistance which is undesirable. The director works best when comparatively close to the driven element, about  $\frac{\lambda}{8}$  from it. The exact spacing depends on which of several interdependent characteristics is most important (see the later paragraph 'Measures of Performance').

### **Demonstration 8**

This demonstration introduces parasitic arrays (fig 4.9) based on  $\frac{\lambda}{2}$  and  $\frac{\lambda}{4}$  Marconi antennas. In each case a driven element is provided, together with one parasitic element shorter and one longer than the exact half- or quarter-wavelength. The parasitic elements which approximate to  $\frac{\lambda}{2}$  are mounted on insulating bases, since each end is a voltage maximum. The quarter-wave parasitic elements ideally should be connected to the ground plane, since the lower end is a current maximum. To avoid contact problems a metal base with a large flat lower surface is used; if it makes contact with the ground plane the desired condition is achieved, but in the absence of contact (likely because the ground plane is anodised) the capacitance between the base and the ground plane is sufficient to provide an effective connection of low reactance.



*Fig 4.9*

The demonstration is an exploration of the distribution of radiation around the antenna by carrying the Radiation Detector around it. This is done first for the  $\frac{\lambda}{2}$  single-driven element, then with reflector and director elements added one at a time, then with all three elements. The demonstration can then be repeated using the  $\frac{\lambda}{4}$  elements, with very similar results. The Voltage and Current Detector should be used to show that voltage and current in the parasitic elements are comparable with those in the driven element.

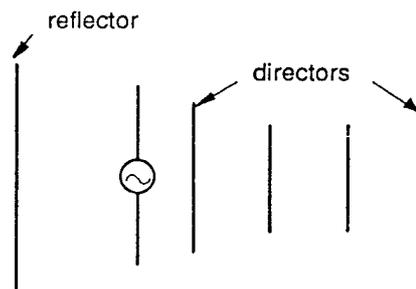
**NOTES**

## DIRECTIONAL ANTENNAS AND RADIATION PATTERNS

## CHAPTER 4

**Larger arrays**

It is quite common to increase the number of directors, especially in antennas for short wavelengths. The first few elements give useful increases in gain, but for further similar increases in gain larger numbers of added elements are required. UHF arrays with thirty elements are not uncommon. The arrangement in line of a reflector, driven element and a number of directors, fig 4.10, is known as a 'Yagi-Uda' array, after its inventors. However parasitic arrays are by no means confined to this configuration. Fig 4.11 shows a large broadside array for use in long-distance HF broadcasting, having a somewhat similar array forming a curtain of parasitic reflectors behind it, the whole providing a substantially unidirectional radiation pattern. This is an example of a 'stacked' array, in which by selecting suitable numbers of elements in both dimensions of the plane of the array the desired directivity can be obtained both horizontally and vertically.



*Fig 4.10*

Alternative feed points can be seen on the line connecting the two halves of the array. Use of one or other of these alters the relative phase in which the two halves are energised, owing to the different lengths of feeder travelled by the input signal. By this means the beam emitted can be 'steered' over an angle of several degrees.



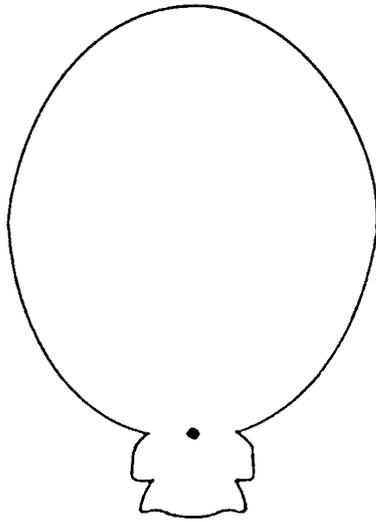
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### E and H plane patterns

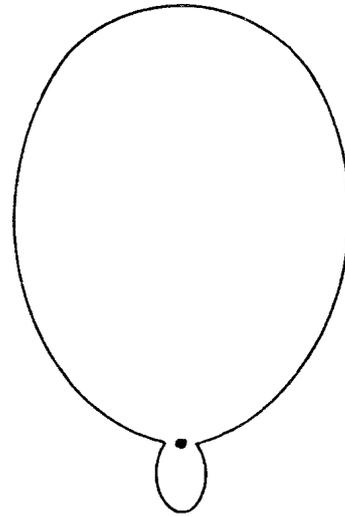
Fig 4.1 shows a circular pattern which could represent for instance the radiation from a horizontal dipole in a vertical plane normal to its elements. Fig 4.2 represents its horizontal radiation pattern. If however the dipole were rotated so that its elements were vertical, fig 4.1 and 4.2 would have to be interchanged. It is convenient to have some system of reference in which 'horizontal' and 'vertical' are not used, since these words relate to the ground, which is often quite irrelevant to consideration of an antenna some distance from it. A much-used way of distinguishing planes related to the antenna is by reference to the direction of the electric and magnetic fields produced. Thus the plane containing a dipole and the direction of propagation is called the E-plane, since it contains the lines of electric force. The plane perpendicular to the dipole is called the H-plane because it contains the lines of magnetic force. (With modern theoretical approaches to electricity and magnetism one might rather call the latter plane the B-plane instead of H-plane, but the H-plane nomenclature seems likely to persist).

These names should not be allowed to suggest that only an E-field exists in the E-plane; radiation necessarily includes both E and H (or B) components.

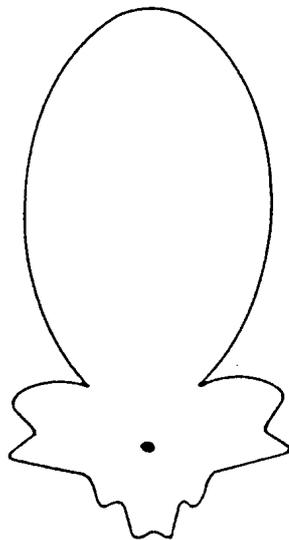
It is evident from the dipole example that E-plane and H-plane patterns can be quite different. However they can be similar; this applies to extensive Yagi arrays, which are directive in both E and H planes, with little difference between them. See fig 4.12.



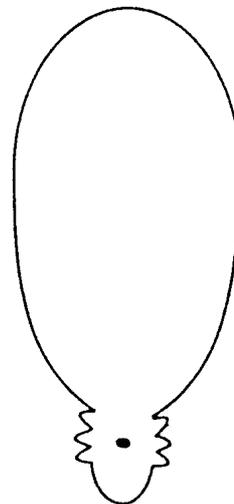
(a) Measured H-plane radiation pattern of a four-element Yagi array at 520MHz.



(b) Measured E-plane radiation pattern of a four-element Yagi array at 520MHz.



(c) Measured H-plane radiation pattern of a 12-element Yagi array at 520MHz.



(d) Measured E-plane radiation pattern of a 12-element Yagi array at 520MHz.

Fig 4.12

## Measures of performance

The antenna gain, already discussed, is clearly an important measure of directional performance, but there are many others. Strictly speaking the definitions previously given refer to the *maximum* gain, and the radiation pattern is the complete specification of the variation with direction of a more generally defined gain.

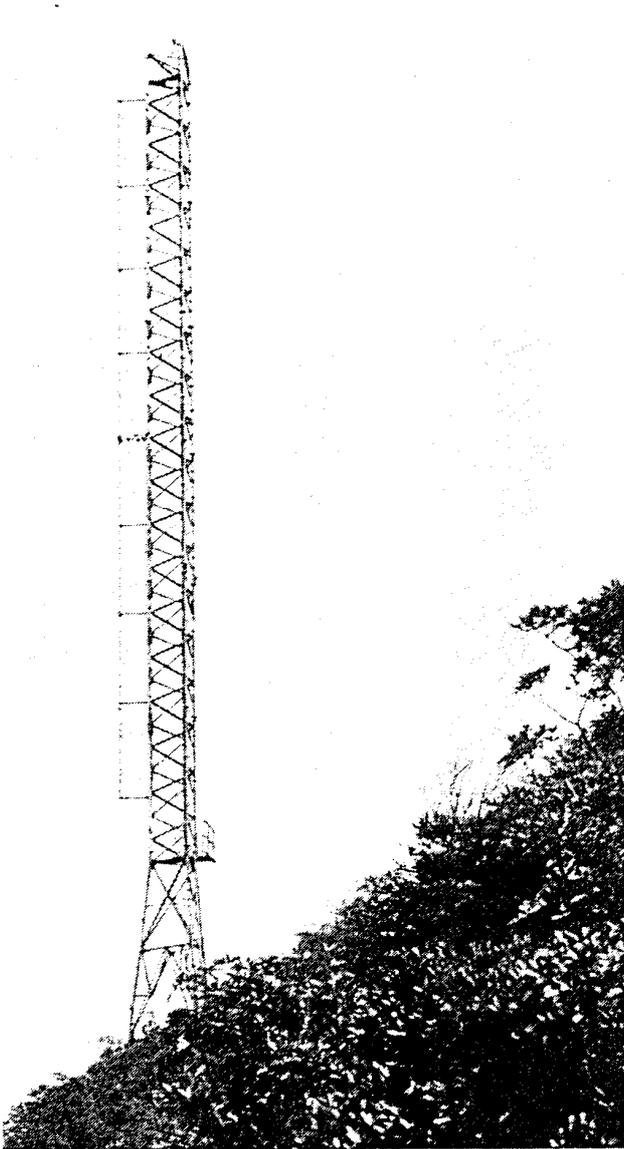
The power radiated from the back of the antenna must decrease when it is directional and we can measure the ratio of the power radiated forward to the power radiated backwards. This would also be expressed in decibels. It would be a larger number than the forward power gain. It might be 10dB in a simple parasitic array for example. This is the 'front to back ratio'.

Large arrays may have quite complex radiation patterns whose polar diagrams exhibit a number of 'lobes' or loops like fig 4.12. They may be designed for maximum gain measured in the direction of one particular lobe, the 'main lobe', or for minimum gain in the direction of other lobes called 'side lobes'; both attributes are often required. In this case we may be interested in the ratio of the maximum gain of any side lobe to the gain of the main forward lobe. This ratio, usually expressed in dB, is called the 'side lobe suppression'. It can be vitally important in a radar for instance, in which the signal received from a large object on a side lobe could be indistinguishable from that of a small object on the main lobe, or maximum response.

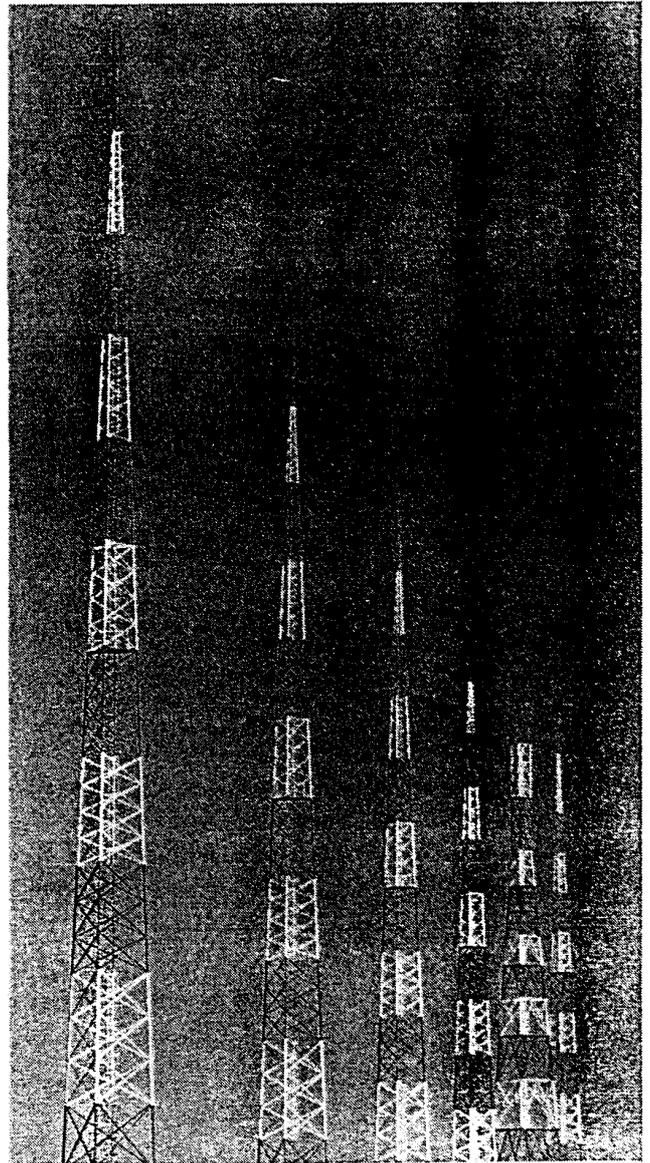
The power radiated in a given direction depends both on the transmitter's output power and on the antenna gain. The 'effective radiated power' of a transmitting station is defined as the power which would have had to be fed to an isotropic radiator to produce the same useful radiation. It is thus equal to the actual transmitted power multiplied by the power gain of the antenna. If for instance a 1kW transmitter were used with an antenna of forward gain 3dBi, then the forward effective radiated power (e.r.p) would be 2kW. The e.r.p is often quoted by VHF and UHF broadcasting stations rather than the actual transmitter power.

DIRECTIONAL ANTENNAS AND RADIATION PATTERNS

CHAPTER 4



*Stacked multi-element VHF broadcasting array at Mount Gough (Cable and Wireless)*



*2 MW 6-element MF Yagi antennas used for high-power long distance medium-wave broadcasting. (Marconi).*

**NOTES**

It has already been seen that a dipole (Hertz antenna) can be bisected by a conducting sheet, and that each half will act as an antenna in its own right (Marconi antenna). A Marconi antenna relies on the presence of the ground, or of an artificial substitute, acting like a conducting sheet, since in its absence there is no second terminal to which the feed can be connected. In this chapter we shall look at further related matters, such as the effects of imperfectly conducting ground, the curvature of the earth and the effect of the ground on more general kinds of antenna including those which do not require an electrical connection to the ground.

### **Modes of Propagation**

It is useful to distinguish three different propagation modes. Radiation may be emitted by one antenna and travel directly through space to another antenna which receives some of the transmitted energy. This is often called 'line of sight' propagation. 'Ground wave' propagation is somewhat similar, except that the presence of the ground has a slight bending effect which enables the ground wave to follow the curvature of the earth to some degree. 'Sky-wave' propagation is that in which radiation travels upwards until it meets an ionised layer in the thin gas outside the atmosphere; the wave 'bounces' back to earth, possibly at a great distance. Other modes are used, but are less relevant to explanations of antenna behaviour.

### **Sky waves**

Sky-wave propagation is much used in the frequency band between about 2MHz and 20MHz because great distances can be covered with quite reasonably small powers transmitted. The ionised layers are in a continual state of change and a full study is well beyond the scope of this book. There are however a few important ideas which are fairly easy to grasp.

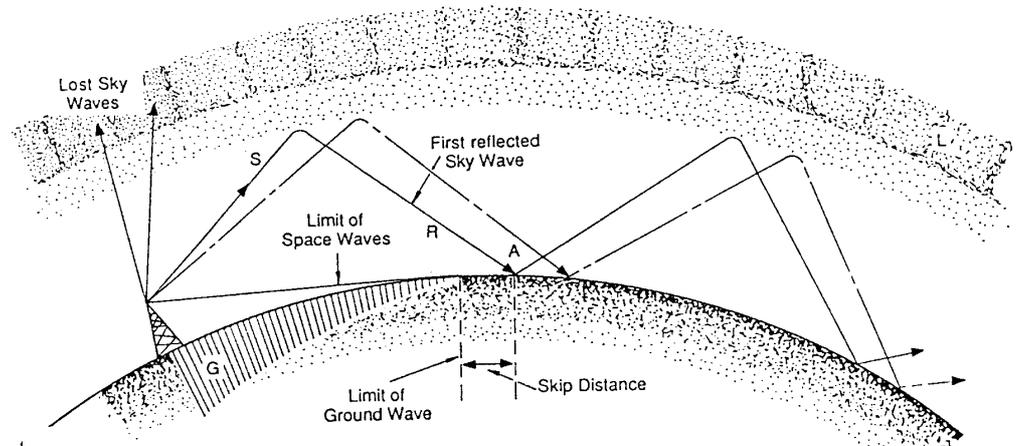


Fig 5.1

Fig 5.1 shows a transmitter which emits a ground wave G which travels along the earth's surface progressively losing strength. A sky wave S is projected upwards to the reflecting layer L (there are several layers which can perform this function). It returns to earth as the reflected wave R. It may well be that a more nearly vertical wave will fail to be reflected by the layer, and be lost into space. If this is so a receiver at A will receive no signal. The region in which this applies is called the 'skip distance'. If on the other hand the layer L is capable of reflecting even a vertical wave, the reflected and ground waves can interfere with one another, the effect varying as phase changes occur with movements of the layer. This is a major cause of fading and distortion of signals in the region of 0.5-1.5MHz in the evening.

For long-distance transmission a sky wave may bounce between earth and sky several times. In order to lessen the chance of multiple waves arriving, and in order to overcome problems of multiple skip distances, it is sometimes required to control the vertical angle with which the radiation leaves an antenna with some precision. The conductivity and shape of the ground near the antenna play quite an important part in this.

### Generalised effect of a perfectly conducting flat ground

Whatever kind of antenna is considered, when energised it will produce electric and magnetic fields in its neighbourhood. If a perfectly conducting surface is near it will interact with the fields. The electric field is altered so that it meets the conducting surface at right angles. If it were not so a component of electric field would exist along the conducting surface, but this cannot be true because a perfectly conducting surface is one in which no electric field can exist. The magnetic field on the other hand

must be parallel to the surface at the surface, or in other words it can have no component which penetrates the surface. If it were not so and magnetic field did penetrate the surface it would induce an emf in the surface, but as before this is impossible; with even the smallest penetration the perfect conductivity would permit infinite currents to circulate, opposing the magnetic field.

### **Image antennas and their effects**

The idea of an image antenna should be familiar from the equivalence of the Marconi antenna to a dipole formed by it with its image. The image effect is however quite general, since whatever antenna is taken, if the conducting plane is removed the field conditions at its position (described in the previous paragraph) can always be recreated by putting an image antenna in place, suitably energised. For, considering any small length of the original antenna and any one point on the conducting surface, the corresponding length of the image antenna will produce at the same point the same contribution to the total field in a direction and polarity which will satisfy the required conditions, both for the electric and for the magnetic field.

The effects of the ground, regarded as perfectly conducting may therefore be thought of in terms of the effects of the image antenna. The effects of an image antenna, and therefore of the ground include the following.

### **Radiation pattern**

The image antenna's radiation adds to that of the real antenna. In some directions the radiations will be in phase and in others they will cancel one another more or less completely. The radiation pattern of the real antenna is therefore modified.

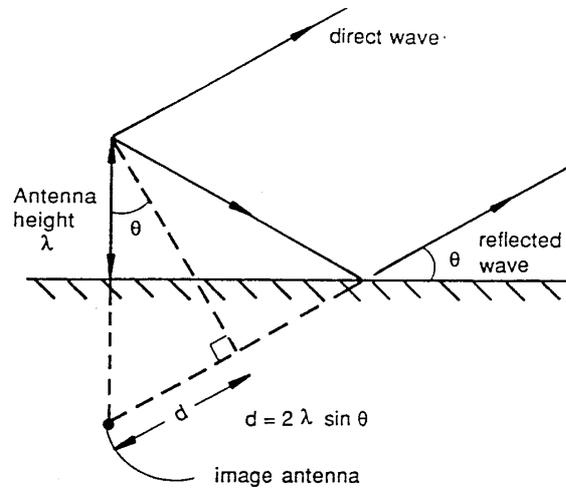


Fig 5.2

In fig 5.2 an antenna is shown at a height  $h$  above the conducting ground, and an image antenna correspondingly below the ground. The radiation in a direction  $\theta$  from the horizontal is a combination of the direct radiation from the real antenna and the reflected radiation which appears to come from the image antenna. The latter has travelled a distance which is greater by  $2h \sin \theta$ . In considering the relative phase of the direct and reflected waves it must be remembered that the polarity of the image antenna is reversed in order to null the field in the conducting earth. The two fields therefore are in phase and reinforce one another if the excess distance travelled by the reflected wave is half-a-wavelength, or an odd number of half-wavelengths. Conversely for an even number of half-wavelengths difference the two radiations will cancel, giving a null in the radiation pattern. Fig 5.3 shows a series of vertical polar diagrams for a horizontal dipole at different heights above the conducting ground. In the absence of the ground the corresponding diagram would be a circle.

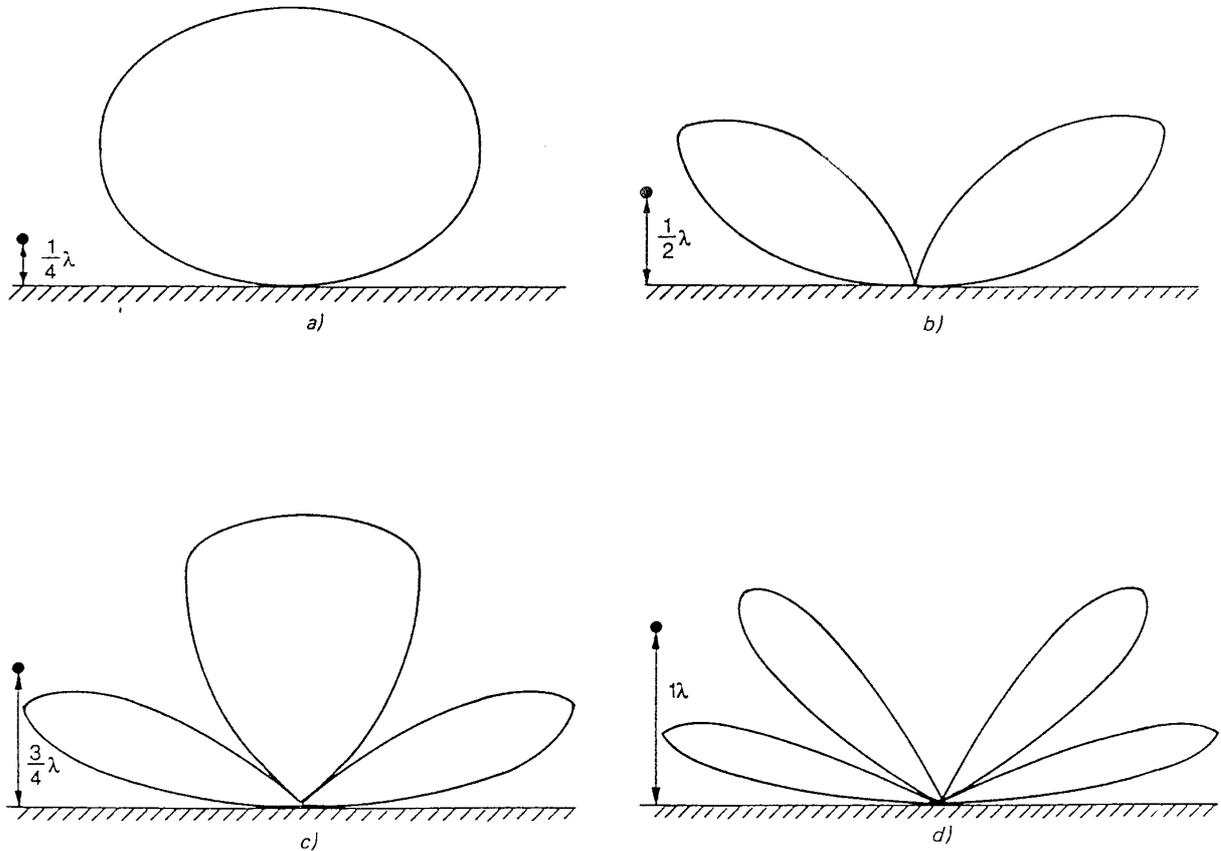


Fig 5.3

### Antenna impedances

Depending on the precise geometry, the total amount of radiation emitted for a given current in the (real) antenna's conductors may be increased or decreased. The radiation resistance is therefore liable to be changed.

Because of the change of radiation resistance and more generally because of the field of the image antenna surrounding the real antenna, the drive point impedance of the latter is liable to be changed.

### Effects of ground resistance

#### *Antennas driven with respect to ground*

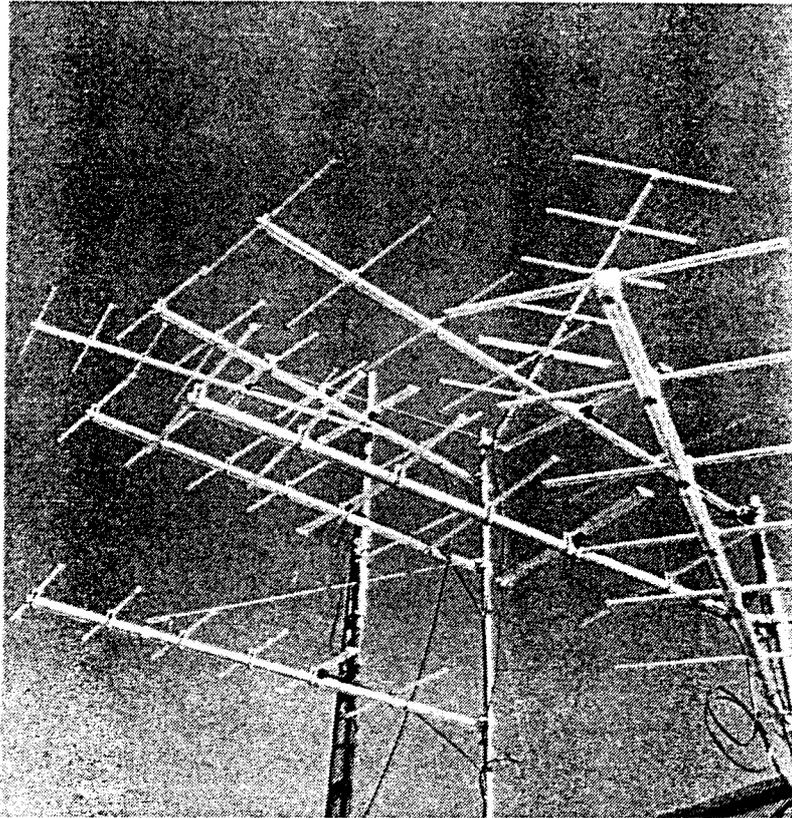
When the drive current flows into the ground, the ground resistance is placed in series with the inherent drive point impedance of the antenna. A power loss results which lowers the efficiency of the antenna. The effect is most serious when either the radiation resistance or the drive point impedance is low; often both occur together if the frequency or circumstances make it difficult to construct a long enough antenna. The low radiation resistance means that a considerable current is necessary in order to achieve the required radiation, and a low drive point impedance means that the current causing radiation all flows in the drive terminals.

These losses may be reduced either by redesigning the antenna so that the drive current is reduced, or by reducing the ground resistance by some means. The former approach is applied for instance in a half-wave Marconi antenna, whose drive impedance is high, and in which the drive current is considerably less than that flowing in the radiation resistance. Even in this case however it is desirable to reduce the ground resistance as well, since capacitance currents flowing from points near the base to the ground must pass through the resistive ground causing losses.

The ground resistance is reduced by the use of additional conductors which may be placed just above, on the surface of or just beneath the ground.

#### *Effect on a ground wave*

The imperfect conduction of the ground at greater distances within the service area has one desirable effect. Low- and medium-frequency broadcasting normally relies on the 'ground-wave' being propagated. If the ground conducted perfectly it would not be possible for the ground wave to follow the curvature of the earth. With imperfect conduction however the wave is slowed down near the ground, owing to the slower propagation of that part of the wave which penetrates the ground. In consequence the wavefront tilts, and the wave does follow the earth's curvature to a useful extent. 'Ground' wave propagation is actually most effective over the sea.



*VHF Yagi antennas in Muscat, for point-to-point communications, pointing in various directions (ie. they are not all part of one large array). Note the folded dipole driven element (Cable and Wireless Ltd.)*

**NOTES**

### ANTENNAS WITH FOLDED ELEMENTS

It is frequently necessary to modify the drive point impedance of an antenna. For instance a simple half-wave dipole having an impedance of 70 ohms might be required to be fed from an open-wire feeder of 300 ohms characteristic impedance. With parasitic arrays, the parasitic elements tend to localise the field; the reduced expansion of the field results in a reduced radiation resistance, perhaps to 15 ohms in an array of ten or more elements; a problem if this is also the drive point impedance.

In both these cases it is required to increase the drive point impedance, and usually it is convenient to drive such antennas at the centre. The requirement can be met by 'folding' the elements.

Fig 6.1a shows a folded half-wave dipole. It is like an ordinary dipole except that its ends are joined by another conductor of the same total length  $\frac{\lambda}{2}$  so that there are two dipoles close together and joined at the ends. The arrows show the current flow which is in the same direction for each dipole (although travelling along the conductor one finds a current reversal at the points of maximum voltage,  $\frac{\lambda}{4}$  from the current maximum in the centre, as one would expect). The currents are so close together that the radiation characteristics are simply those of an ordinary dipole carrying the double current of the two joined dipoles, fig 6.1b.

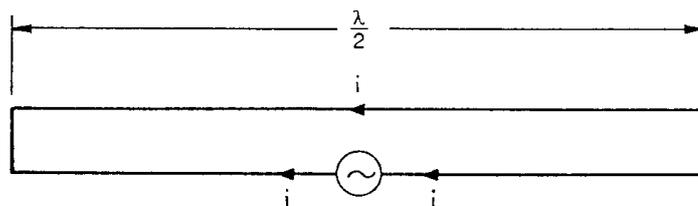


Fig 6.1a

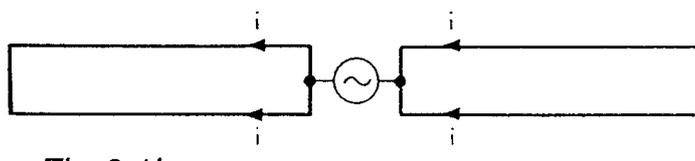


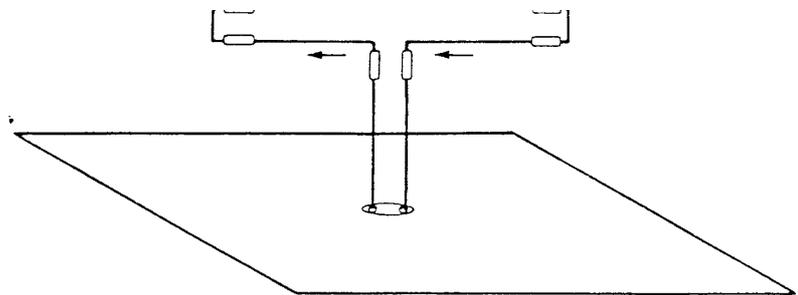
Fig 6.1b

If the current in the centre of each folded dipole element is  $i$ , the equivalent single dipole will carry a current  $2i$ . If its radiation resistance (equal to its drive impedance) is  $R$ , the radiated power is therefore  $4i^2R$ .

If we now go back to the folded dipole, radiating the same power  $4i^2R$ , we find that the current at the drive point is only  $i$ . The resistance presented by the drive point must therefore be  $4R$  to maintain the same power.

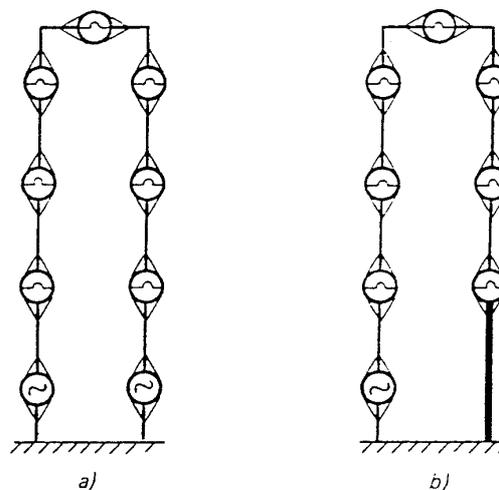
### **Demonstration 9**

This demonstration starts with a folded dipole supported by its feeder, fig 6.2. It is shown that the radiation pattern is similar to that of the simple dipole. The current and voltage in the two joined dipoles are shown to be equally distributed in magnitude; that they are the same also in direction may be inferred from the presence of radiation.



*Fig 6.2*

It was shown at the start of Chapter 3 that a dipole can in effect be bisected by a conducting plane, each half then becoming a unipole. This can be done equally well with a folded antenna, and enables a more vivid demonstration of the current distribution to be given, using the equipment which was previously demonstrated as a feeder.



*Fig 6.3*

The quarter-wave feeder with lamps in it is set up as in fig 6.3a. Adjustment should be made to the drive matching to equalise the currents in the two limbs as nearly as possible. It will then be found that there is little radiation. The arrangement is a balanced feeder with a short-circuited termination. There is a current maximum at the short-circuit, either side of which the currents flow in opposite directions, so that the radiation is small. A quarter-wavelength back from the termination, at the drive point, the voltage is a maximum.

If now one of the drive terminals is grounded fig 6.3b, the situation completely changes. With zero impedance at the grounded terminal we may expect a high impedance point to exist a quarter-wavelength from it, i.e at the top of the structure, and a quarter-wavelength even further along the conductor is a low impedance, that is at the driven terminal. The change from having the upper lamps lit to lighting the lower ones is quite obvious. The currents in the two vertical limbs are now in the same direction, and this is indicated by the radiation emitted.

The currents will now differ in magnitude. This is because the unbalanced drive causes a current to circulate around the two conductors as if they were simply a  $\frac{\lambda}{4}$  feeder, in addition to the radiating currents which flow in the same direction in each limb. The circulating current can be useful. It is small at resonance but when the frequency is not that of resonance the circulating current becomes reactive in the opposite sense to that in which the radiating current becomes reactive. Thus if the reactive circulating current is made large enough it can cancel out the reactive radiating current very nearly, over a range of frequencies, thus increasing the bandwidth of the antenna. The effect is small in the ASD512 folded unipole; in practice the circulating current is large enough only when the characteristic impedance of the antenna, regarded as a shorted feeder, is low, which is achieved using multiple wires or strip material instead of a single wire for each limb.

### Adjustment of the impedance

The discussion which showed the 4:1 impedance change with a folded element assumed equal cross-section between the basic element and the added element forming the folded configuration. If elements of different diameters are used, different impedance ratios are obtained, and the impedance ratio becomes dependent on the separation between the elements. Practical diameter ratios vary up to about 10:1.

### Applications of folded elements

The folded  $\frac{\lambda}{2}$  dipole is extensively used as the driven element in large parasitic arrays such as are used at VHF. Such arrays not only have low radiation resistance, but also limited bandwidth; the bandwidth is often increased by constructing the folded dipole from strip material so as to reduce the reactance.

Another VHF application is for omnidirectional communication, for which a folded  $\frac{\lambda}{4}$  unipole is often used in conjunction with a few radial elements acting as a ground plane.

### THE SLOT ANTENNA

The antennas so far mentioned have used conductors, thin in comparison with their length, extending in space. The slot antenna is just the opposite; it could be described as a thin space extending in a conductor. Its operation may be understood by starting with a quarter-wavelength of feeder with a short-circuited termination, which is then modified. The  $\frac{\lambda}{4}$  feeder does not radiate (Chapter 2), and with the short-circuit termination presents a high-impedance (demonstrated for instance in Demonstration 9).

Two such feeders may be connected in parallel as indicated in fig 6.4. The terminals will present a high impedance and there will be no radiation. The electric and magnetic fields are concentrated near the conductors as indicated in fig 6.5.

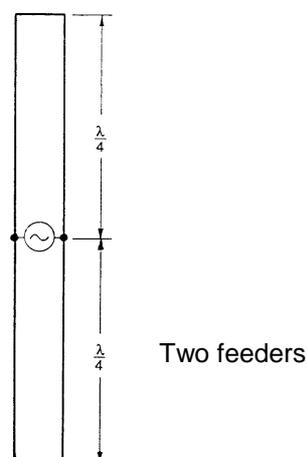
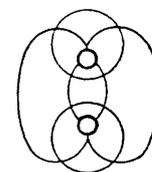


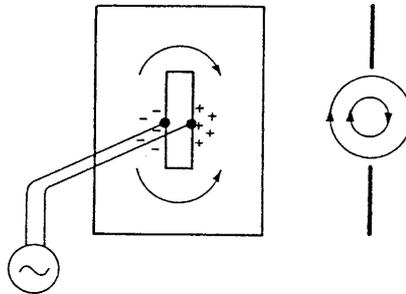
Fig 6.4



Enlarged section of feeder showing electric and magnetic fields.

Fig 6.5

Suppose now that the conductor is increased in cross-section in one plane only, so as to form a large conducting sheet with a slot formed by the original gap between the conductors, fig 6.6.



*Slot antenna with cross-section showing extended magnetic field*

*Fig 6.6*

The RF magnetic field cannot penetrate a conducting sheet, since any slight penetration sets up circulating currents in the sheet which oppose the field. The magnetic field is thus forced to circulate between one end of the slot and the other, and is expanded, causing radiation to take place. The electric field too spreads across the plate and is expanded. Notice that it runs in a direction at right angles to the slot, so that a vertical slot will give horizontally polarised radiation.

The driving point impedance of the two quarter-wave feeders was very high, but with radiation now taking place from the slot the resistance drops to about 500 ohms. When the slot is about a half-wave long the drive point impedance is purely resistive and the slot is resonant.

If the slot is longer it becomes capacitive, unlike a wire antenna which is inductive when longer than the resonant length. If it is short the slot becomes inductive.

There is a simple relationship between the impedance of a slot and the impedance of the dipole formed by cutting in half the strip of metal removed from the slot as in fig 6.7 (shown overleaf).

The formula is:

$$(Z \text{ slot}) (Z \text{ dipole}) = \frac{377^2}{4} \Omega^2$$

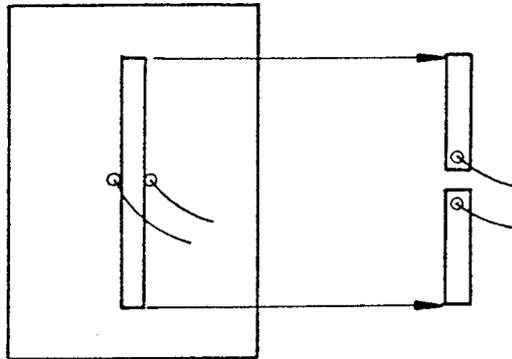


Fig 6.7

Within limits the impedance of a dipole is not affected by the width of the element (although the bandwidth is) thus also within limits the width of the slot has no effect on the driving point impedance.

The polar diagram of a slot in an infinite sheet of metal is shown in fig 6.8a. It is omnidirectional. This is clearly an impractical case and when a finite sheet is used the diagram is modified to fig 6.8b. This is very similar to a dipole.

### Demonstration 10

This is a straightforward demonstration of a vertical slot radiator, giving horizontally polarised radiation. The radiation pattern should be found to correspond with fig 6.8b. The distribution of current indicated in fig 6.6, with a current null at the centre of the slot, and the concentration of electric field near the centre, can be explored using the Voltage and Current Detector.

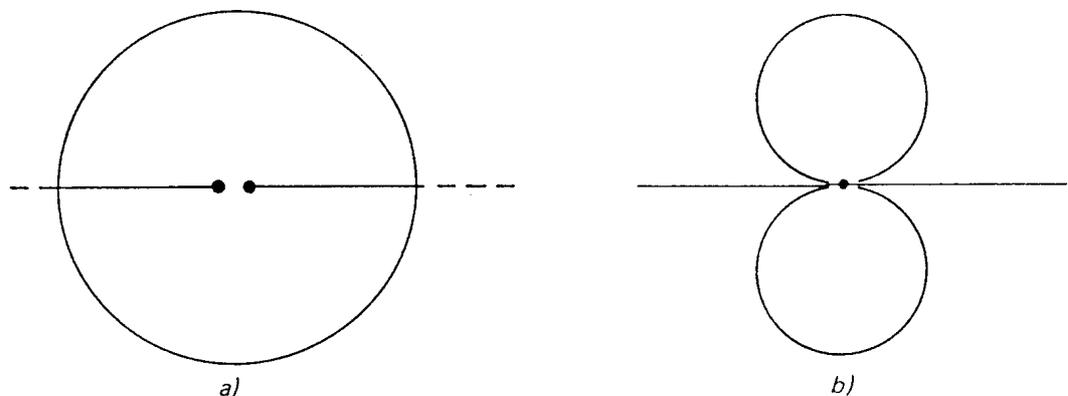


Fig 6.8

**NOTES**

### Cylindrical slot antenna

Various forms of antennas can be made by cutting one or more slots in a cylinder. The development of such antennas can be followed in fig 6.9. The simple slot, fig 6.9a, radiates in two directions. It can be made to concentrate its radiation in one direction only by enclosing one side in a box, fig 6.9b, for which dimensions  $\frac{\lambda}{2}$  parallel to the slot and  $\frac{\lambda}{4}$  in the other directions are suitable. If now the large conducting sheet is made smaller, radiation starts to spread somewhat round to the back; a similar effect is given by a cylinder, fig 6.9c, of about  $\frac{\lambda}{4}$  diameter, giving a heart-shaped polar diagram.

Cylindrical slots are much used in VHF and UHF broadcasting, for which a uniform horizontal spread of radiation is generally required. This can be achieved very nearly by narrowing the cylinder of fig 6.9c to about  $\frac{\lambda}{10}$  in diameter. Reduction of the cylinder diameter causes the slot to be shunted by an inductance, and to bring it back to resonance its length must be increased, which helps to increase the effective radiated power. This does tend to narrow the bandwidth. An alternative way of producing uniform horizontal radiation is to use several slots distributed around a larger cylinder, fig 6.9d. These slots being shorter, the antenna height and therefore its vertical directivity are often restored by stacking slots as in fig 6.9e. The diameter must still be restricted to about  $\frac{\lambda}{4}$  unless special precautions are taken to avoid trouble with resonances occurring inside the cylinder cavity. Fig 6.10 shows horizontal (E-plane) and vertical (H-plane) polar diagrams for a typical stacked cylindrical slot antenna.

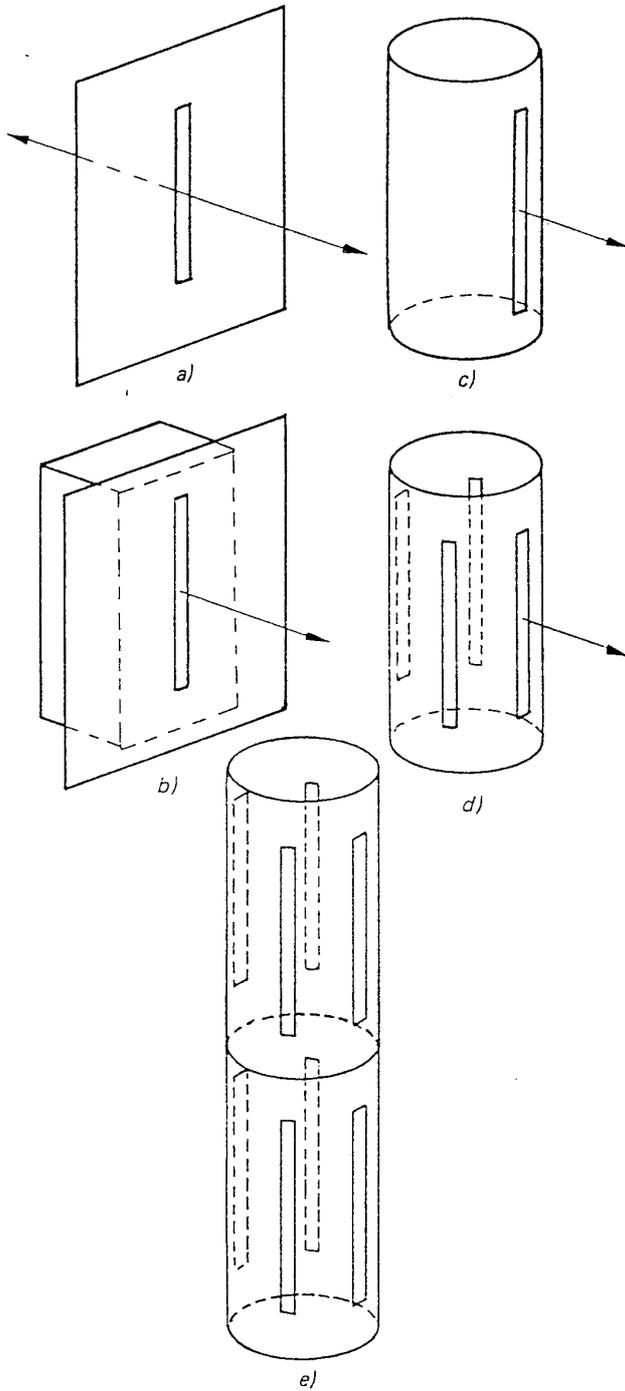


Fig 6.9

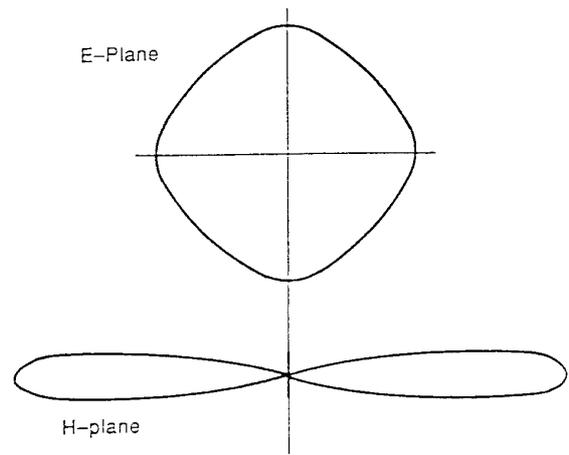


Fig 6.10

### Demonstration of the cylindrical slot antenna

No cylindrical slot antenna is provided within the ASD512 kit. It is not very difficult however to make one following the indications given in Appendix D.

In demonstrating this antenna it will be found that the radiation from the vertical slots is horizontally polarised, as in Demonstration 10. The vertical radiation pattern should be explored. It will be found that the radiation is fairly well concentrated towards the horizontal even though only one tier of slots is used.

### Applications of slot antennas

The stacked cylindrical slot antenna is very convenient for VHF broadcasting, and is easily protected against the weather by enclosing it with perspex windows. Such an arrangement is often mounted at the top of a tower as in fig 6.11.

Slot antennas also find applications in aircraft and the like, in which projecting wires or rods cannot be used for aerodynamic or other reasons. While a slot has the advantage that it does not protrude, it does tend to weaken the metal skin in which it is cut, which is usually stress-bearing. An open slot would also prevent the use of the skin as a pressure vessel, which is required of the fuselage of most aircraft. The slot is therefore usually filled in with high-quality dielectric material providing as nearly as possible the unbroken surface and strength of the unslotted skin. This dielectric material naturally affects the electric field within the slot, and alters its resonant length.

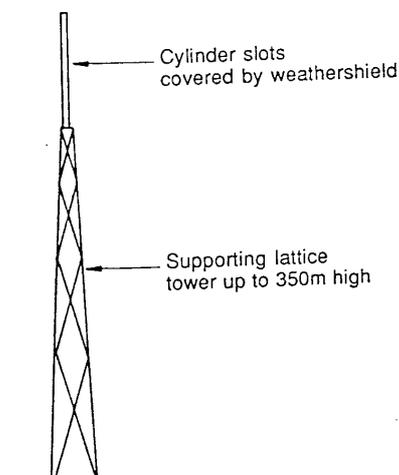


Fig 6.11

## LOOP ANTENNAS

The loop antenna exists in two main forms, both in practical use. They are called the 'small' loop and the 'large' loop, the size being described in relation to the wavelength at which they are operating.

The small loop is essentially a coil which, although small compared with a wavelength is still large enough to link a useful amount of the magnetic flux in any surrounding electromagnetic radiation. It is inefficient, having a very low radiation resistance. It is therefore only used for reception at low radio frequencies when the size of an efficient antenna would be inconvenient. In this application its inefficiency is often unimportant, since signals (wanted and unwanted) and noise are generally so strong at these frequencies that an efficient antenna would bring little advantage.

The transition between a small and a large loop occurs when the perimeter is about  $0.8\lambda$ . For the small loop the current may be regarded as more or less constant all round the loop, but as the perimeter increases a signal applied to one terminal can only travel part way around the loop before the beginning of the next cycle of signal at the terminal. As with feeders and other types of antenna therefore, the current and voltage suffer reversals at approximately quarter-wavelength intervals around the loop.

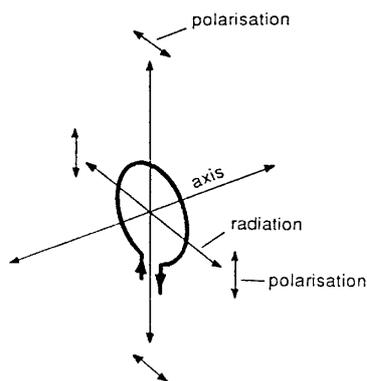
### ***Demonstration 11***

In this demonstration the difference in behaviour between a small and a large loop is clearly demonstrated through the choice of a dimension of long loop which provides contrasts both in the radiation pattern and in the polarisation compared with the small loop.

The small loop, although most useful for receiving, is demonstrated as a transmitting antenna for convenience. Current in the loop causes a magnetic field centred on the line through its centre and normal to its plane, which we may call its axis. Radiation always travels at right angles to both electric and magnetic fields, so that maximum radiation is to be found at right angles to the axis, in the plane of the loop. Furthermore the electric and magnetic fields are always at right angles to one another, so that with the coil axis horizontal, the radiation travelling horizontally must be vertically polarised. Fig 6.12a shows four directions of radiation and the respective polarisations.

The large loop provided for demonstration has the form of a square, each of whose sides is  $\frac{\lambda}{4}$  long. Therefore  $\frac{\lambda}{2}$  away from the drive point there is a short-circuit between the conductors connected to it; the drive point is therefore a current maximum, and so is the farthest point (the top). The corners between are voltage maxima. This situation is shown in fig 6.12b. The electric field extends between the two voltage maxima, so that the polarisation is horizontal, in contrast to the small loop.

Because the current reverses at a voltage maximum, it can be seen that the currents in the top and the bottom of the antenna are in the same directions. The antenna behaves therefore rather like a pair of stacked dipoles driven in the same phase. The maximum radiation is normal to the plane of the loop; again this is the opposite of the small loop case.



Figs 6.12a

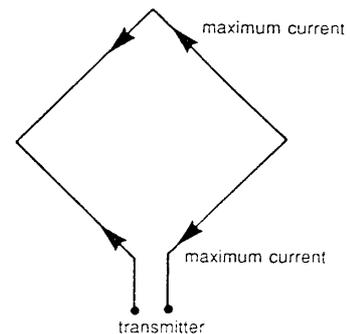
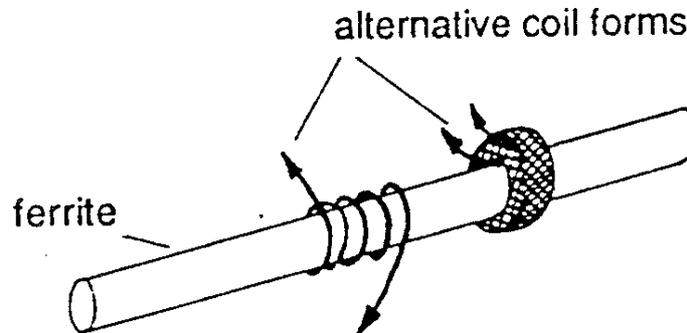


Fig 6.12b

### Practical forms of loop antenna

The small loop for reception at low radio frequencies is usually made with many turns of wire. This increases the induced voltage and also raises the inductance to a value which can be resonated with a practical value of tuning capacitance. A very common variant is the 'ferrite' antenna, fig 6.13. In this antenna a small coil is made to link an amount of magnetic flux which is greatly increased by the presence of the long axial rod of magnetic ferrite material. This rod, by providing an easy path for magnetic flux, causes much more flux to enter the coil than would enter without the rod. Single-layer or multilayer coils may be used as indicated.



*Fig 6.13*

These types of antenna, especially when enclosed within a screen which removes the effect of the electric field, show a null along the axis, which can be used for radio direction finding.

The radiation pattern and polarisation of large loops vary quite considerably as the length is varied. Used for portable television receivers this variation is caused when changing channels, for although the physical size is unchanged, the number of wavelengths varies appreciably as the magnitude of a wavelength changes from channel to channel.

A large square loop antenna with a perimeter of about one wavelength is often referred to as a 'quad' antenna. The quad is used at HF and VHF, providing some increase in gain compared with a simple dipole. It is sometimes combined with parasitic elements also in the form of a loop, tuned to slightly higher or lower frequencies. At VHF quad elements are often combined with simple Yagi elements, forming a hybrid calling a 'quagi'.

## VARIOUS ANTENNA TYPES

## CHAPTER 6

LOG-PERIODIC  
ANTENNAS

It is often necessary to operate on a wide range of frequencies using a single antenna. Antenna systems with a very large bandwidth are required for this application and one of the commonest is the log-periodic array. This consists of a number of dipole elements fed in parallel and varying in length, fig 6.14. The dipoles whose lengths are closest to resonance at the frequency of operation radiate and the effect of adjacent elements in the array is to make it directive.

The gain of a log-periodic antenna is inferior to that of a Yagi tuned for a specific frequency, but the very wide bandwidths possible more than compensate in many applications, and the front-to-back ratio and side-lobe performance can be excellent. Fig 6.15 shows a typical polar diagram.

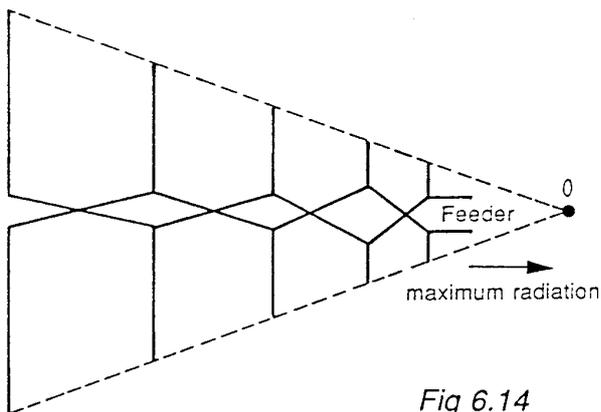


Fig 6.14

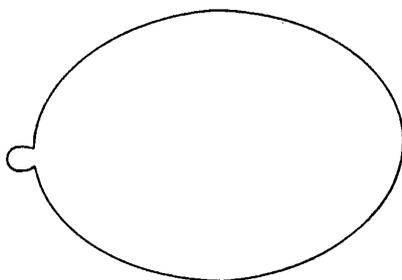
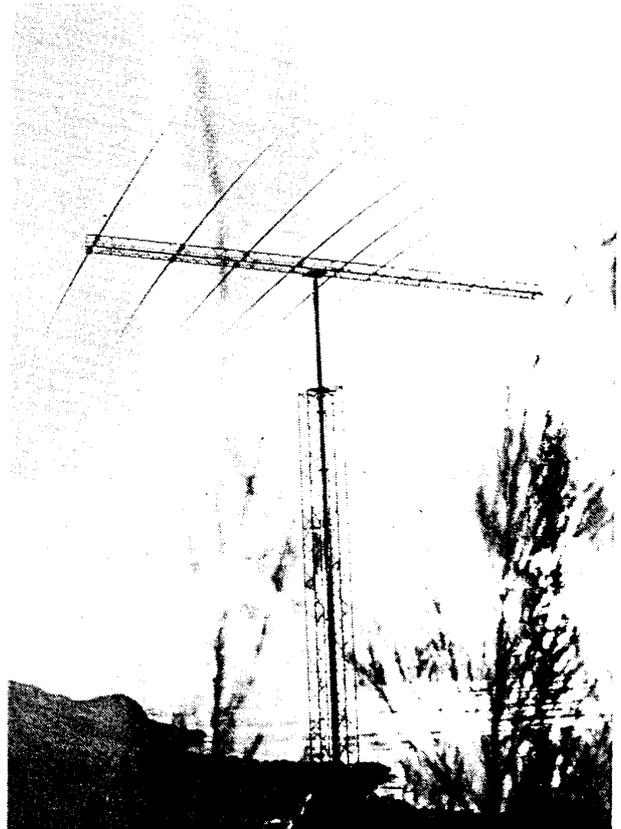


Fig 6.15



*HF rotatable log-period antenna used for long distance point-to-point communication and installed in the Seychelles.  
(Cable and Wireless Ltd)*

The log-periodic antenna finds most of its uses at HF, especially in communications where space is important. Systems are available that will operate from 3-30MHz with only a few side lobes. They are often in evidence at airports and on top of diplomatic missions and embassies.

Notice several features of fig 6.14 carefully. In moving from one element to the next the ratio between the lengths is always the same, and fairly close to 1. The ratio of successive spacings between elements is in the same ratio. The polarity with which dipoles are connected to the feeder alternates.

The elements are all connected to a feeder which runs the length of the antenna. Little power is absorbed from this feeder by elements whose lengths are far removed from resonance. But as the signal reaches elements of near-resonant lengths the element currents increase and power is absorbed. The phases of the currents in successive elements interact to produce quite strongly directed radiation travelling as indicated.

These elements absorb most the available power, so that little is fed to the longer elements at the distant end. The longer and shorter elements do however contribute, as in a Yagi, to a directional effect, so that radiation is fairly strongly directed towards the feeder end of the antenna.

As the frequency is varied the active region moves from one group of elements to the next, and the drive impedance varies cyclically with the logarithm of the frequency. That is why the name 'log-periodic' is given to this type of antenna.

## RHOMBIC ANTENNA

The rhombic is another wide-band antenna. It is much larger than a Yagi for the same frequency, but its combination of wide-band capability with high gain and directivity makes it very useful for long-distance point-to-point work and for broadcasts to specific remote countries.

The basic form of this wide-band antenna is shown in fig 6.16a. It resembles a section of open-wire feeder whose wires have been pulled apart, thus allowing the associated fields to expand and therefore to radiate. Because of the angle of the wires, the wave arriving from the feeder travels towards the far end of the antenna with a speed somewhat less than that of light. Radiation leaving the feeder end of the antenna is thus reinforced by radiation emitted farther along in a direction at a slight angle to the plane of the diagram, but generally in the direction indicated. Not all the energy supplied is radiated, and the remaining energy is absorbed at the far end of the antenna by a terminating resistor of about 600 ohms resistance.

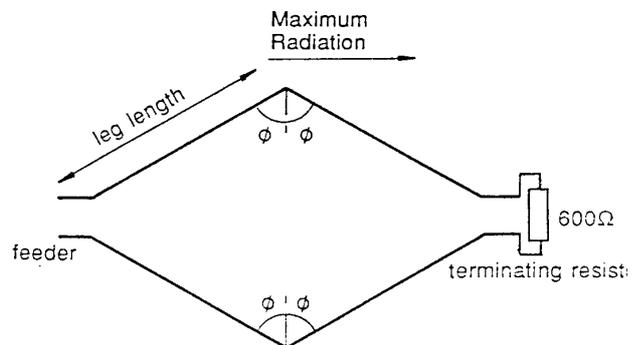


Fig 6.16a Terminated Rhombic

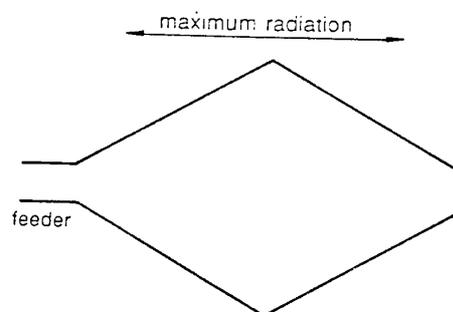
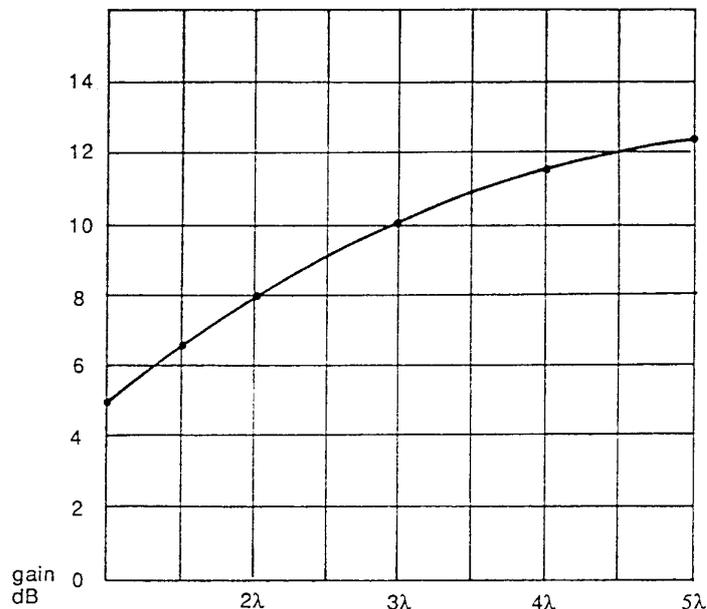


Fig 6.16b Resonant Rhombic

If the terminating resistor is omitted, the energy arriving at the far end is reflected and travels back toward the feeder. This gives rise to radiation in the opposite direction, so that the antenna becomes bidirectional. In this condition the reflected wave arriving at the feeder will upset the drive point impedance; this problem is usually dealt with by tuning the antenna, e.g by making each leg an exact multiple of a wavelength, so that it becomes resonant. This does however limit the range of frequencies for which the antenna can be used unless the matching between feeder and antenna is separately adjusted for each frequency.

The gain is proportional to the leg length and fig 6.17 shows a graph of the forward gain compared with leg length.

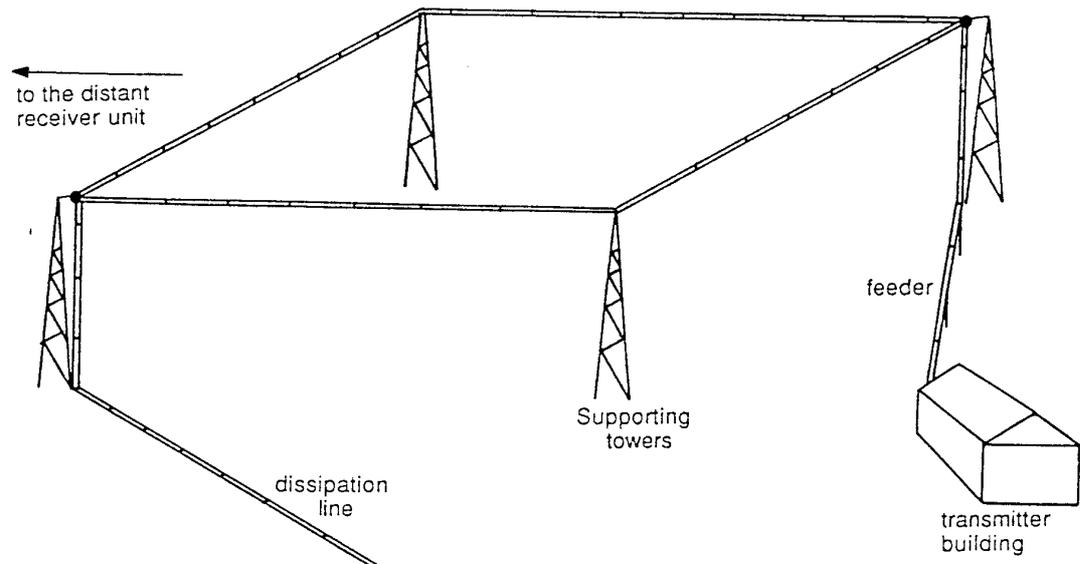


*Fig 6.17*

An important parameter used to describe rhombics is called 'tilt angle'. This is the angle  $\phi$  in fig 6.16. By changing it we can adjust the wave angle of the main lobe, i.e the angle between the direction of maximum radiation and the plane of the rhombic.

When operating a rhombic close to a ground plane, which is almost always the case in practice, the downwards wave is reflected as an upwards wave. The two waves will not reinforce one another if the rhombic is too close to the ground, so the height of the antenna is important. In the usual case where a rhombic is used on a sky-wave transmission path, there is an optimum value of the upward wave angle for each path. The antenna height affects the wave angle and must be adjusted accordingly.

Because of their size it is very difficult to rotate them, unlike say a log-periodic, and they are very directional. A rhombic with sides equal to approximately six wavelengths has a main lobe only a few degrees wide. The already wideband characteristic can be improved by using a multi-wire construction as in fig 6.18.



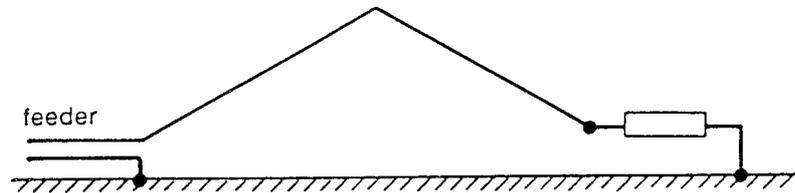
*Fig 6.18*

The termination resistance has to dissipate up to half the transmitter power and remain non-reactive throughout the required frequency range. This is often achieved by using a dissipation line, i.e length of open-ended transmission line made from resistance wire. This has so much loss that the impedance is mainly resistive as the wave reflected from the end is so attenuated that it has little effect.

Further rhombics can be added instead of a terminating resistor thus improving gain, but at the sacrifice of more space. Rhombic antennas are mainly used for HF transmission and reception using sky-wave propagation where a regular use is established for a particular transmission path, but changing propagation conditions demand frequent changes of frequency. Examples are point-to-point communications such as radio-teleprinter signalling for newspapers and long-distance broadcasting.

Another long-wire antenna having somewhat similar properties is the inverted-V, fig 6.19. This in effect forms a rhombic with its image in the ground. It has the advantage of great structural simplicity, since only one supporting mast is required. The

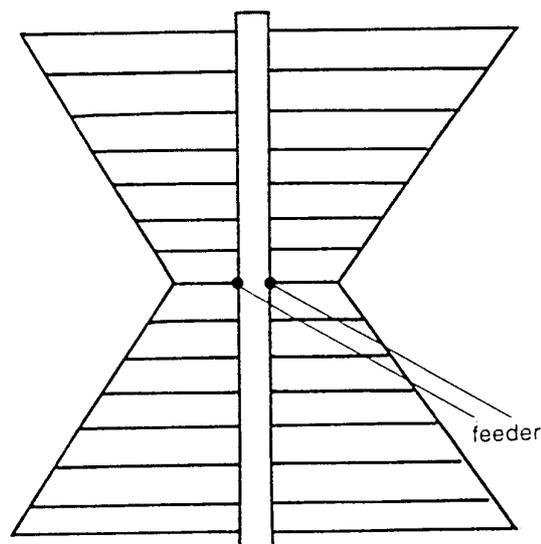
terminating resistance is half that of the equivalent rhombic, i.e. about 300 to 400 ohms.



*Fig 6.19*

### BATWING ANTENNA

As shown in fig 6.20 this antenna can be regarded as a vertical slot in a skeletonised sheet, and it also has some resemblance to a pair of dipoles connected to a single feeder. When it is radiating it behaves similarly to a slot and has a similar drive-point impedance at its design frequency. However, when driven at frequencies away from the design frequency the reactance changes in the slot are largely compensated by opposite reactance changes in the dipoles. If for instance the drive frequency is low, the drive impedance of the slot becomes inductive, while the dipoles tend to become capacitive; the dipoles' capacitive reactance in parallel with the slot inductance tends to maintain resonance over a usefully extended frequency range.



*Fig 6.20*

The radiation pattern of this type of array is in general similar to a standard slot, but the exact pattern can be changed by small dimensional changes to the antenna. Fig 6.21a shows a typical radiation pattern in the E-plane and fig 6.21b shows the H-plane diagram. Antennas of this type are used mainly at VHF where their wide-band characteristics make them very suitable for television transmission. They can be fixed to the side of a vertical tower and several are often used as a stack to increase the directivity in the H-plane.

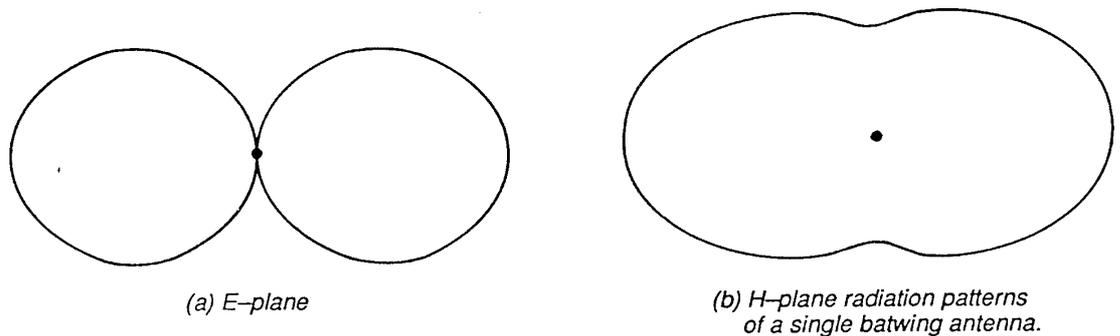


Fig 6.21

## SURFACE REFLECTOR ANTENNAS.

We have seen previously how a large conducting surface (we have usually thought of the ground) near an antenna appears to reflect radiation away from itself. A large metal sheet will likewise tend to direct radiation from itself, i.e behave as a reflector, fig 6.22. The reflector can be bent at an angle to confine the radiation still further and make the antenna more directional. This is called a 'corner reflector', shown in fig 6.23. It could be bent in a parabolic shape as in fig 6.24; this produces a similar pattern. Notice however that both these arrangements only increase the directivity substantially in one plane.

The shape swept out by rotating a parabola about its axis is called a paraboloid. This is the shape of mirrors used for reflecting light in spot lamps and reflecting telescopes.

There is a particular point, called the 'focus', in front of a paraboloid dish, from which every ray striking the dish is reflected parallel to the same direction (the 'axis'). Fig 6.25 illustrates this. If a radiator were concentrated at the focus so that all the radiation came from there, the emerging radiation would all go in the desired direction and the gain of the antenna would be infinite. In practice the radiation cannot all come from one point, but must come from a region comparable with a wavelength in size. However the paraboloid reflector works well

when the diameter of the dish is large compared with the wavelength. This is easily achieved when dealing with light, whose wavelength is in the region of 1nm, but less so at radio wavelengths. It is generally accepted that a paraboloid dish should have a minimum diameter of ten wavelengths for successful operation. Dish antennas are therefore confined to the UHF and microwave region from 20cm down to a few millimetres.

The 'antenna' with the highest gain in the world at present is the 200-inch optical telescope on Mount Palomar in the USA, whose gain is 148dBi. Typically gains for radio dish antennas range from 30 to 45dBi.

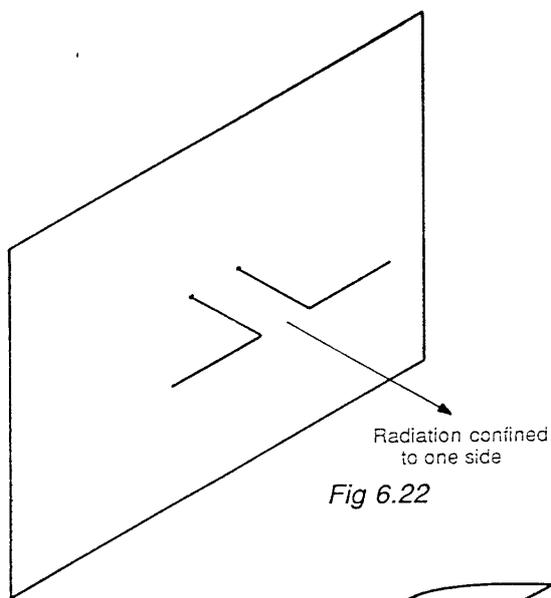


Fig 6.22

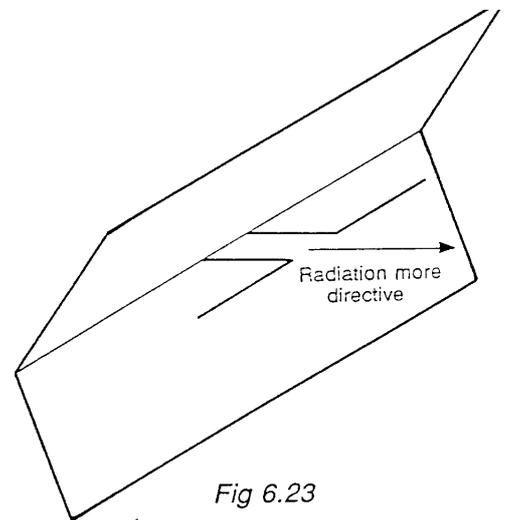


Fig 6.23

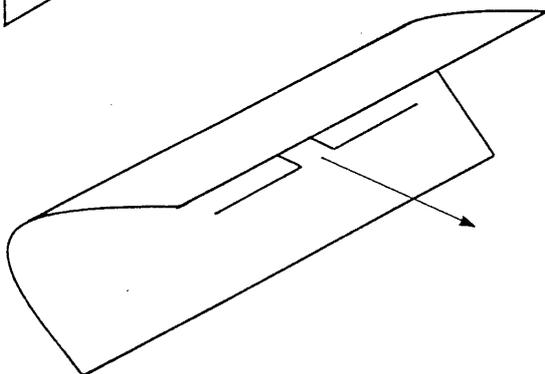


Fig 6.24

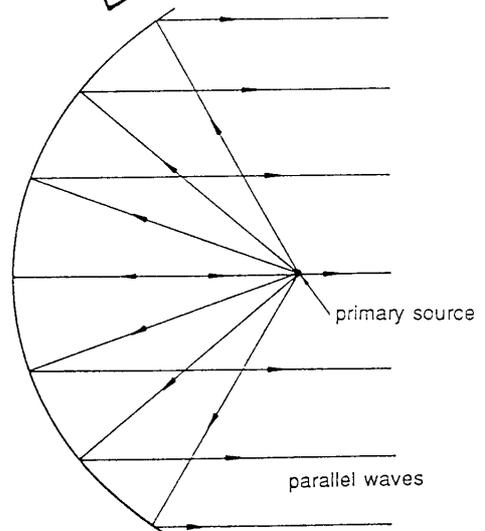


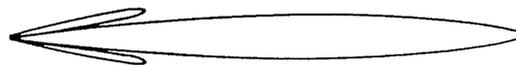
Fig 6.25

There is a theoretical limit to the gain obtainable with a particular size of dish, which may not be realised due to imperfections in it. But the most important factor which reduces the efficiency is poor 'illumination' of the dish. A crucial factor in the design of a dish-type antenna is the prime radiator which launches the radiation into the space between itself and the dish. At the highest frequencies launching will be done by an adaptation of a waveguide feeder system, outside the scope of this book; but it is not unusual for large dish antennas to be illuminated by dipoles, Yagi arrays, or generally by small antennas such as this manual has dealt with. If the illuminating antenna is correctly designed so that a high proportion of its radiation falls on the reflector surface it is not then too difficult to get the reflector right. In practice it is not easy to achieve a better illumination efficiency than 50%. In other words, even a good design wastes half of the launched radiation; clearly design of the launcher is important.

It may be desirable for mechanical reasons to use a mesh instead of a continuous surface for the reflector. A mesh is just as satisfactory if the holes are small, since very little radiation will pass through a hole whose largest dimension is less than  $\frac{\lambda}{10}$ .

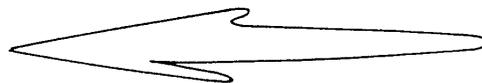
Applications are mainly in high-capacity point-to-point communication links, in satellite links and in radar. The first two of these operate with low power, and satellites also over enormous distances, while radar operates with a large loss of power due to scattering at the target. High gain is thus required in all these cases.

Fig 6.26a and b show typical radiation patterns for a paraboloid dish and you can see how very sharp it is. The gain of the dish was 34dBi.



Paraboloid diameter = 1220 mm = 18.7 wavelengths

*Fig 6.26a*



Paraboloid diameter = 1220 mm = 18.7 wavelengths

*Fig 6.26b*

The sight of dish antennas is becoming increasingly common as the need for high capacity communication increases. Fig 6.27a shows how a dish might be used in a terrestrial microwave link and fig 6.27b shows a typical satellite communications link.

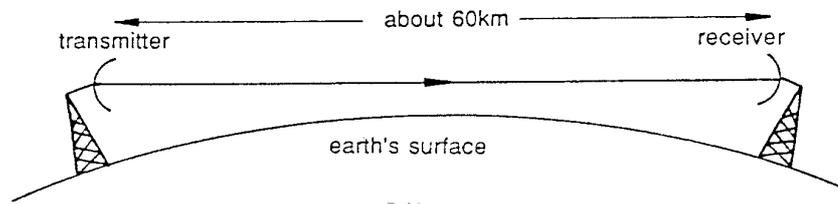


Fig 6.27a .

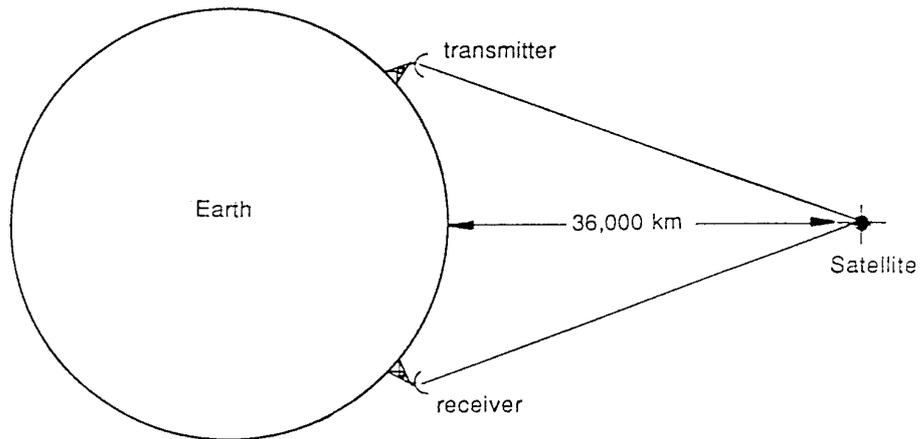


Fig 6.27b



*Parabolic dish antenna for use with geosynchronous communications antenna in the 4 to 6 GHz band. Note the cassegrain feed using a hyperbolic sub-reflector (Cable and Wireless Ltd)*



**SELF-ASSESSMENT QUESTIONS**

**CHAPTER 7**

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**Question 12.**

***A receiving antenna for a distant long-wave station with another station operating on the same frequency from another direction?***

## SELF-ASSESSMENT QUESTIONS

## CHAPTER 7

ANSWERS TO  
QUESTIONS

- Question 1** A 'T' type antenna would be a solution, as a full size antenna would be impracticable at this low frequency.
- Question 2** A two-element phased array with a facility for feeding the second tower either with a phase shift of  $+90^\circ$  or  $-90^\circ$ . If the soil conditions were very bad a larger-than-average ground system would be used to avoid the losses due to ground resistance.
- Question 3.** As the direction is the same and it is a long distance path, a rhombic antenna would be used. The wide-band characteristic would also be useful as a wide range of frequencies are used.
- Question 4** As the directions are different and space is likely to be limited a rotatable log-periodic antenna would be used. The wide band characteristic would also be useful.
- Question 5** A simple wire dipole would be erected very quickly and, as the band-width requirement is small, would work quite well.
- Question 6.** The requirement here is for a tower system with an upwards radiation pattern. A tower of about quarter wavelength gives more upwards radiation than the more common height just over  $\frac{\lambda}{2}$ . The system could have added parasitics to give more gain in a required direction.
- Question 7.** A Yagi antenna would be used with some 10-16 elements as the direction is always fixed. The gain obtained would enable a high ERP to be produced without a high power transmitter. At UHF such a Yagi would be quite small, and thus easy to install.
- Question 8.** A simple dipole, with a single reflector if required, could be used. It could be made from metal tubing or from wire.
- Question 9.** Vertical polarisation is easier to install on trucks and cars and coupled with the need for all-round coverage a vertical ground plane with a radial plane could be used.
- Question 10.** A cylinder slot would be the obvious choice here.
- Question 11.** As the frequency is high and only one direction is required a parabolic dish would be used. The high gain would enable the transmitter power to be very low.

**SELF-ASSESSMENT QUESTIONS****CHAPTER 7**

---

**Question 12.**

As the requirement is for a directional receive-only antenna operating at low frequency, the only solution is a small tuned loop antenna. As the main lobes are quite broad and the nulls quite sharp, the antenna would be orientated so that a null points towards the interfering station.

## LOGPERIOD ANTENNA

## APPENDIX A

It is not possible with a fixed-frequency source of RF to demonstrate directly the wide band-width of the log-periodic antenna, which is its most important feature. Its general mode of operation can be demonstrated however, including the concentration of current into a particular group of elements. If it were constructed with the largest and the smallest elements removable, then the version with the large end removed could be regarded as a scale model of the version with the small end removed, thus changing the scale of the antenna to simulate a change of frequency.

The antenna will be quite large. Some suitable dimensions for a nine-element array are given in the table which follows.

half-length of element y mm	distance between elements x mm
618	198
494	158
395	127
316	101
252	81
202	65
162	52
130	41
103	
total length	823mm

Rather than transpose the feeder as in fig 6.14, it is simpler to have the feeder in one plane (say horizontal) and to erect the half-elements in the plane at right angles (vertical in the example). Construction can then be done by making two assemblies of 3mm tube each as indicated by the full lines in fig A1. They are then placed together as indicated by the broken lines showing the second group of elements. The feeder conductors should ideally be quite close to one another, about 10mm, and may be connected to the Ground Plane of the ASD512 by an open-wire feeder.

LOGPERIOD ANTENNA

APPENDIX A

A cheaper and lighter structure could be made by constructing a wooden frame to surround the antenna and, with a feeder as before, making the elements of wire soldered at one end to the feeder and suspended at the other end by a piece of nylon thread from the frame.

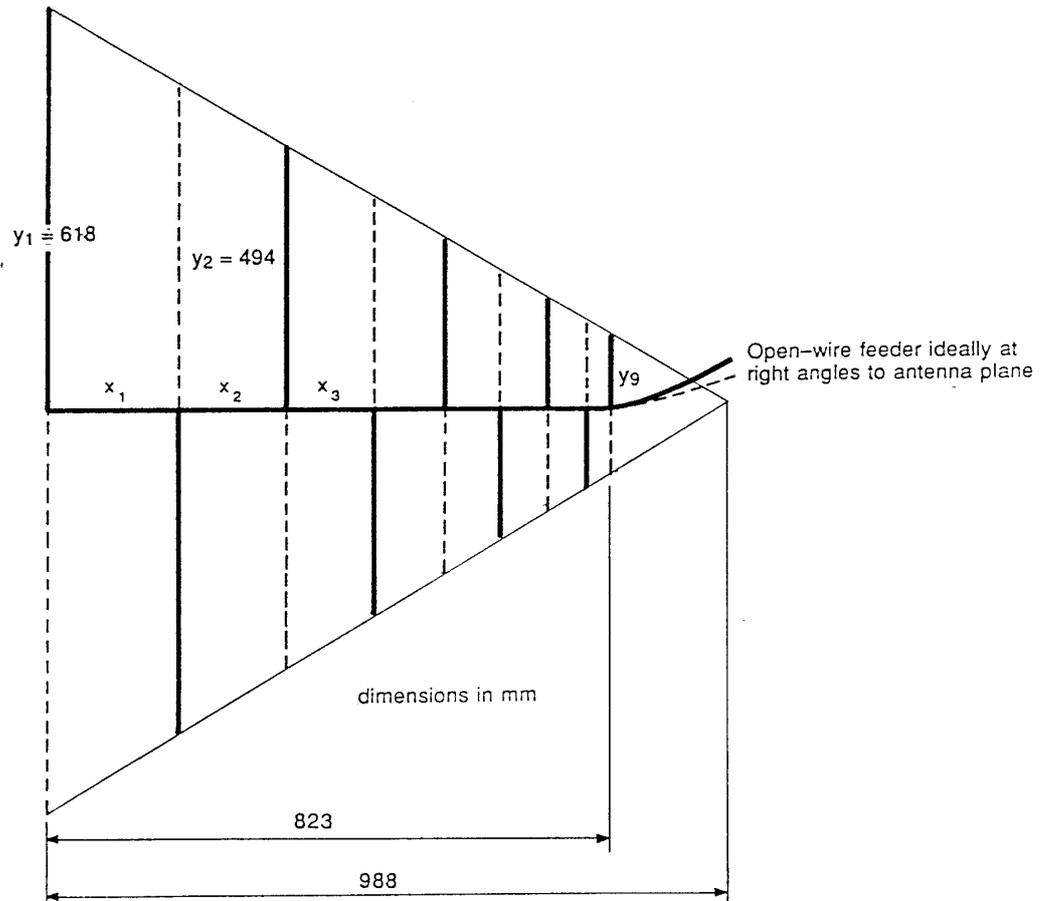


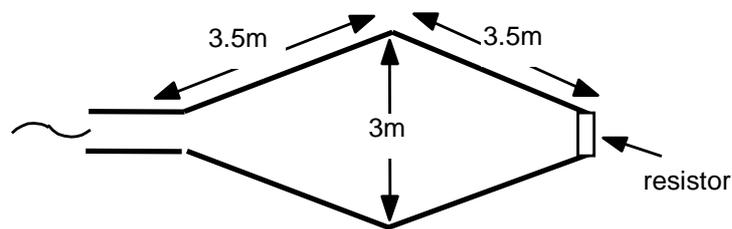
Fig A1

**RHOMBIC ANTENNA****APPENDIX B**

A rhombic antenna for use with the ASD512 would need each leg to be about 3.5m long (i.e two wavelengths, so that plenty of space is required). The antenna may be constructed of wire to the dimensions indicated in the figure (approximately). For the resistive termination the resistor provided in the kit will suffice, although its resistance is less than the optimum value.

The wire should be supported at least half a wavelength (0.9m) above the ground, on low-loss insulators. If these have to be improvised, pieces of polythene are suitable; or for a quick temporary set-up earthenware mugs could be inverted over the support posts and the wire threaded through the handles. Avoid loops in the wire which would contribute inductance.

In testing the antenna do not forget that the nearness of the ground will cause the main lobe to be directed upwards, which may make it difficult to locate; it should be quite well-defined and radiate well however.



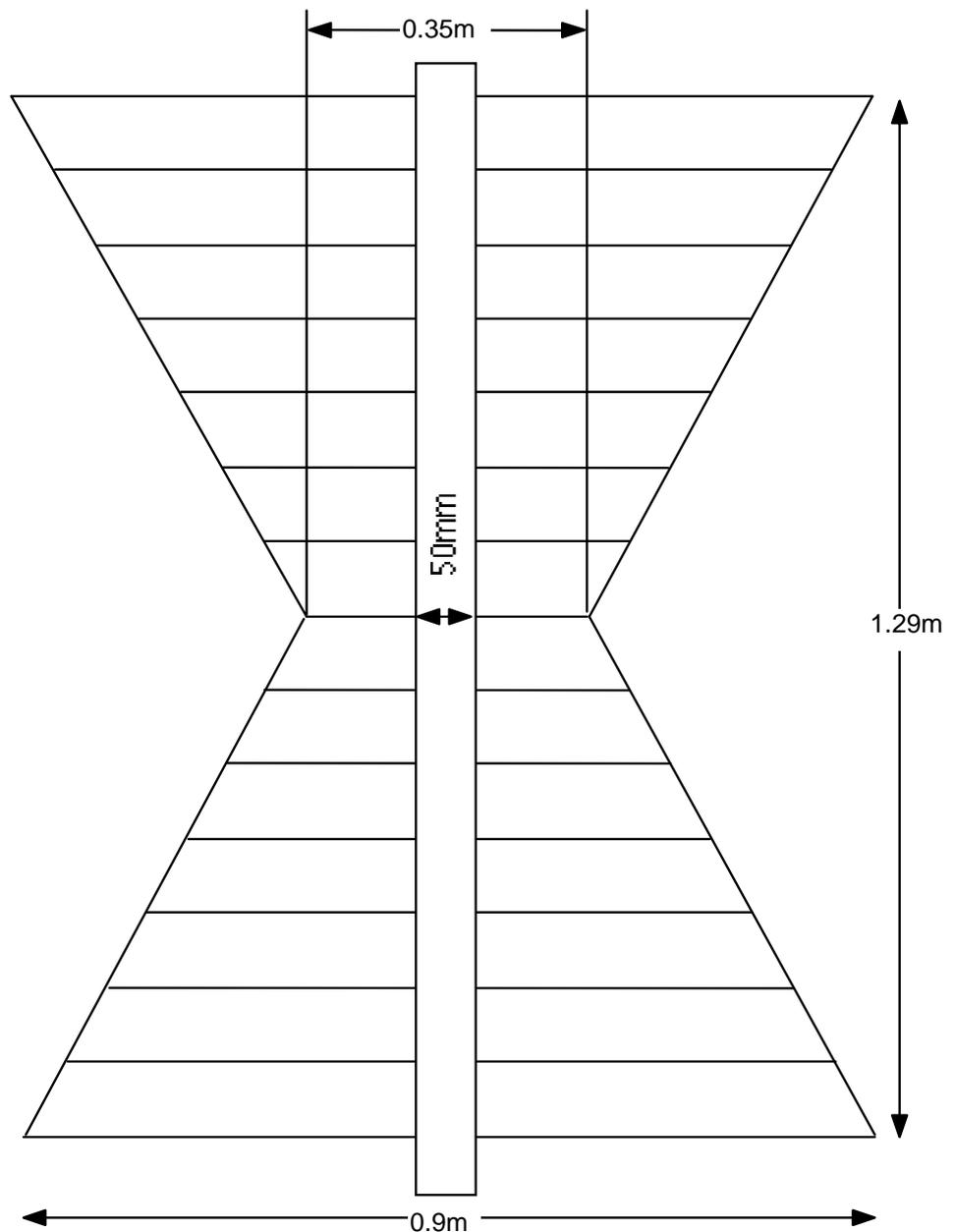
*Fig B1*

**NOTES**

## BATWING ANTENNA

## APPENDIX C

The main advantage of a batwing antenna is its wide bandwidth, which it is not possible to demonstrate using the fixed frequency available from the ASD512. It is possible to demonstrate that it radiates and what its polarisation is. The figure shows dimensions of an antenna which can be made up by soldering brass tube similar to that used for the parts in the kit.

*Fig C1*

**NOTES**

## CYLINDRICAL SLOT-ANTENNA

## APPENDIX D

A cylindrical slot antenna can be made from aluminium sheet bent round into a tube and either bolted or welded together, dimensions suitable for ASD512 being shown in the figure. If for mechanical convenience the join is made at top and bottom of one of the slots and bolted, care is needed to make the electrical connection good, since this is a point of maximum current; a join midway between the slots is less critical. The assembly can be stood directly on the Ground Plane, which avoids increasing the inevitably awkward business of connecting the feeders. Care is necessary to connect these to each slot with the same polarity as viewed when facing the slot, as indicated in the smaller diagram.

It should be found that strong radiation is emitted with horizontal polarisation in all horizontal directions, and that the radiation pattern is strongly directional in the vertical plane.

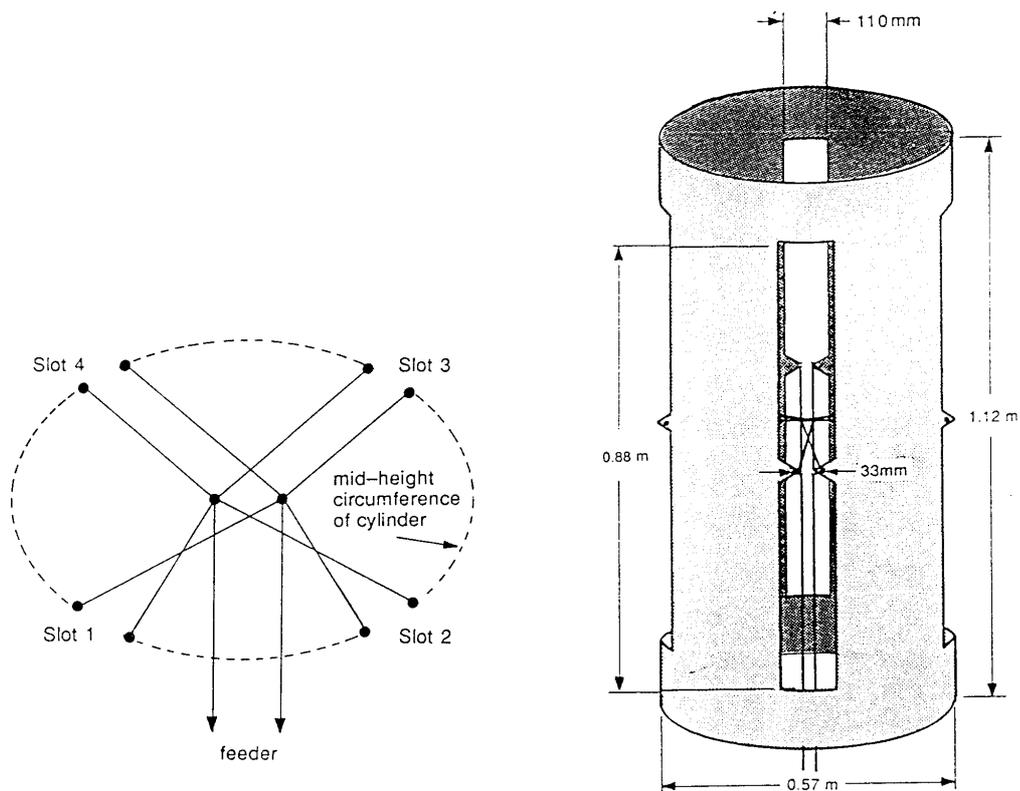


Fig D1

Fig D2

**NOTES**