## 13

# Antenna Basics and Construction

The antenna is the essential link between free space and the transmitter or receiver. As such, it plays an essential part in determining the characteristics of the complete system. The design of the antenna and its working environment will decide its effectiveness in any particular system.

In *Antennas* (2nd ed), John D Kraus defined an antenna as: "A structure that transforms electromagnetic energy contained in a guided wave to that of free-space propagation or vice versa."

## THE ELECTROMAGNETIC WAVE

An electromagnetic wave in free space comprises electric (E) and magnetic (H) components perpendicular to each other. If the x co-ordinate is taken along the line in the direction of wave travel, then the E and H field vectors lie entirely in the yz plane as shown in **Fig 13.1**. The wave front is a plane surface normal to the direction of propagation and is called a transverse electromagnetic wave (TEM).

It can best be envisaged as the surface of a rapidly inflating balloon, otherwise known as a wave front, however, a small area of this expanding surface can be regarded as flat plane at a distance from the source. A TEM wave, in which the electric and magnetic vectors, while varying in magnitude and sign, remain along the same axis in space is said to be polarised, the plane of polarisation (by convention) being that contained in the electric vector, ie the xy plane in **Fig 13.1**.. Polarisation is discussed in more detail later. The wave illustrated in Fig 13.1 travelling in free space is unrestricted in its motion and is known a travelling wave.

### Near and Far-Field Antenna Regions

The TEM wave described above is formed some distance away from the antenna in a region known as the far field. In this region the total electric and magnetic fields are at right-angles to each other and to the direction of propagation, and their respective maxima are phased 90° (one quarter-wavelength) apart as shown in Fig 13.1. In space, the ratio of the E/H fields yields a value of 377 ohms, which is the impedance of free space.

At distances closer to the antenna, the fields become more complex, and there are additional field components directed along the direction of propagation. This is the near field region, in which coupling between the antenna and adjacent conductive structures (power wires, plumbing or other antennas) becomes significantly greater than would apply from illumination by a freely propagating electromagnetic wave. Conductive objects within the near field of an antenna can seriously affect both its radiation pattern and its input impedance. The elements of antenna arrays usually lie within the near field of adjacent elements, and the mutual coupling between them must be taken into account if the best overall gain is to be achieved. Radiation pattern, input impedance and mutual coupling will described later.

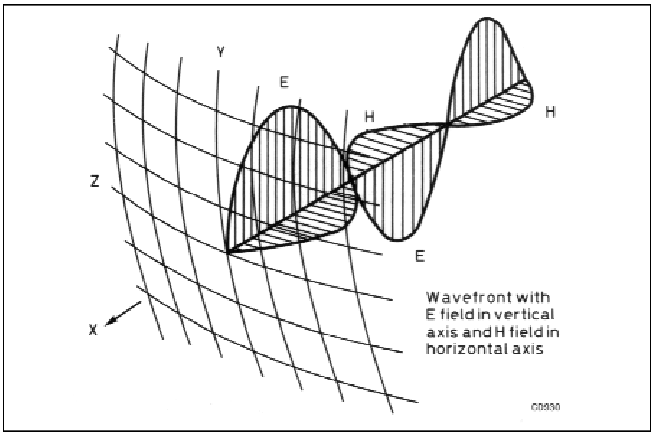
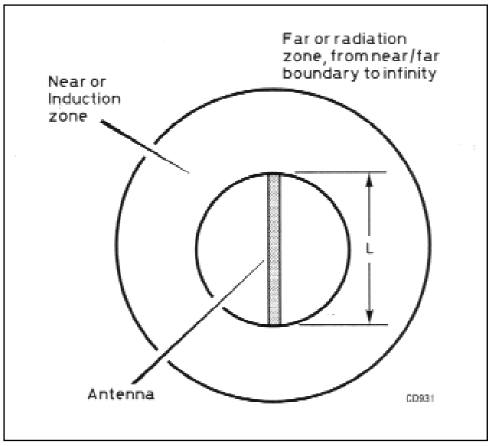


**Fig 13.1: Conceptual diagram of Transverse Electromagnetic (TEM) Wave**

**Fig 13.2: Near and far fields of an antenna**



The approximate near/far field boundary is defined as:

$R=2L^2$/wavelength

Where R is the distance and L is the length of the antenna as illustrated in **Fig 13.2**.

## RESONANCE

If an oscillatory current is passed along a wire, the electric and magnetic fields associated with it can be considered as a wave attached to the wire and travelling along it. If the wire finally terminates in an insulator the wave cannot proceed but is reflected. This reflection is an open-circuit reflection and produces standing-wave fields on the wire. How these standing waves are produced is described in the chapter on Transmission Lines.

**Fig 13.3** shows two typical cases where the wire is of such a length that a number of complete cycles of the standing wave can exist along it. Since the end of the wire is an open-circuit, the current at that point must be zero and the voltage a maximum. Therefore at a point one quarter-wavelength from the end, the current must be a maximum and the voltage will be zero. At positions of current maxima, the current-to-voltage ratio is high

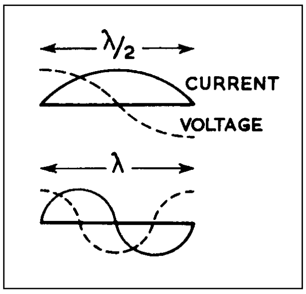


**Fig 13.3: Standing waves on resonant antennas, showing voltage and current variations along the wire at its fundamental resonant frequency and at second harmonic frequency**

and the wire will behave as a low-impedance circuit. At voltage maxima the condition is reversed and the wire will behave as a high-impedance circuit.

A wire carrying a standing wave as illustrated in **Fig 13.3** exhibits similar properties to a resonant circuit and is also an efficient radiator of energy. This is a resonant or standing wave antenna and the majority of the antennas met with in practice are of this general type. The length for true resonance is not quite an exact multiple of the half-wavelength because the effect of radiation causes a slight retardation of the wave on the wire and also because the supporting insulators may introduce a little extra capacitance at the ends. An approximate formula suitable for wire antennas is:

Length (m) = 155(n - 0.05)/f
or
Length (feet) = 485(n - 0.05)/f

Where n is the number of complete half-waves in the antenna and f is the frequency in megahertz.

It must be emphasised that an antenna does not have to be resonant to radiate. Radiation takes place from any elevated wire carrying a radio frequency current; if this wire is terminated in a resistor the wave will be a travelling wave rather than a resonant one. Radiation will always occur unless prevented by screening or cancelled by an opposing field of equal magnitude, as occurs in transmission lines.

## RADIATION RESISTANCE

When power is delivered from the transmitter into the antenna, some small part will be lost as heat, since the material of which the antenna is made will have a finite resistance, and a current flowing in it will dissipate some power. The bulk of the power will usually be radiated and, since power can only be consumed by a resistance, it is convenient to consider the radiated power as dissipated in a fictitious resistance which is called the radiation resistance of the antenna. Using ordinary circuit relations, if a current I is flowing into the radiation resistance R, then a power of $I^2R$ watts is being radiated.

As depicted in Fig 13.3 the RMS current distribution along a resonant antenna or indeed any standing wave antenna is not uniform but is approximately sinusoidal. It is therefore necessary to specify the point of reference for the current when formulating the value of the radiation resistance, and it is usual to assume the point of maximum current.

A halfwave dipole in free space has a radiation resistance of about 73Ω. If it is made of highly conductive material such as copper or aluminium, the loss resistance may be less than one ohm. The conductor loss is thus relatively small and the antenna provides an efficient coupling between the transmitter and free space.

## FEED IMPEDANCE

When the antenna is not a resonant length, it behaves like a resistance in series with a positive (inductive) or negative (capacitive) reactance and requires the addition of an equal but opposing reactance to bring it to resonance, so that it may be effectively supplied with power by the transmitter. The combination of resistance and reactance, which would be measured at the antenna terminals with an impedance meter, is referred to in general terms as the antenna input impedance. This impedance is only a pure resistance when the antenna is at one of its resonant lengths.

**Fig 13.4** shows, by means of equivalent circuits, how the impedance of a dipole varies according to the length in wavelengths. It will be seen that the components of impedance vary over a wide range.

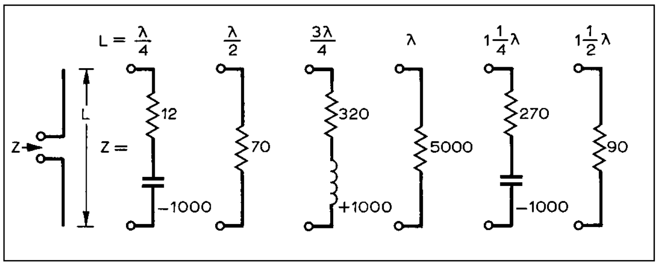


**Fig 13.4: Typical input impedance (Zi) value for dipoles of various lengths**

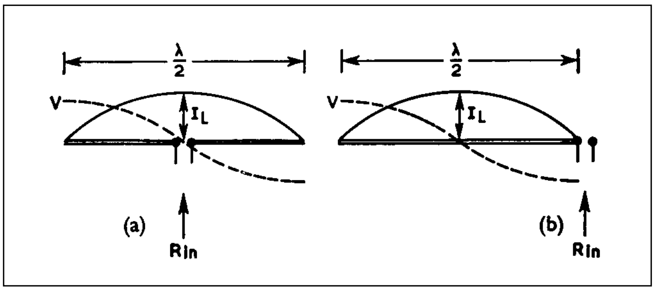


**Fig 13.5: The input resistance (fixed point impedance) of a halfwave dipole is low at (a) and high at (b)**

The input impedance of the antenna is related specifically to the input terminals, whereas the radiation resistance is usually related to the point of current maximum. It is possible to feed power into an antenna at any point along its length so that the input impedance and the point of current maximum even of a resonant antenna may be very different in value, although in this case both are pure resistances. Only when the feed point of the antenna coincides with the position of the current maximum on a single wire will the two be approximately equal, **Fig 13.5(a)**. If the feed point occurs at a position of current minimum and voltage maximum, the input impedance will be very high, but the the point of current maximum remains unaltered **Fig 13.5(b)**. For a given power fed into the antenna, the actual feed-point current measured on an RF ammeter will be very low because the input impedance is high. Such an antenna is described as voltage fed.

Earlier it was stated that a centre fed halfwave dipole in free space has a radiation resistance of about 73Ω. However, the impedance presented at the feed point by an antenna is a complex function of the size and shape of the antenna, the frequency of operation and its environment. The impedance is affected by the proximity of other conducting objects, where the induction of RF currents alters the impedance through mutual coupling between the antenna and object. The elements of a Yagi antenna are mutually coupled together, and the driven element would present a very different impedance if measured in isolation from the rest of the structure.

## RADIATION PATTERNS, DIRECTIVITY AND GAIN

The performance of an antenna can be assessed by its radiation pattern. A VHF base station or repeater usually requires antennas that distribute the signal equally in all directions, whilst a station configured for DX operation will require antennas that focus the energy in one particular direction. Methods of achieving focus of energy are described later.

Such a pattern can be made by energising the antenna with a known level of RF power and then performing a large number of

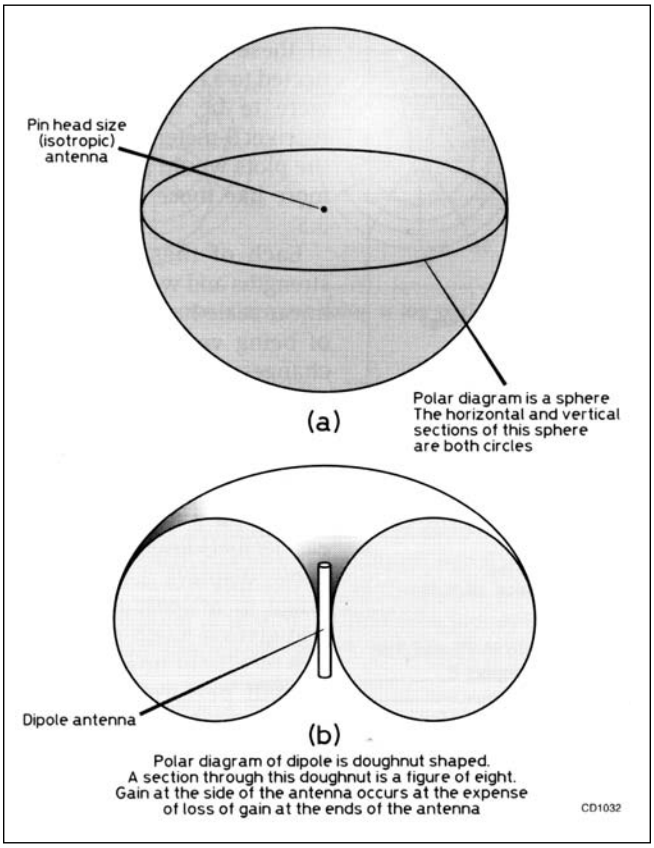


**Fig 13.6: Three-dimensional free-space polar diagrams for (a) an isotropic radiator and (b) a dipole**

field strength measurements at various angles, then plotting the results on a polar graph to produce an azimuth polar diagram. This diagram would then present the relative field strength or power intensity as a radial distance from the centre of the graph at the relevant angle.

The directivity of an antenna is the ratio of maximum radiation intensity to the average intensity. The isotropic antenna, see below, radiates equally in all directions and has directivity of 1, a theoretical minimum. The smaller the three-dimensional beam angle the greater the directivity.

If one antenna system can be made to concentrate more radiation in a certain direction than another antenna for the same total power supplied, it is said to exhibit gain over the other antenna in that direction. The gain of an antenna is a combination of directivity and efficiency when compared with a reference antenna.

If an antenna were minutely small and radiated equally in all three dimensions the overall radiation pattern would be a sphere. Although the construction of such an antenna is not possible it is used as a theoretical entity in antenna mathematical modelling and is known as an isotropic source; it is used as a theoretical reference for measuring antenna gain. Gain or loss relative to an isotropic radiator is stated in dBi. A radiation pattern of an isotropic source is shown in Fig 13.6(a).

The simplest practical form of antenna is the dipole. Although this antenna may be of any length, the word 'dipole' usually implies a half-wavelength long resonant antenna, fed via a balanced feeder at the centre.

The dipole antenna does not radiate equally in all directions because the current along its length is not constant and it produces a three-dimensional doughnut shaped radiation pattern. This pattern and a polar diagram section is shown in Fig 13.6(b).

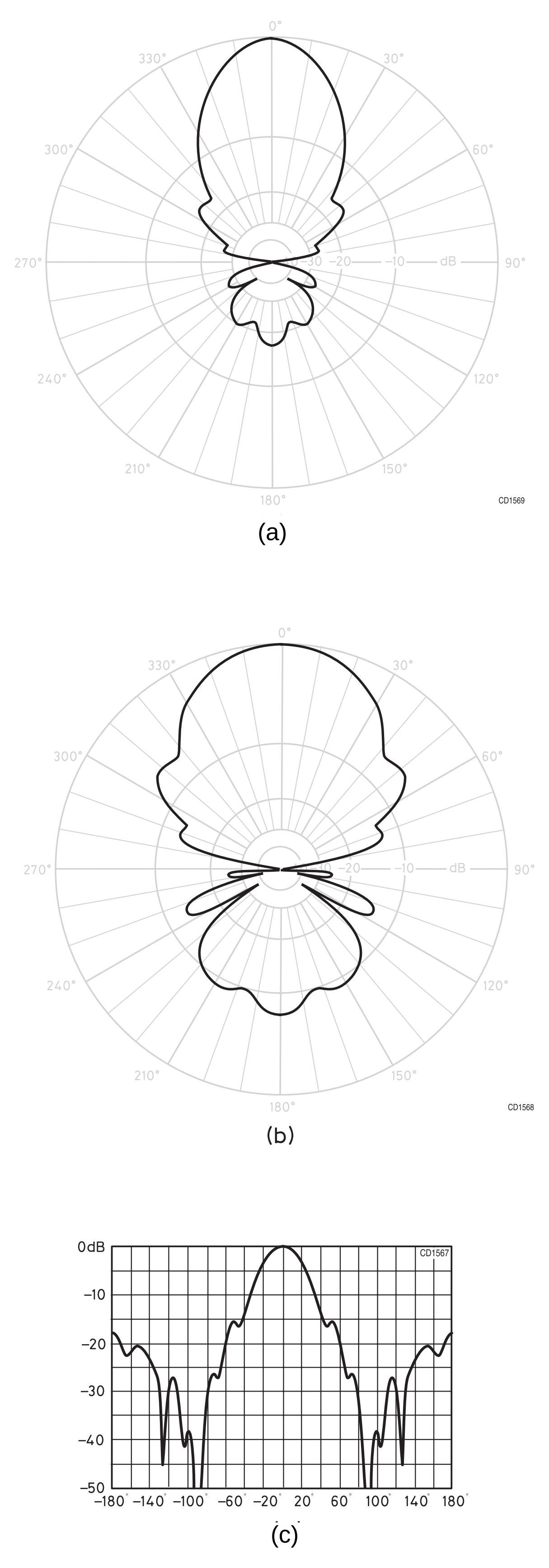


**Fig 13.7: Radiation of a 12-element VHF Yagi antenna using (a) Polar format, ARRL logarithmic decibel scale. (b) Polar format, linear dB scale. (c) Rectangular format, linear dB scale**

Because of its simplicity the dipole itself has become a reference standard and has a power gain of 2.15dbi. Gain figures, using the dipole radiator as a reference, are symbolised dBd.

A practical antenna may have good directivity, but low gain if the antenna has losses through poor design, the use of lossy components or poor mechanical construction. If the antenna were lossless, the gain and directivity would be the same.

Sections through a three-dimensional radiation pattern are normally either vertical (elevation) or horizontal (azimuth). The diagrams so far discussed ignore the effects of ground that could affect the diagram with reflections. Such diagrams are called free space diagrams, and like the isotropic antenna, are theoretical and only used in antenna mathematical models. Radiation patterns that include the effects of ground are described later in Computer Modelling.

Polar diagrams in early antenna literature used polar graphs plotted on a linear scale. This enabled the main lobe beamwidth to be measured but sidelobes were barely visible. The ARRL has promoted the use of a hybrid polar chart, **Fig 13.7(a)**, which combines features of both linear and logarithmic radial scaling in decibels [1], which is used in most amateur radio publications these days. The logarithmically scaled chart, **Fig 13.7(b)**, clearly shows the levels of the sidelobes at the expense of the main lobe.

There is also the more specialised rectangular format, **Fig 13.7(c)**, which uses the linear dB scale. The vertical axis of the rectangular plot represents the relative field strength or power density as a function of the angle shown on the horizontal axis. This presentation is useful for high-gain VHF/UHF antennas as a lack of symmetry can be easily seen, and is often an indication of loss of efficiency or incorrect feeding of multiple-element arrays

The radiation pattern characteristics of directional antennas are usually expressed as the beamwidth in two principal planes at right angles to each other. The beamwidth in these principal planes is usually defined as the angle including the main beam at which the radiated energy falls to one half the maximum level. This is called the half-power beamwidth, and the points on the radiation pattern are often called the 3dB or half-power points of the radiation pattern, being 3dB below the main beam as shown in **Fig 13.8**.

Key features of the radiation patterns of the antenna shown in Fig 13.8 are the main lobe or main beam, and the presence of several sidelobes including one pointing in the opposite direction to the main lobe. The front-to-back or F/B ratio is the ratio of the energy radiated by the peak of the main lobe to that in the opposite direction, and is often used as an estimate of the 'goodness' of a beam antenna. This ratio is usually expressed in decibels. As more power is radiated in minor lobes, less power is available in the main lobe, and the gain of the antenna is reduced.

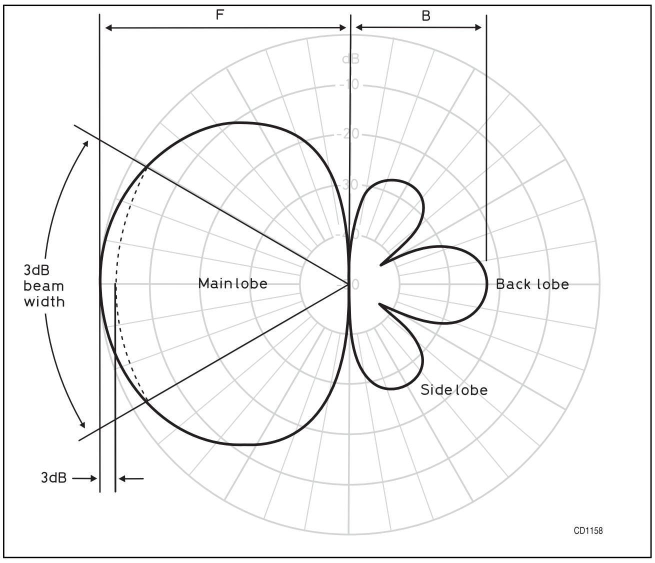


**Fig 13.8: Typical polar diagram of a Yagi antenna**

Whilst gain is usually measured by direct substitution of the antenna under test with a reference antenna, it is possible to estimate the directivity of directional antennas with fair accuracy if the half-power beamwidths can be measured in the principal (E and H) planes of the main beam. If the antenna losses can be assumed to be very small, the gain will be essentially equal to the calculated directivity. Measuring techniques with readily available amateur radio equipment are described in [2].

## POLARISATION

Earlier it was stated that the plane of polarisation was, by convention, contained in the electric component of a TEM wave. A linear dipole generates the electric component of the TEM wave along its axis so this antenna, or linear antenna array, oriented vertically with respect to earth is said to be vertically polarised. The same antenna oriented horizontally is horizontally polarised.

Polarisation is important on paths that don't alter the transmitted polarisation (a line-of-sight VHF/UHF or microwave link, for example). Two such antennas must be co-polarised (polarised in the same direction) in order to communicate; totally cross-polarised antennas theoretically cannot communicate. They are also important when making antenna measurements on an antenna range.

For HF antennas, polarisation is not so important because polarisation is altered when a TEM wave is refracted by the ionosphere.

Satellite users on VHF/UHF often use circular polarisation to reduce the effects of propagation, ground reflections or the spinning motions of the satellites on the signals. The effect of circular polarisation can be visualised as a signal that would be radiated from a dipole that is spinning about its centre at the radiating frequency.

The tip of the electric vector traces out a corkscrew as it propagates away from the antenna and, like a corkscrew, the polarisation is described as right- or left-handed circular, dependent on the direction of rotation of the electric vector as seen from the transmitter. Methods for generating circular polarisation are shown in the chapter on practical VHF/UHF antennas.

A fixed linear dipole will receive an equal signal from a circularly polarised wave whether it is mounted vertically, horizontally or in an intermediate position, if there are no ground reflections.

The signal strength will be 3dB less than if a circularly polarised antenna of the same sense is used; however, a circularly polarised antenna of the opposite sense will receive no signals. Both these effects are due to polarisation mismatch between the wave and the receive antenna.

## BANDWIDTH

There are no unique definitions for antenna bandwidth. Dependent upon the operational requirements of the antenna, the definitions fall into two categories: radiation pattern bandwidth and impedance bandwidth.

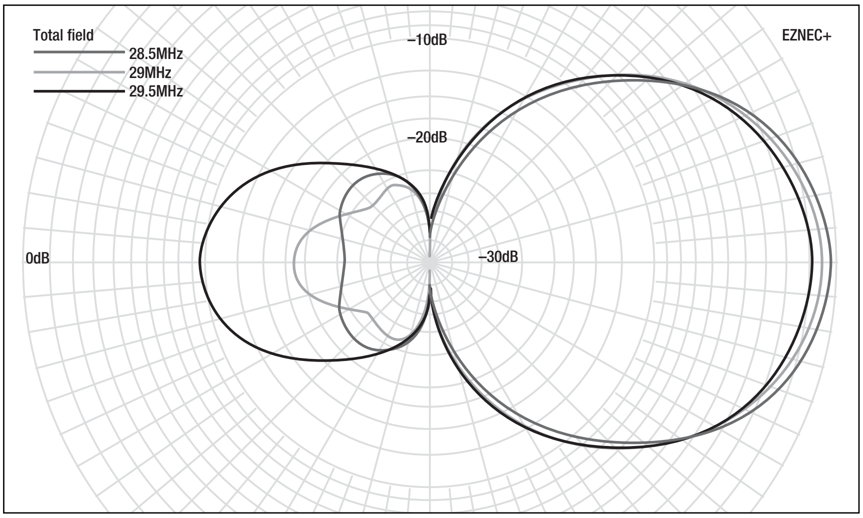


Fig 13.9: Variation in free-space radiation pattern of a three-element Yagi antenna

## Radiation Pattern Bandwidth

Antenna radiation patterns are dependent upon the operating frequency. Their sensitivity to frequency changes are in turn dependent on the degree of tuning or inherent Q required to achieve the desired characteristic. Bandwidth is defined as the frequency range over which satisfactory performance can be obtained.

The criteria for defining bandwidth could be one or more of the following:

- Main lobe beamwidth
- Acceptable sidelobe level
- Minimum gain or directivity
- Polarisation qualities

With the relatively limited frequency range within the amateur bands, the gain normally does not change too radically with frequency, although this is not always the case with very-high-gain VHF/UHF Yagi antennas where the gain and the pattern shape or direction of radiation may be stable over only a very narrow frequency band. An example of this is shown in **Fig 13.9**.

For beam antennas, such as the Yagi, the radiation pattern bandwidth is often defined as the frequency range over which the main lobe gain decreases to 1dB below its maximum value. This is not to be confused with main lobe directivity beamwidth, described earlier

For electromagnetically simple, small antennas (ie when the linear dimensions are of the order of half a wavelength or less) the limiting factor is normally the input impedance.

With circular polarisation antennas the change of the polarisation characteristic with frequency is often the limiting factor. In end-fire linear arrays, collinears and the like, the main lobe direction and shape can change considerably before the gain deteriorates significantly.

For any antenna array or multiply fed antenna, the limiting factors may be determined by the ability of the feed arrangements to maintain the correct current distribution to the antenna elements as the frequency is varied.

Such antennas bandwidths may also be limited by excursions of input impedance, as described below.

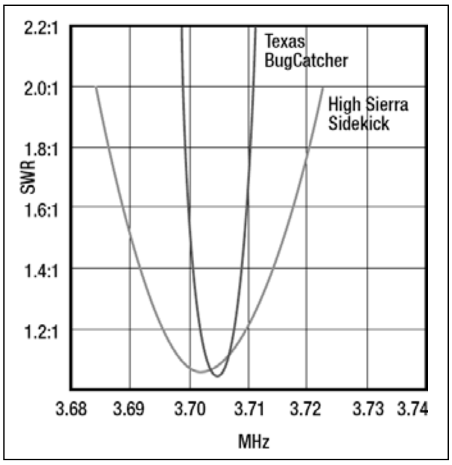


**Fig 13.10: Comparative SWR curves of two commercial antennas. Assuming a SWR limit of 2:1, the Texas Bugcatcher antenna has a bandwidth of 12kHz on 80m**

## Impedance Bandwidth

The impedance bandwidth of an antenna is defined as the frequency range over which the antenna impedance results in a standing wave ratio (SWR) less than some arbitrary limit. This may be typically 1.5:1 or 2:1 for amateur operation with solid-state transmitters, or higher values for other applications. The impedance bandwidth can be very narrow on electrically small antennas such as HF mobile antennas, as shown in **Fig 13.10**.

Ideally, an antenna should be impedance matched to the feedline and thence to the transmitter or receiver. Although tuned feed arrangements are often used at HF, where a high standing wave ratio may be acceptable on the feedline, the losses in VHF feeders and tuning components usually preclude this approach at VHF and UHF.

Impedance bandwidth and radiation pattern bandwidth are independent of each other. It is quite possible for the impedance bandwidth to be greater than the radiation pattern bandwidth, especially with high-gain antennas, and to be able to feed power into an antenna that is then wasted by radiating it in other than the desired direction.

## THE EFFECT OF GROUND

The ground under the antenna acts as a reflector. Electromagnetic waves from the antenna radiate in all directions and some of these waves are reflected by ground. If the reflected wave is in phase, or partially in phase, with a direct wave it enhances radiation and increases gain at a particular angle. Other combinations of reflected and direct waves, whose phases tend to cancel, reduce gain at other angles.

Waves A and C shown in **Fig 13.11** enhance gain while B and C tend to cancel and reduce the gain. This is the cause of the

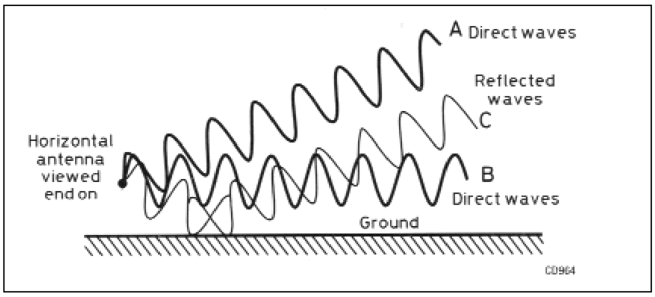


Fig 13.11: The effect of ground reflection on directly radiated waves

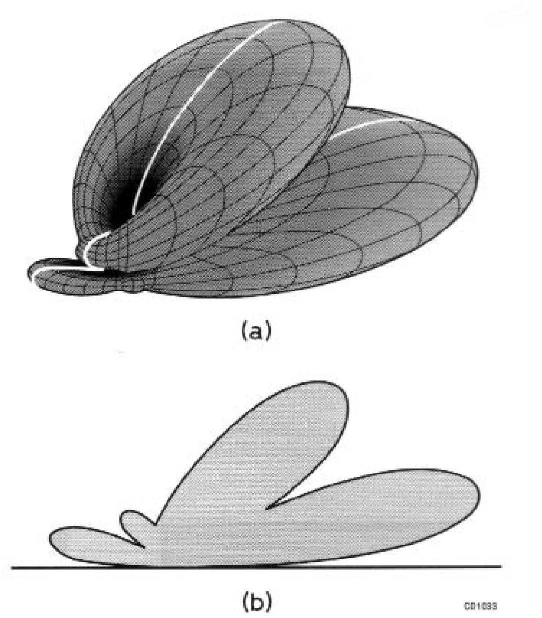


**Fig 13.12: (a) Three-dimensional polar diagram of a three-element beam, showing a vertical section at the angle of maximum radiation. (b) Elevation diagram resulting from this section**

familiar vertical antenna patterns. This aspect is most important and has implications viewing any horizontal polar diagram of a practical antenna. It is also important that ground effects are taken into consideration when setting up equipment on an antenna range.

Consider the three-dimensional polar diagram of a three-element beam in Fig 13.12(a). If we take a vertical or elevation cross section of this diagram it produces the familiar elevation diagram shown in Fig 13.12(b).

Determining the horizontal diagram is not as easy; it can not be plotted through the true horizontal because of the effect of ground (theoretically the radiation strength will be zero in the horizontal plane although this is not the case in practice). The practical solution is to plot the horizontal diagram at the angle of maximum radiation of the main lobe as shown in Fig 13.13.

## ANTENNA MODELLING USING A COMPUTER

Modelling is the technique of evaluating the performance of one object or system by evaluating the performance of a substitute called a model. Models can be physical objects, like a VHF scale model sometimes used to evaluate a HF antenna. Models can also be purely mathematical, like the equations used in circuit analysis. The following discussion describes a mathematical model on your personal computer using readily available software.

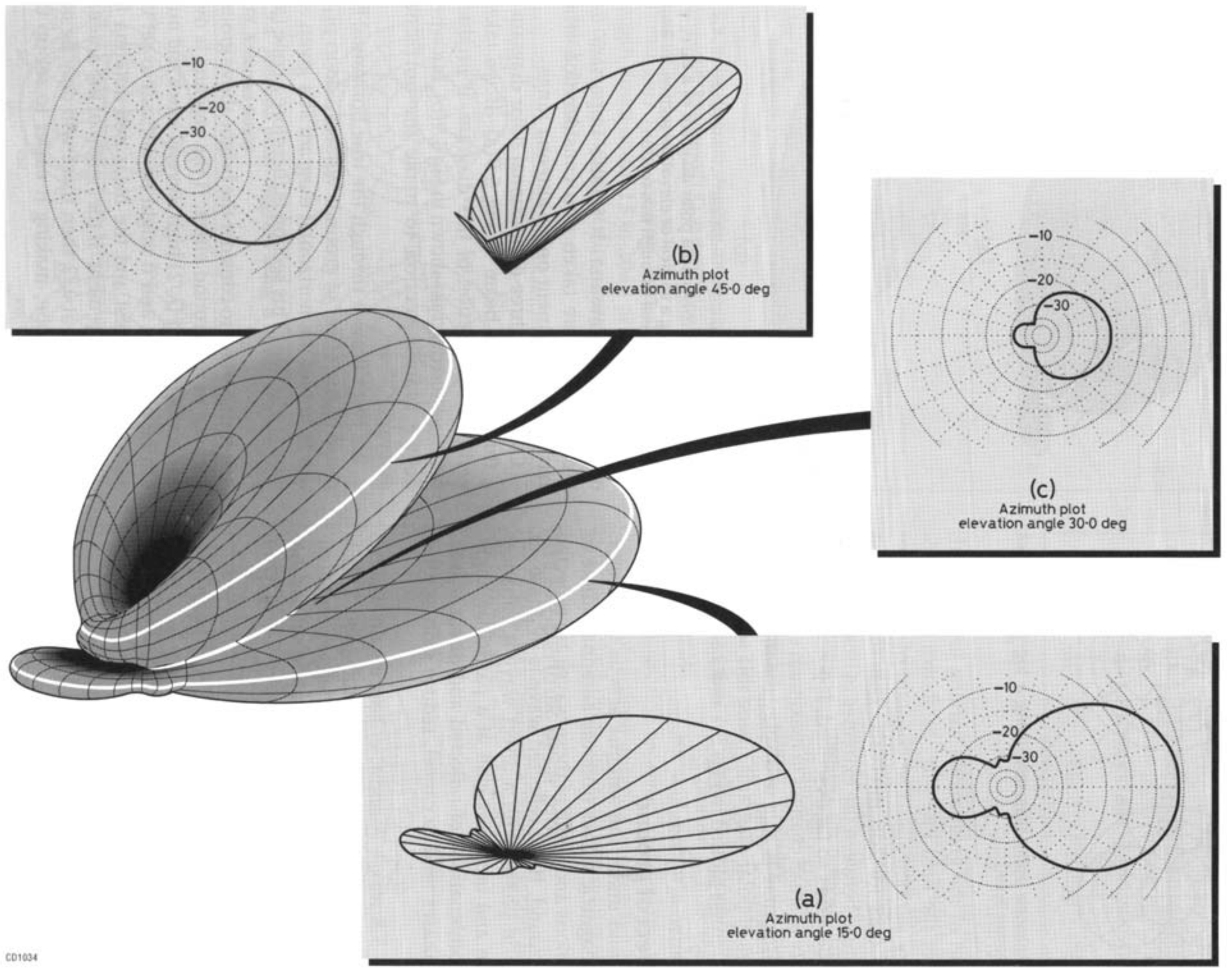


**Fig 13.13: Three-dimensional polar diagram of a three-element beam showing: (a) A horizontal conical section at the angle of maximum radiation. (b) Diagram at the angle of maximum radiation. (c) Diagram at an angle other than that of maximum radiation**

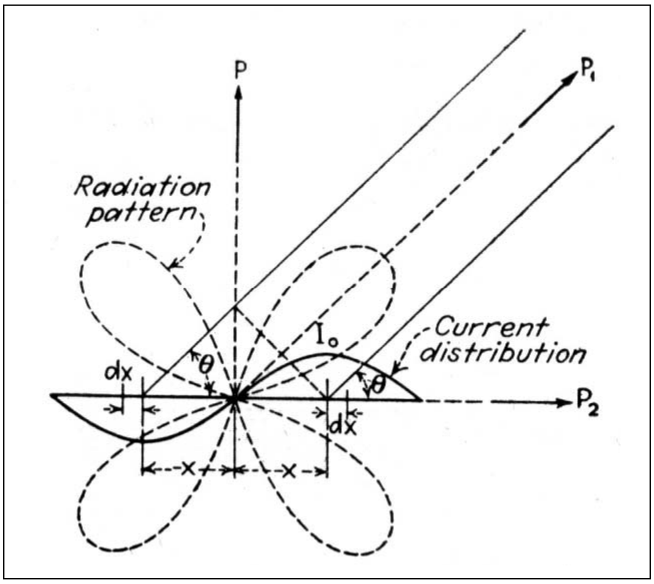


**Fig 13.14: Diagram showing the factors controlling the directional characteristics of an antenna (from [3])**

The essential equations describing the performance of antennas were known in the early 1900s but were complex, consequently early mathematical solutions were only used for limited conditions and special cases.

By the 1930s solutions were available for dipoles with a sinusoidal current distribution at resonance. The diagram shown in **Fig 13.14**, is from [3], which is then followed by a full page of mathematical analysis. This model is limited to the analysis of the directional characteristics of a simple antenna in free space. To model a multi-element antenna with environmental effects is a far more complex and intractable business using normal mathematical methods.

While in the past the mathematical model was impractical for all but limited conditions the situation changed with advent of the computer. It is now possible to evaluate fairly complex antennas with a relatively inexpensive computer and to even question optimistic claims made regarding some antennas. There is a further advantage of modelling an antenna using a computer; with the graphic interfaces provided with these latest programs it provides an excellent means of understanding how an antenna functions, without being bogged down with mathematical detail.

The most commonly encountered programs for antenna analysis are those derived from a program developed at government laboratories in the USA called NEC, short for Numerical Electromagnetics Code [4].

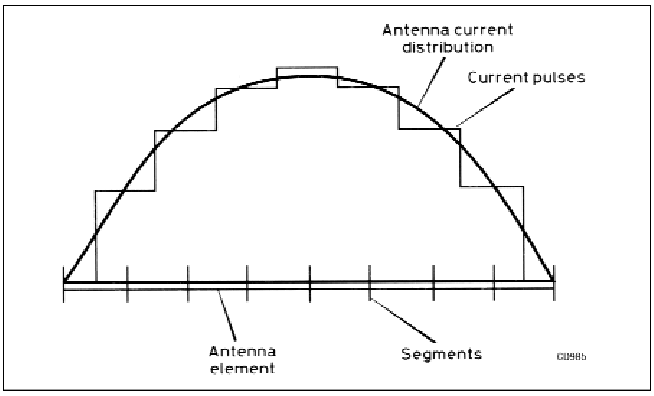


**Fig 13.15: Simplified diagram of the real and modelled current distribution over a half-wave dipole**

NEC uses a Method of Moments (MoM) algorithm, which calculates values at selected points, such as the ends of the antenna and some specified intermediate points. The accumulation of errors at the points not specified can be controlled and is known as its moment. NEC is now in its 4th implementation although most of the antenna analyser programs used by amateurs use NEC2

The first NEC program designed for use with a personal computer was MININEC [5]. Although originally visualised as a cut-down version of NEC a considerable amount of original development went into this program. The authors had to reduce some of the complex mathematical operations to a level that a PC (in the late 1980s) could handle in a reasonable amount of time. A number of compromises were necessary and most of that program's limitations were due to these consciously chosen compromises.

As the complexity of personal computer increased, so have the programs. However, this does not mean that they are more difficult to use; in fact quite the reverse, particularly in the case where adjustment to the antenna geometry can be seen simultaneously in a graphic display when using Windows.

## The Analysis Program

The antenna structure is divided into a number of straight wires and each of these wires are divided into segments. The current in each of the segments of each wire is calculated by assuming a known level of RF power to the antenna.

If we consider the simplest of algorithms and the simplest of antennas, the centre-fed half-wave dipole, the actual current distribution, as modelled by earlier programs, is approximated by segments of constant current. This means that the actual current on the element (which approximates half a sine wave with the current maximum at the centre and zero at the ends as shown in **Fig 13.15**) can be modelled by a series of steps of constant current. It can be seen that the greater the number of segments, the more closely the model will represent the real current distribution. However, the more sophisticated programs now available use a sinusoidal current distribution within the segments. For example the NEC calculating engine assumes that the current has an essentially sinusoidal shape over the length of a segment, and that the currents of adjacent segments match at their junctions. This produces good results with fewer segments.

Once the magnitude and phase of the current is known then the complex impedance for any part of the element can be calculated. The total antenna electromagnetic field pattern can be built up from the magnitude and phases of the currents in the individual segments.

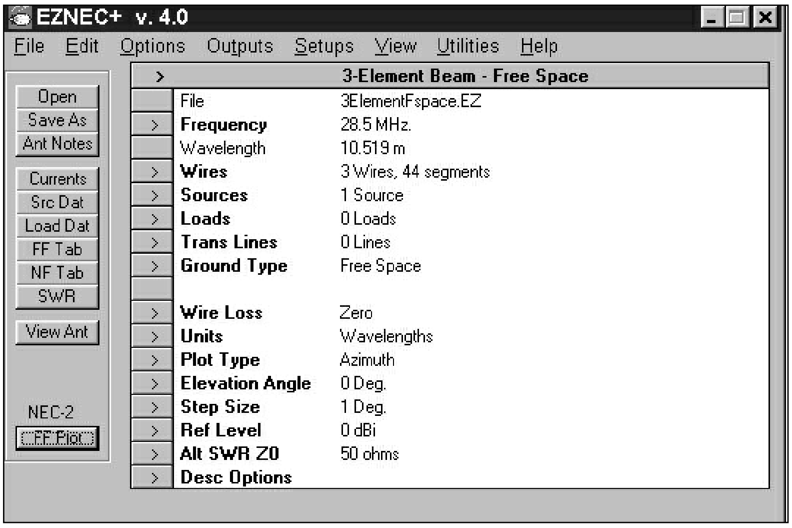
Conversely, current in a conductor segment, located in an electromagnetic field of known intensity, can be calculated from the current amplitudes and phases in these segments.

Calculation of magnitudes and phases of these currents should enable the model, provided that it is sophisticated enough, to represent any antenna configuration or environment. Antenna systems are often made up of more than one element. These additional elements or wires may be excited by direct connection to the wire or element energised by the source, or connected parasitically as in a Yagi.

The radiation pattern and input impedance of an antenna can be calculated, provided that the current distribution on the structure is known. The current distribution on short, thin wires, where the wire radius is a very small fraction of a wavelength approximates to a sinusoid with a minimum at the free end of the wire. However, if the wire is thick, an appreciable fraction of a wavelength long, or close to other conductors, the current distribution deviates considerably from the sinusoidal.

There are several programs for antenna analysis available for the amateur, most of which are based on NEC2. Regardless of which program is used the antenna is modelled in three stages. In the first part the user describes the antenna using a text editor or spreadsheet. Key words and a carefully structured input enable the second part of the program to recognise both the variables and their values. This part of the program computes the antenna performance using the MoM method described earlier.

The third part of the program allows the calculated data to be displayed as an azimuth, elevation or three-dimensional plot to give a graphic representation of antenna performance. Most programs also show a graphic representation of the antenna structure to confirm the model has been constructed correctly. Most models also include sources (the point where the transmitter or feedline is connected to the antenna), loads, transmission lines, and ground media. The accuracy of the model depends on how accurately the actual antenna and its environment can be represented by the model made from these components. Some physical objects, like a physical wire or metallic tube, are easily modelled with high accuracy. Some, like a round loop or small flat metal plate, must be approximated.



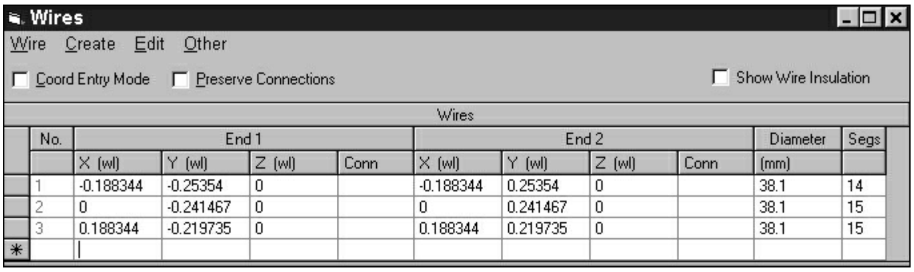
3-Element Beam - Free Space

| | |
|---|---|
| File | 3ElementFspace.EZ |
| **Frequency** | 28.5 MHz. |
| Wavelength | 10.519 m |
| **Wires** | 3 Wires, 44 segments |
| **Sources** | 1 Source |
| **Loads** | 0 Loads |
| **Trans Lines** | 0 Lines |
| **Ground Type** | Free Space |
| **Wire Loss** | Zero |
| **Units** | Wavelengths |
| **Plot Type** | Azimuth |
| **Elevation Angle** | 0 Deg. |
| **Step Size** | 1 Deg. |
| **Ref Level** | 0 dBi |
| **Alt SWR Z0** | 50 ohms |
| **Desc Options** | |

**FIg 13.16: The Control Centre Information window in EZNEC, from which all other screens are accessed**

## The EZNEC Program

To give some idea of the scope of available programs the antenna analysis software, EZNEC, written by Roy Lewallen, W7EL [6] is shown here as an example. It was originally available in the early 1990s as ELNEC, a DOS based program and has gone through many revisions to EZNEC+ v.4.0, now described. This description is necessarily brief - the on-disk user manual that comes with this program runs to 146 pages. In spite of its complexity the EZNEC program is one of the easiest to use if you are new to antenna modelling using a computer. This ease of use is achieved using a Control Centre Information Window, shown in **Fig 13.16**, from which all other screens are accessed.



Wires

| No. | End 1 | | | | End 2 | | | | Diameter | Segs |
|---|---|---|---|---|---|---|---|---|---|---|
| | X (wl) | Y (wl) | Z (wl) | Conn | X (wl) | Y (wl) | Z (wl) | Conn | (mm) | |
| 1 | -0.188344 | -0.25354 | 0 | | -0.188344 | 0.25354 | 0 | | 38.1 | 14 |
| 2 | 0 | -0.241467 | 0 | | 0 | 0.241467 | 0 | | 38.1 | 15 |
| 3 | 0.188344 | -0.219735 | 0 | | 0.188344 | 0.219735 | 0 | | 38.1 | 15 |
| * | | | | | | | | | | |

**Fig 13.17: The EZNEC Wires Window Spreadsheet display showing a model of a 3-element Yagi. The Z co-ordinate is zero because this is a free-space model. The unit of measurement specified is wavelength**

### Building the model

From this Control Centre the important WIRES spreadsheet type screen, shown in **Fig 13.17**, is used to build the model. This is the place where the basic structure of the antenna is defined.

The antenna is modelled as a set of straight conductors called 'wires', the ends of which are specified in space using X, Y and Z co-ordinates. X and Y are in the horizontal plane and Z is height. Wires are defined by specifying their end coordinates in the appropriate grid cells. The unit of measurement can be in metres, millimetres, feet, inches or wavelength. A useful feature is that the units are automatically converted when a different unit is selected.

You will notice that in the model of the 3-element Yagi, shown in Fig 13.17 the Z co-ordinate is zero. This is because this is a free-space model; the reason for using free-space models was discussed earlier in the chapter.

The number of segments is also entered using the Wires Window. As described earlier, each wire is divided into segments for analysis purposes. Some skill in modelling is required in choosing the number of segments although EZNEC has an automatic segmentation feature, which is useful particularly for newcomers to antenna modelling with a computer.

A three-dimensional view of the antenna geometry, see **Fig 13.18**, can be seen by selecting View Ant in the Control Centre Information Window. Also shown are the X, Y and Z co-ordinates and the segmentation. The antenna can also be rotated and viewed from any angle, and scaled in size.

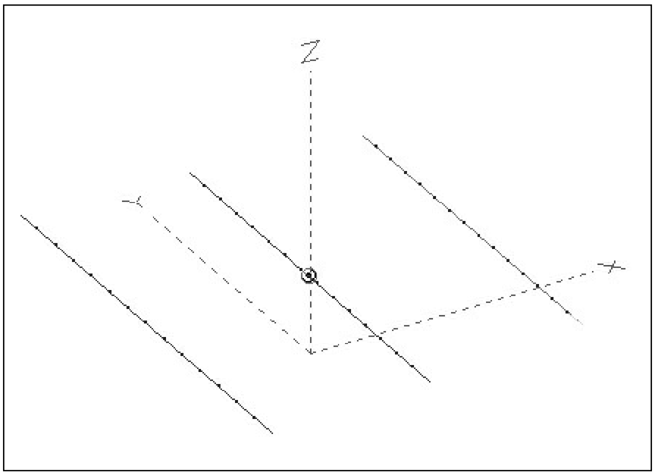
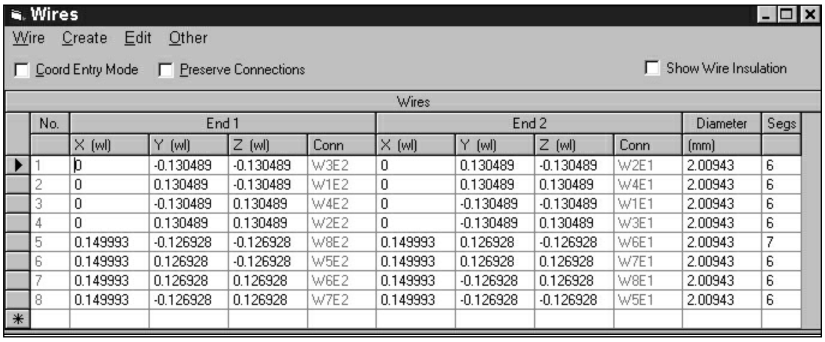


**Fig 13.18: A three-dimensional view of the 3-element beam modelled in Fig 13.17. The feedpoint (source) is shown as a small circle**



☐ Coord Entry Mode ☐ Preserve Connections ☐ Show Wire Insulation

Wires

| No. | End 1 | | | | End 2 | | | | Diameter | Segs |
|---|---|---|---|---|---|---|---|---|---|---|
| | X (wl) | Y (wl) | Z (wl) | Conn | X (wl) | Y (wl) | Z (wl) | Conn | (mm) | |
| 1 | 0 | -0.130489 | -0.130489 | W3E2 | 0 | 0.130489 | -0.130489 | W2E1 | 2.00943 | 6 |
| 2 | 0 | 0.130489 | -0.130489 | W1E2 | 0 | 0.130489 | 0.130489 | W4E1 | 2.00943 | 6 |
| 3 | 0 | -0.130489 | 0.130489 | W4E2 | 0 | -0.130489 | -0.130489 | W1E1 | 2.00943 | 6 |
| 4 | 0 | 0.130489 | 0.130489 | W2E2 | 0 | -0.130489 | 0.130489 | W3E1 | 2.00943 | 6 |
| 5 | 0.149993 | -0.126928 | -0.126928 | W8E2 | 0.149993 | 0.126928 | -0.126928 | W6E1 | 2.00943 | 7 |
| 6 | 0.149993 | 0.126928 | -0.126928 | W5E2 | 0.149993 | 0.126928 | 0.126928 | W7E1 | 2.00943 | 6 |
| 7 | 0.149993 | 0.126928 | 0.126928 | W6E2 | 0.149993 | -0.126928 | 0.126928 | W8E1 | 2.00943 | 6 |
| 8 | 0.149993 | -0.126928 | 0.126928 | W7E2 | 0.149993 | -0.126928 | -0.126928 | W5E1 | 2.00943 | 6 |
| * | | | | | | | | | | |

**Fig 13.19: The EZNEC Wires Window Spreadsheet display, showing the construction of a 2-element quad. Although this is a free-space model, Z co-ordinates are required to model the three-dimensional structure. The specified unit of measurement is wavelength**

As mentioned earlier the antenna can only be modelled as a straight conductor. A bent wire is modelled by connecting two or more straight wires. Wires are considered to be connected when their ends share the same XYZ co-ordinates.

For example, each loop of a cubical quad antenna is described by four separate wires whose end points lie at four points as shown in **Fig 13.19**. A two-element quad, is thus modelled by eight wires, even though a real quad antenna actually has only two continuous wires strung around the spreaders. The quad structure is shown in **Fig 13.20**.

Overlapping wires aren't automatically connected by the program. For example, four wires are required to model an X-shaped structure if the conductors are connected at the centre of the X. A Yagi element composed of tapered sections of telescoping tubing may be modelled by using several connected wires having different diameters.

## Plotting

Once the antenna model is built, its performance can be calculated by selecting FFPlot in the Control Centre Information Window.

The field strength diagrams can be plotted as azimuth, elevation or three-dimensional patterns and are plotted in polar coordinates. These are plotted in the ARRL log periodic scale, described earlier in this chapter. An example of an azimuth plot of the 3-element beam is shown in **Fig 13.21**, which shows the forward gain, front-to-back ratio, maximum sidelobe level and directivity beamwidth. The plots can be saved and viewed later without redoing the analysis.

At his stage, after the impedance values have been calculated, the View Antenna window (Fig 13.16) is modified to show the current distribution, as shown in **Fig 13.22**. Wire currents are displayed directly in relation to the wires in their true physical context, the greater the distance of the current trace from the element, the greater the relative current magnitude.

If the current phase is required then the current trace is displayed at an angle relative to the wire axis to represent phase. This aspect can be seen more easily when the antenna model is rotated to view the elements end-on so that the phase and amplitude of the currents can be seen.

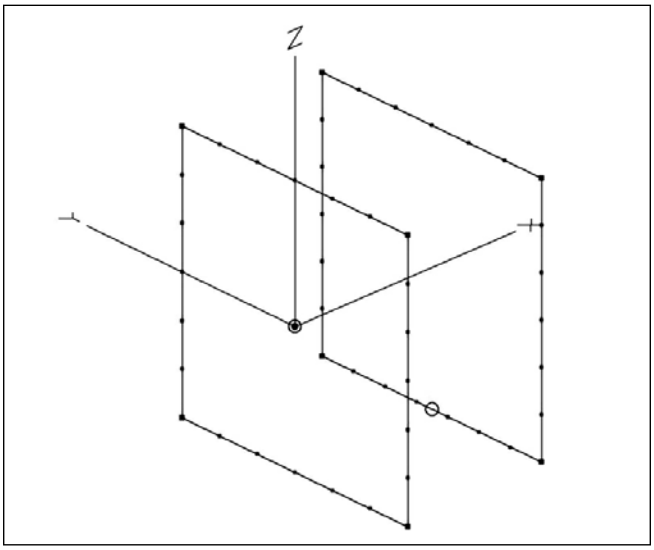
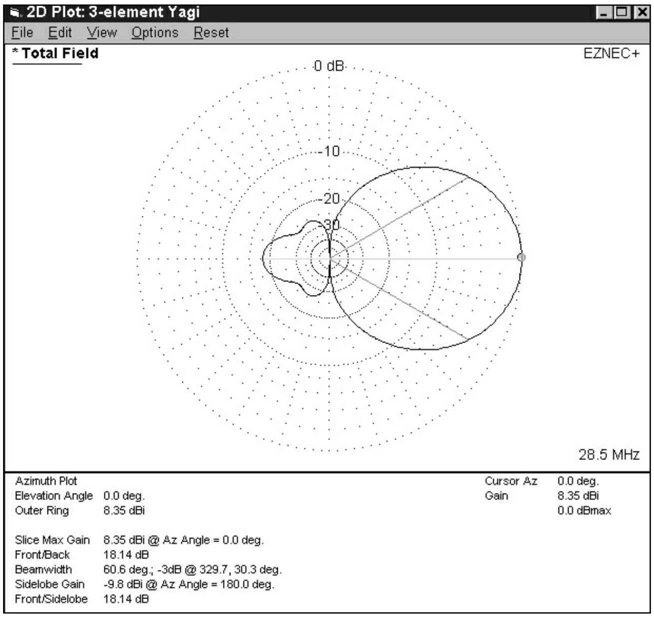


**Fig 13.20: The three-dimensional view of a 2-element quad antenna showing the X, Y and Z axes. The dots at the corners of the loop are connection points. The dots along the wires are**



```
Azimuth Plot                                                        Cursor Az    0.0 deg.
Elevation Angle   0.0 deg.                                          Gain         8.35 dBi
Outer Ring        8.35 dBi                                                       0.0 dBmax

Slice Max Gain    8.35 dBi @ Az Angle = 0.0 deg.
Front/Back        18.14 dB
Beamwidth         60.6 deg.; -3dB @ 329.7, 30.3 deg.
Sidelobe Gain     -9.8 dBi @ Az Angle = 180.0 deg.
Front/Sidelobe    18.14 dB
```

**Fig 13.21: An example of an azimuth plot of the 3-element Yagi. The forward gain, front-to-back ratio, maximum sidelobe level and main lobe directivity beamwidth is shown in the data box**

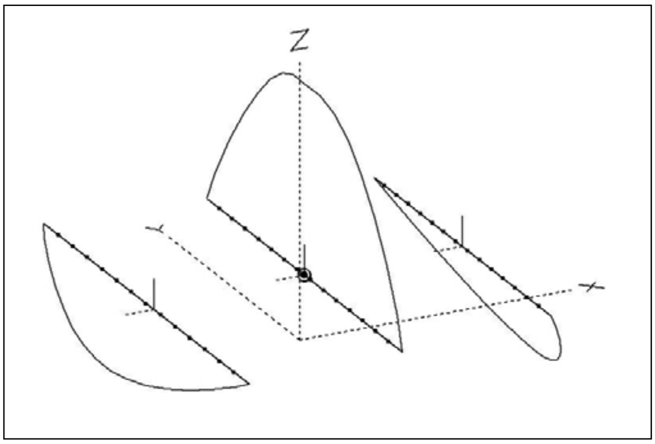


**Fig 13.22: Three-dimensional view of a 3-element Yagi, showing relative current distribution and phase on the driven element and the parasitic elements. Small markers, showing 0 and 90 degrees are used as phase references**

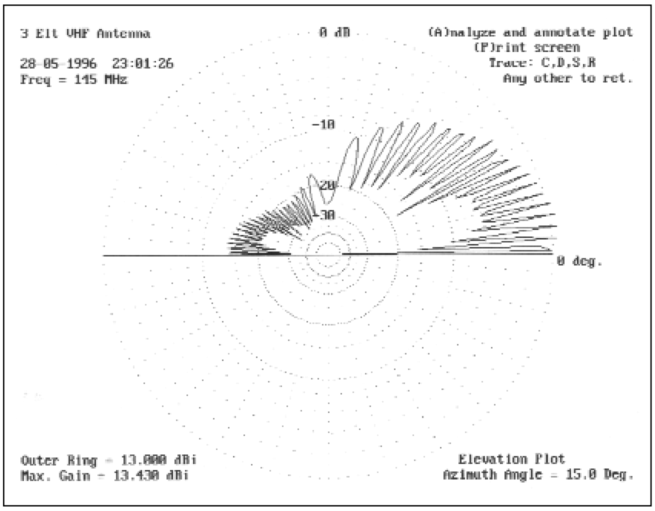


**Fig 13:23: Computed elevation polar diagram of a 145MHz 3-element Yagi, 10m above ground**

### Modelling ground

All the polar diagrams shown so far are plotted as free space diagrams that assume no ground reflection effect. As described earlier in this chapter, a horizontal section at zero degrees relative to the X-axis through the three-dimensional diagram describes characteristics of the antenna without the complication of taking ground into consideration. This is the easiest way to model or compare antenna configurations in early stages of comparison or development.

In the real world ground affects the far field patterns of all antennas and the effect of ground on a three element beam is shown in Figs 13.12 and 13.13. Even VHF and UHF antennas located many wavelengths above ground have radiation patterns quite different to free space patterns, as shown in **Fig 13.23**.

There are various ways in which ground can be modelled and can be ideal ground, or 'real' ground environments. If either a perfect or 'real' ground is specified, EZNEC assumes a perfect ground for impedance and current calculations. The 'real' ground description is used only for determining the shape and strength of the far field (pattern). EZNEC calculates the far field pattern that results from ground absorption or partial reflection due to finite ground conductivity and permittivity.

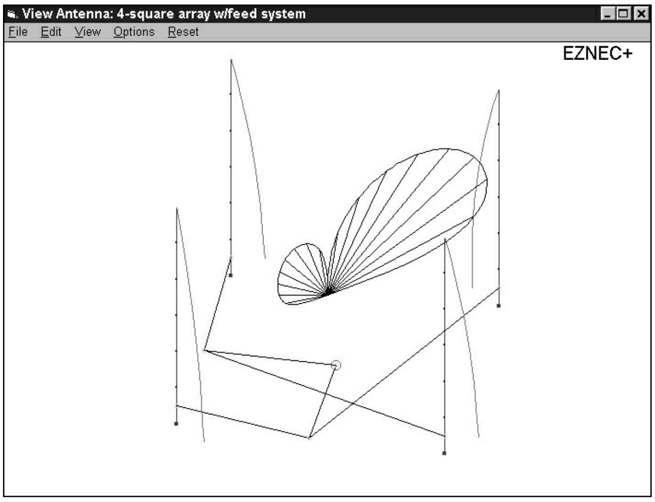


**Fig 12.24: A model of the four-square array, one of the several antenna models supplied with EZNEC. Transmission lines provide the correct phasing, which is indicated by the current traces on each element. The view is overlaid with an elevation plot of the directivity pattern**

When an antenna is modelled with a ground environment using an azimuth plot, the elevation angle must also be selected for the reasons described earlier in the text associated with Fig 13.12.

EZNEC has a facility for changing the height of the entire antenna using a Change Height By function which modifies the z coordinates of both ends of all wires by the specified amount.

When modelling an antenna using a ground environment a Wire is connected to ground by specifying a zero z-co-ordinate. To give some idea of the sophistication of EZNEC, a model of a four-square array is used as an example. In **Fig 13.24** a four-square array is modelled using four verticals, each fed at the point where it contacts ground and fed via transmission lines that provide the correct phasing. This antenna model comes with a library of antenna models supplied with EZNEC.

This popular phased array has several desirable properties. Because of its symmetry, it's easy to switch in four directions. The forward lobe is broad enough that four-direction switching gives good coverage to all directions. Good rejection of signals occurs over a broad region to the rear. The small rear nulls can be eliminated and the forward gain increased slightly by increasing the element spacing.

Note that the transmission line lengths are not the same as might be expected. This is because the delay in a transmission line isn't equal to its electrical length except in special circumstances -- circumstances which don't occur in most phased arrays. To see where these feedline lengths came from, see reference [7].

As it stands, the model isn't good for testing the feed system over a range of frequencies. This is because the feedline lengths are specified in degrees, rather than length. This makes the lines magic, because they keep the same electrical length regardless of frequency. To make a realistic frequency-dependent model, the transmission line lengths would have to be specified in metres or feet.

Like any other modelling program, NEC-2 and therefore EZNEC, has limitations of its own. The most severe probably is inaccuracy in modelling wires which change diameter, as in elements made from telescoping tubing. It has a serious effect on Yagis and other sharply-tuned antennas, (The situation is even worse when modelling wire connected to the end of tubing as in the construction of the all metal quad antenna and the metal G3LDO Double-D described in the chapter on practical HF antennas, but isn't generally serious for others.

### Loads

EZNEC can model lumped circuits such as terminating resistors or loading coils and are described as 'loads'. The impedance load is a resistor in series with reactance. This model can be used to model antennas containing a resistive load, such as a Rhombic or a Beverage. EZNEC has been used successfully to model electrically short antenna with loading coils, as used on the 136kHz band.

## ANTENNA MATERIALS

There are two main types of material used for antenna conductors, wire and tubing. Wire antennas are generally simple and therefore easier to construct, although some arrays of wire elements can become more complex. When tubing is required, aluminium tubing is used most often because it is relatively strong and lightweight.

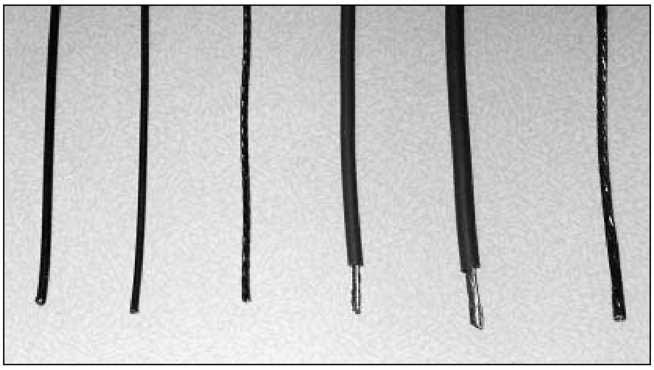


**Fig 13.25: Various types of antenna wire. From the left to right (1) 16SWG hard drawn single strand, (2) 14SWG hard drawn single strand, (3) 14SWG multi-strand, (4) Plastic covered 1.5mm multi-strand (5) Plastic covered 2mm multi-strand (6) Multi-strand FLEXWEAVE antenna wire (wire samples supplied by WH Westlake Electronics)**

## Antenna Wire

Wire antennas can be made from any copper wire. The RF resistance of copper wire increases as the size of the wire decreases. However, in most types of antennas that are commonly constructed of wire (even quite thin wire), the radiation resistance will be much higher than the RF resistance, and the efficiency of the antenna will still be adequate. Wire sizes as small as 0.3mm have been used quite successfully in the construction of 'invisible' antennas in areas where more conventional antennas cannot be erected. In most cases, the selection of wire for an antenna will be based primarily on the physical properties of the wire. For long wire antennas the best material is 14SWG hard-drawn copper wire, which is ideal for applications where significant stretch cannot be tolerated. Care is required when handling this wire because it has a tendency to spiral when it is unrolled. Make sure that kinks do not develop; wire has a far greater tendency to break at a kink.

The most practical material for wire beams is insulated 14 to 16SWG multi-strand flexible tinned copper wire. Wire having an enamel coating is also useful and preferable to bare wire, since the coating resists oxidation and corrosion.

Wire antennas should preferably be made with unbroken lengths of wire. In instances where this is not feasible, wire sections should be spliced. The insulation should be removed for a distance of about 100mm from the end of each section by scraping with a knife or rubbing with sandpaper until the copper underneath is bright. The turns of wire should be brought up tight around the standing part of the wire by twisting with broad-nose pliers.

The crevices formed by the wire should be completely filled with rosin-core solder. A large wattage soldering iron will be required to melt solder outdoors, or a propane torch can be used. The joint should be heated sufficiently so the solder flows freely into the joint when the source of heat is removed momentarily. After the joint has cooled completely, it should be wiped clean with a cloth, and then sprayed generously with acrylic to prevent corrosion.

Most antenna material dealers sell various types of antenna wire as shown in **Fig 13.25**. Antenna wire can often be obtained from scrap yards. Scrap electrical wire is usually heavily insulated and therefore too heavy for antenna elements but is fine for radials.

A cheap source of hard-drawn material is scrap outdoor telephone twin, insulated wire, used (in the UK) to distribute underground cable to subscribers via a telegraph pole.

## Aluminium Tubing

Many of the beam antennas described in the antenna chapters are constructed from aluminium tubing.

Self-supporting horizontal HF beam elements require careful mechanical design to arrive at the best compromise between storm survival, sag and weight. This is done by 'tapering' the elements, ie assembling the elements from telescoping tubes, thick in the centre and thinner, in several steps, towards the tips as shown in **Fig 13.26**. G4LQI [8] has investigated the availability of aluminium tubing and what follows is the result of his work.

The most common range of American tubing comes in OD steps of 3.18mm (1/8in), and with a wall thickness of 1.47mm (0.058in). This means that each size neatly slides into the next larger size.

British amateurs who have tried to copy proven American designs have found that this could not be done with alloy tubing available in the UK. The only tubing sizes easily obtainable in the UK are Imperial, regardless whether designated in inches or millimetres. They come in outside diameters steps of 1/8in (3.18mm) but with a wall thickness of 1.63mm (0.064in), so the next smaller size does not fit into the larger one. This means that the smallest taper step is 6.35mm (1/4in), requiring the filling of the 1 .55mm gap with aluminium shims. This method of construction is described later.

Metric sizes are a compromise; they fit with an easily shimmed gap. Metric size tubing (all inside and outside diameters in whole millimetres), standard in mainland Europe, are a good compromise. See **Table 13.1**,

Aluminium tubing is also available from scrap yards. However, with the exception of scaffolding poles, aluminium tubing is the scarcest material to find. This is because there are not many commodities in our society using this material, and where it is available it only comes in one-off items such as tent poles. There is a further type of material called duralumin, commonly used

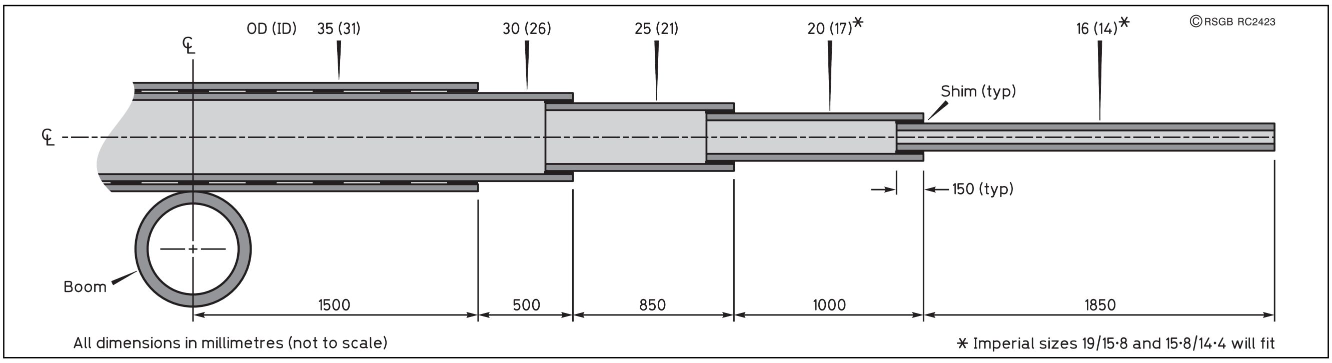


**Fig 13.26: A 14MHz reflector designed to survive wind speeds of up to 159km/h, sagging 16cm and weighing 5.6kg**

| OD mm | Wall g/m | Weight |
|---|---|---|
| 6 | 1 | 42 |
| 8 | 1 | 60 |
| 10 | 1 | 76 |
| 12 | 1 | 93 |
| 13 | 1 | 103 |
| 14 | 1 | 110 |
| 16 | 1 | 127 |
| 19 | 1.5 | 227 |
| 20 | 2 | - |
| 20 | 1.5 | 235 |
| 22 | 2 | 339 |
| 22 | 1.5 | 261 |
| 25 | 2.5 | 477 |
| 25 | 2 | 398 |
| 25 | 1.5 | 298 |
| 28 | 1.5 | 336 |
| 30 | 3 | 687 |
| 30 | 2 | 484 |
| 32 | 1.5 | 387 |
| 35 | 2 | 564 |
| 36 | 1.5 | 438 |
| 40 | 5 | 1495 |
| 40 | 2 | 644 |
| 40 | 1.5 | 489 |
| 44 | 1.5 | 541 |
| 45 | 2 | - |
| 48 | 1.5 | 603 |
| 50 | 5 | 1923 |
| 50 | 2 | 820 |

**Table 13.1: Metric-size alloy tubing available in continental Europe. Material F22 (AlMgSo 0.5%). Tensile strength 22kg/mm$^2$. Standard lengths are 6m**

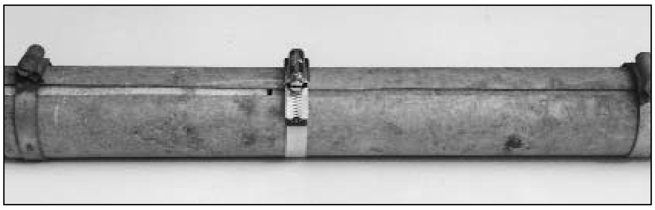


**Fig 13.27: Method of joining lightweight tube of equal diameters**

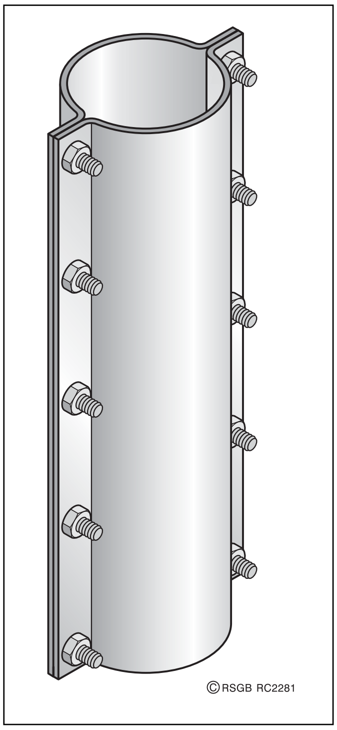


**Fig 13.28: Two-piece steel sleeves of the type used to join scaffolding tubes together**

for aircraft construction and boat masts. It has the advantage of being lighter and stronger than aluminium but is more brittle. In fact almost all aluminium tube is an alloy of some sort because pure aluminium is rather malleable.

Aluminium or duralumin tubing is useful for making lightweight masts. Lightweight sections of thin-wall tubing can be joined together using a short joining section, which is sliced longitudinally with a hacksaw and sprung open using a screwdriver, see **Fig 13.27**. The two sections to be joined are forced into the joining section and clamped tight using hose clamps.

Aluminium scaffolding poles are useful for masts and booms of larger HF beams. This material is thick walled and is strong and has the advantage of having clips, clamps and extension sleeves, see **Fig 13.28**, used in the process of building scaffolding platforms. Its use in the construction of a fold-over mast is described later in the chapter.

## Steel tubing

Steel tubing is an excellent material for constructing antenna masts and is usually available in scrap metal yards. Tubing used for antenna masts should be free from damage and excessive corrosion.

The lower sections of a 12metre (40ft) high steel self-supporting mast should be at least 10cm (4inches) in diameter, with a wall thickness of 5mm.

Steel tubing is often available, threaded, with screw couplers. These couplers are fine for the purpose for which the tubing was designed ie piping liquid or gas. When tubing is used for antenna supports it is often under some bending stress. Couplers only have a short length of screw thread and will be a source of weakness when tubing is employed as an antenna mast, so do *not* be tempted into making a mast using these couplers.

Steel tubes should only be joined by employing lengths that telescope into each other, with at least 30cm (12inches) of overlap and secured with a nut and bolt. Do not weld the sections together, a 12-metre section of steel tubing is very heavy and difficult to manage. It is much easier to assemble a mast in sections. Details on how to construct a steel mast are described later.

When a small diameter pole is joined to larger diameter pipe, eg scaffolding pole into 8cm (3in) pipe, metal strip or angle iron shims can be used to pack any space between the differing diameters before securing with a nut and bolt.

## Copper tubing

Copper has a very good conductivity but is rather heavy so is not suitable for large HF antennas. Copper is suitable for small compact HF antennas, mobile and VHF antennas. A further advantage of copper for the antenna constructor is that there is a good selection of couplings available.

Copper tubing is also relatively plentiful at scrap metal yards because of changes to central heating systems. In the UK the most common copper tubing diameters available are 16 and 22mm. However, some old scrap tubing may have imperial dimensions so check these if the tubing is to be integrated with an existing structure.

## Metal plates

Aluminium plates are particularly useful for making mast-to-boom and boom-to-element fixings as shown in **Fig 13.29**.

Fig 13.29: Method of fixing mast-to-boom and boom-to-element using aluminium plate and U-clamps

Fig 13.30: (a) Mast top guy ring bearing suitable for mast diameters up to 50mm (2in) This is an upside-down view to show guy connection holes. (b) Bearing suitable for base and mast top, for mast diameters up to 9cm (3.5in). Supplied with fittings (not shown) to connect guys

## Scrapyards as a Source of Material

Some antenna material can be bought from a scrap metal yard. The best yards are those located near an industrial estate. These contain a much more useful selection of material for antenna constructor. Materials obtainable from scrap metal yards, useful for antenna work construction, are listed below:

- Steel tubing (for antenna masts)
- Steel casing (for mast foundations)
- Steel angle material (for ginpoles, clamps and guy rope anchors)
- Copper and aluminium tubing (for elements and booms)
- Paxolin, Bakelite or plastic sheet (Insulators)
- Electrical wire (antenna elements)
- Electric motors and gear-boxes (for rotators)
- Aluminium angle stock (quad and Double-D spreaders)
- Aluminium plate (couplers for joining elements to booms and booms to masts)

## Other Materials

The following materials are very useful for antenna construction.

### Hose clamps

Jubilee clips, the antenna constructors friend. They can be used for joining different diameter sections of elements, joining sections of mast, joining wire to metal elements, joining quad spreaders to angle stock - the list is endless. They are readily available at all hardware, DIY and car (auto) part stores. When a clamp is used as part of an outdoor antenna structure, always coat it with a film of grease to prevent corrosion. Never use paint or varnish because this will make it very difficult to dismantle.

### Insulators

Antenna insulators should be made of material that will not absorb moisture. The best insulators for antenna use are made of glass or glazed porcelain. Depending on the type of wire antenna, the insulator must also be capable of taking the same strain as the antenna wire and insulators.

### Pulleys

Several types of pulleys are readily available at almost any hardware store. Among these are small galvanised pulleys designed for awnings and several styles and sizes of clothesline pulleys. Heavier and stronger pulleys are those used in marine work. The factors that determine how much stress a pulley will handle include the diameter of the shaft, how securely the shaft is fitted into the sheath and the size and material that the frame is made of.

Another important factor to be considered in the selection of a pulley is its ability to resist corrosion. Most good-quality clothesline pulleys are made of alloys that do not corrode readily. Since they are designed to carry at least 15m of line loaded with wet clothing in strong winds, they should be adequate for normal spans of 30 to 40m between stable supports. Choose a pulley to suit the line. The worst situation that can happen with a pulley is when a thin line gets trapped between the pulley wheel and the sheath.

### Exhaust pipe clamps

In the USA these are called muffler clamps. They can be used to construct boom-to-mast and element-to-boom fittings.

### Spreaders for wire beams

Cane (lightweight bamboo) or fibreglass rod. Fibreglass rods are preferred because they are lightweight and weather well. In addition they have excellent insulating properties.

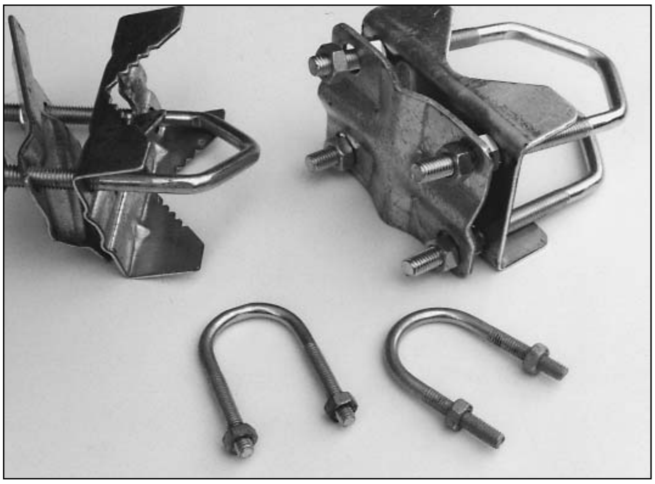


**Fig 13.31: A selection of commercial antenna fittings**

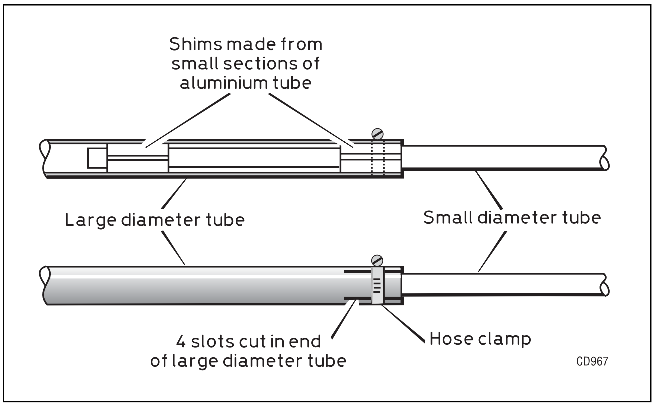


**Fig 13.32: Method of joining sections of aluminium tube where the tube diameters present a poor fit (top drawing depicts a cross section of the joint)**

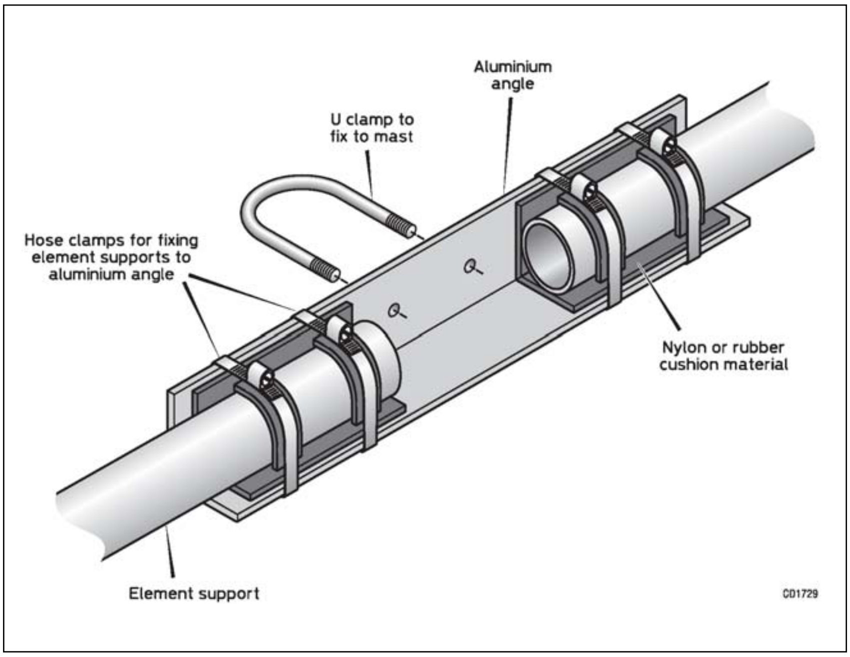


**Fig 13.33: Method of fixing cane or fibreglass supports for wire beam elements to a boom or mast. The length of the aluminium angle material and the spacing between the hose clamp supports depends on the size of the antenna structure (not to scale)**

### Polypropylene rope

Used as halyards and guys for pulling up, and keeping up, mast and antenna structures.

### Specialised antenna fittings

The importance of guying masts correctly is discussed later. The problem of how to guy a rotating mast can be overcome with appropriate fittings. There are a number of specialised commercial fittings available for antenna constructors. A mast top guy ring bearings suitable for mast diameters up to 50mm (2in) and 90mm (3.5in) are shown in **Fig 13.30**. These bearings are supplied with fittings to connect the guys.

### TV type fittings

There are several fittings that are used by the TV antenna industry that can be pressed into amateur radio antenna service. These are mainly clips for fitting a small antenna to a boom, as shown in **Fig 13.31**. They can be used for fixing elements to booms of HF antennas or VHF antennas to masts

# BEAM ANTENNA CONSTRUCTION

Antennas can be built using all-metal construction or with wire elements supported between insulators or on spreaders.

## All-Metal Construction

The boom can be fixed to a tubular mast with a metal plate and car exhaust U-clamps as shown in Fig 13.29. Elements can be connected to booms in a similar manner.

Tapered elements can be constructed from lengths of aluminium alloy tubing with different diameters so that the lengths can be telescoped into each other. Often sections do not fit snugly at the ends of joining sections and need to be modified as shown in **Fig 13.32**.

Additionally, if there is a relatively large difference between the two joining sections, a shim can be made from a short section of tubing, slit longitudinally. Any corrosion on any of the metal surfaces that make up the join should be removed with fine sandpaper. The surfaces are then wiped with a cloth and coated with a thin film of grease to prevent corrosion. The join is clamped tight using a hose clamp. This method is far superior to using a nut and bolt where a new set of holes has to be drilled every time an adjustment to length is made. The hose clamp method also gives the joint a lower contact resistance.

If the antenna elements are constructed from tubing and insulated copper wire (such as the all metal quad, see the chapter on practical HF antennas), then a short length of the plastic insulation is stripped from the wire element extensions. These ends are then fixed with hose clamps to the end of the metal elements used to isolate the metals.

It is particularly important that these copper wire/aluminium tube joints are protected with grease to prevent corrosion. If the connections are protected with grease this should not be a problem. However, one authority [9] goes as far as to state that contact between aluminium and copper should be avoided at all costs and that a small stainless steel washer should be used to provide isolation.

## Wire Beam Construction

Insulating spreaders for wire beam antennas or helically wound elements, can be con-

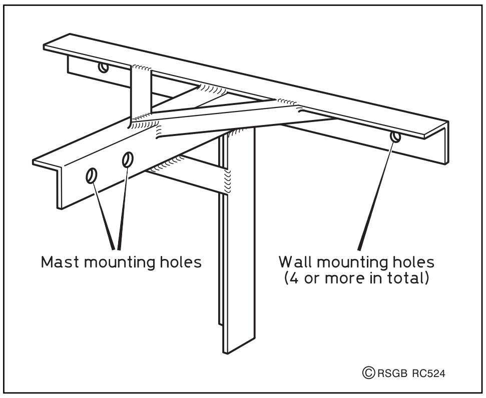


**Fig 13.34: A typical well-braced wall bracket**

structed using cane (lightweight bamboo) or fibreglass rod. The main disadvantage of these materials is that they can easily damaged by crushing at the support point. Special support is required to avoid damaging the ends and aluminium angle stock can be used. The length of this aluminium section depends on the size and the frequency range of the antennas to be supported and for a conventional multi-band quad or Double-D a three-foot length is suitable. Two sections are required for a Double-D or four for a quad. Two holes are drilled at the centre of each section, the distance apart will depend on the size of the mast or boom and hence the size of the U-bolts.

The canes or fibreglass rods are fixed to the ends of the aluminium angle using hose clamps as shown in **Fig 13.33**. Rubber or plastic tubing cushions can be used to prevent the clamps damaging in cane or fibreglass rod supports.

## ANTENNA SUPPORTS

## Using the House as an Antenna Support

Placing a large antenna 10 or 20m into the air, with access for adjustment and tuning can be a minor civil engineering project. Backyard locations often do not have the space for a free-standing mast or tower. In this case the only solution is to fix the antenna to the house. The usual method of doing this is to fix it to the chimney (if you have one) using a chimney bracket or to fix it to the side of the building with a wall bracket.

### Wall brackets

Useful advice for fixing wall brackets comes from G3SEK [10] as follows:

Even a small antenna installation can generate considerable wind forces on the support structure. Think about the directions in which the wind force could act. If the wind is pushing the bracket on to the wall, the force is spread over several bricks, and the fixing is as strong as the wall itself. If the wind is blowing parallel to the wall, and the bracket is strong enough, most kinds of wall fixings will be extremely secure against the sideways forces. The difficult situation is when the wind is blowing away from the wall and trying to pull the bolts straight out of the bricks . . . or the bricks straight out of the wall. This latter possibility is a serious one unless the wall is well built. Older houses with mortar that has weakened over the years, and bricks made before the era of factory quality control, are simply not a good prospect for a mast bolted to the wall.

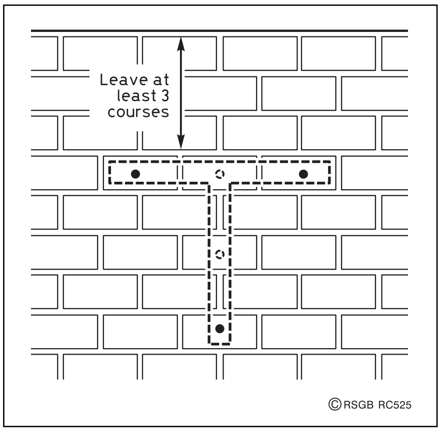


**Fig 13.35: Typical drilling pattern for fixing a wall bracket. Patterns may vary, but always drill into the centre of the bricks**

Assuming your house has reasonably sound brickwork, the aim should be to mount the top bracket as high as possible, to reduce the wind forces but always leave at least three courses of bricks between the ones you drill and the top of the wall. Also leave plenty of sideways clearance from upstairs window openings, which considerably weaken the brickwork. Obviously the best place to mount the top bracket is quite high on a gable end wall, to shorten the unsupported length of mast and reduce the wind forces.

The bracket itself is important. A cheap, poorly made wall bracket, intended for UHF TV antennas, is unsuitable. Go to an amateur radio dealer and get something substantial and well made, and preferably galvanised. A suitable bracket will look something like **Fig 13.34**, with a T-shaped piece that bolts to the wall and a well-braced arm for fixing the mast. All the component parts should be solidly double-seam welded, not just 'tacked' together. Typically there will be two or more bolt holes in the horizontal member of the T, and one or two more in the vertical member. The top row of fixings will bear almost the entire load, and **Fig 13.35** shows a typical drilling pattern.

To fix the bracket, you must use some kind of expanding wall anchor. These come in several kinds, but they all work by expanding outwards and gripping the sides of the holes. The traditional 'Rawlbolts' are best, which can give a very secure fixing. There are other anchor methods. The 'DIY' fixing using large plastic wall plugs and 'coach bolts' are not recommended.

This is a safety-critical application, so spend some money on properly engineered fixings that are designed to work together as a system, and follow the manufacturer's instructions exactly. The holes for the 'Rawlbolt' anchors should be drilled in the centre of the brick as shown in **Fig 13.35**. The optimum size for ordinary brickwork is M10, which requires a 16mm diameter hole. Three or four of these should be more than adequate to withstand the wind forces envisaged - but only if they are installed correctly.

Choose a sound set of bricks for drilling, free from any hairline cracks. If necessary, be prepared to move the mast a little from its planned location. Drill into the exact centre of each brick, not near the edges, and never into mortar. If necessary, make new mounting holes in the bracket to suit your own brickwork. The holes in the brackets should be 10mm diameter for M10 bolts, with some extra clearance to help the bolts line up. Hold the bracket to the wall, level it with a spirit level and mark the centres of the holes. Begin drilling with a small masonry bit. Before you use the electric drill, place the point of the bit exactly on your drilling mark and tap gently with a hammer to chip out a small dimple. This will prevent the point from wandering when you start drilling. If you're using a hammer-drill, start without the hammer action until you've made a deep enough hole to prevent the bit from wandering. Do the same at each change of bit as you open out the holes gradually, using progressively larger sizes. Use patience rather than brute force, and you're more likely to make good cylindrical holes, square to the wall and exactly where you want them. It's also kinder to the electric drill; and above all it's much safer for you on the ladder.

The final holes must be exactly the right diameter as specified by the manufacturer. For example, the hole for an M10 Rawlbolt

**Fig 13.36: Example of a chimney lashing used to support a double-D antenna**

must be 16mm diameter - not 15, not 17, but 16mm This is very important because the entire strength of any type of wall fixing comes from the contact of the anchor sleeve against the inside of the hole. The sleeve should be a gentle tap fit, so that when the bolt is tightened the anchor will immediately start to grip hard.

Tap the anchor sleeve into place just below the surface of the wall so that, when the bracket is bolted on, it contacts the wall and not sitting on the end of the sleeve. Do this without the bolt inserted, and then fit the bracket. Leave the bolts slightly loose, level the bracket, and then tighten them. The tricky part is to tighten the bolts to the correct torque - enough to expand the anchor sleeve and develop the fixing strength, but not so much that it splits the brick and ruins the whole fixing.

Although G3SEK uses Rawlbolts, he notes that they can be very prone to split the bricks if over-tightened. You might consider alternative types, such as the Fischer bolts which use a softer plastic sleeve to grip the inside of the hole. In any case, use the type of anchor with a free bolt, which screws in, and not the type with a stud that takes a nut.

If your house is built using modern bricks that have holes right through the middle, conventional expanding anchors are no use, and you'll need to investigate other systems. Wall anchors using a chemical adhesive fixing system are also available, and have the advantage of not stressing the bricks at all, while having higher claimed strengths than conventional expanding anchors. They can also be used for fixing into hollow bricks, but the strength of the bricks themselves may become a factor. As with any adhesive bonding system, success depends on careful preparation and following the instructions exactly. One suggestion when using conventional Rawlbolts in ordinary brickwork is to use epoxy resin as well, to try and obtain the best of both worlds.

If you are fixing to a gable end wall, yet another possibility is to drill right through the whole wall and into the loft space, and then use long bolts or studs to secure the bracket to a steel plate that spreads the load over the inside wall.

The lower bracket is much simpler, because it bears much less load than the upper one. Its main purpose is to steady the mast and prevent it from bowing below the upper bracket. Mark out and drill for the lower bracket after fixing the upper one, lining them up with a plumb line. The bottom of the mast should also be fixed to prevent it from moving sideways.

In the longer term, wall anchors can work loose owing to either frost or thermal expansion/contraction cycles, and then the wind will work on them further. Check the fixings every spring and autumn. If you are intending to mount a commercial mast or antenna against the wall, obtain specific advice from the manufacturer and follow it exactly.

### House Chimney

The house chimney can be used for an antenna support as shown in **Fig 13.36**. The main advantage of this method is that chimney-mounting brackets are easy to obtain. Some of these mounting brackets can be seen supporting some precariously tall TV antenna structures in fringe TV signal areas.

The chimney of an older house, where the mortar that has weakened over the years, needs to be examined, and if necessary repointed before fitting a chimney mounted antenna.

The single wire lashing kits used for TV antennas are totally unsuitable for amateur radio antennas. A double TV antenna chimney lashing kit is essential and will support a large VHF array or a small sized HF beam.

## ROUTING CABLES INTO THE HOUSE

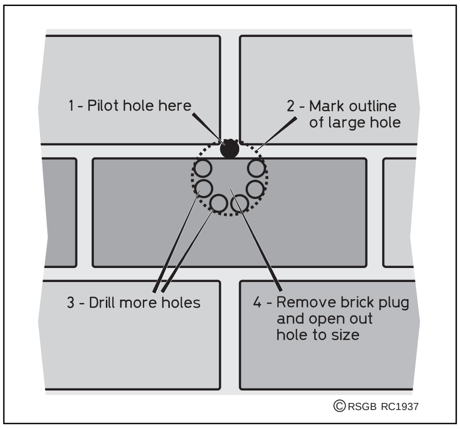
While on the subject of modifying the house for amateur radio this might be a good time to consider how to route cables into the house. You might have a multi-band beam with its coax cable and rotator control cable, plus a VHF antenna and a long wire antenna for the lower frequency bands. And of course there is the earth connection.

The time-honoured way of dealing with this problem is to drill lot of holes in the window frame, however, modern houses (and a lot of older ones) use double-glazing, with its plastic and metal window frames. Using the window frame as a route for cables is not feasible and another method must be sought. G3SEK used the method of routing the cables by inserting a length of plastic drainpipe through the wall [11]. What follows is how he did it.

In a traditional British brick house with cavity outside walls, the job is well within the reach of a competent DIYer and it should make very little mess. Think of it as installing a waste pipe for the kitchen sink, because 40mm sink waste pipe is probably what you'll need - though it's always good to leave enough room for more antennas in the future! You'll also need a good electric hammer drill, at least one masonry bit of about 10mm diameter that is long enough to go right through the double wall, a shorter masonry bit of about the same size, a fairly large hammer and a long, narrow cold chisel.

Plan very carefully to find the best place to drill through. Leave at least one whole brick away from doors or window frames. Remember that the frame has a solid lintel across the top, extending outwards on both sides. Check both the inside and the outside of the wall with a live cable and metal detector to be sure that you

**Fig 13.37: How to drill a 40mm hole through bricks. You can also use the same technique for larger holes**



won't meet any nasty surprises. If yours is a wooden-framed house with a brick outer skin, take great care to avoid structural timbers.

First you need a pilot hole, right through the wall, and then you're going to enlarge the hole from each side by continuing around a circle. Start from the outside and drill through the mortar, halfway along a brick, as shown in **Fig 13.37**.

Use one of the shorter masonry bits to start the hole, and take care to drill it accurately at right angles to the wall - the mortar joint will guide you. It's just possible that you will hit a metal wall tie. If you do, move along to the next brick. When you break through into the wall cavity, change to the longer bit and carry on drilling. To avoid pushing off a big patch of plaster from the inside wall, stop when you're within a few centimetres of breaking through. Switch off the hammer action of the drill, and continue with very gentle pressure until you're right through both walls.

Now mark out a circle on each side of the wall, rather larger than the diameter of the pipe, as shown in Fig 13.37. The pilot hole is at the top of each circle. Work separately from each side, using the shorter masonry bit. Drill a ring of holes as close together as possible, stopping when you're through to the cavity. Because it's important to start each hole in exactly the right place, it helps to begin with a smaller bit, using the drill at slow speed with the hammer action off. When the hole is well started into solid brickwork (or breeze block on the inside wall) it's safe to change to the larger bit with the faster hammer action. Next you need to open out the hole from each side, using the cold chisel and occasionally perhaps the electric drill, until the pipe will slide right through.

Chip away carefully without too much violence so as not to crack the outside brick or do any unnecessary damage to the interior plasterwork - and try to pull the central plugs out rather than pushing them into the cavity. With care you can make almost as good a hole as a professional using a big core drill. Make sure that the pipe will slide through horizontally, or sloping a few degrees upward from the outside so that rainwater won't run in. Set the end of the pipe just proud of the inside wall, and leave any overhang outside. Fill the gaps around the pipe with mortar or exterior filler on the outside and plaster or interior filler on the inside, and let it all set solid. The next day saw off the outside end of the pipe, a few centimetres away from the wall. Now you can start to thread the cables. A 45° or right-angle pipe elbow, facing downwards, fixed to the pipe where it emerges on the outside wall, may be used to help keep the rainwater out. When all the cables are in place, stuff in plastic foam for draught proofing, or use aerosol-expanding foam.

This method of installing a pipe is quite easily reversible before you move house. The pipe will pull out from the outside with a bit of effort, and you can plug and plaster over the hole in the inside wall. On the outside, you'll only need to replace one brick if you have followed the drilling pattern in Fig 13.37.

## CONSTRUCTION OF FOLD-OVER MASTS

Many radio amateurs use commercial lattice construction masts, which have a telescoping and fold-over capability. They have the advantage of having well-defined data regarding heights and wind loading, although they have a fairly high visual impact, which may be a problem in some locations.

A drawback to trying to adjust an antenna using these types of support is that they take some time and effort to raise and lower. Additionally, the winch cables are not designed for the continual raising and lowering normally encountered when a lot of antenna work is being done over a period of time. For this reason a homemade structure can be designed to be easy to raise and lower. An advantage of an easily folded-over mast is that it can be quickly lowered if severe gale force winds are forecast. Two simple designs for single-handed construction will now be described.

### The G2XK Lightweight Fold-over Mast

Eric Knowles, G2XK, used the method described below to support 6-element 10 metre beam on a 11 metre (36 foot) boom at a height of 12 metres (40ft), using only 80mm (3in) diameter thin-wall duralumin tubing, see **Fig 13.38**. This large structure weathered many a gale that swept across the Vale of York.

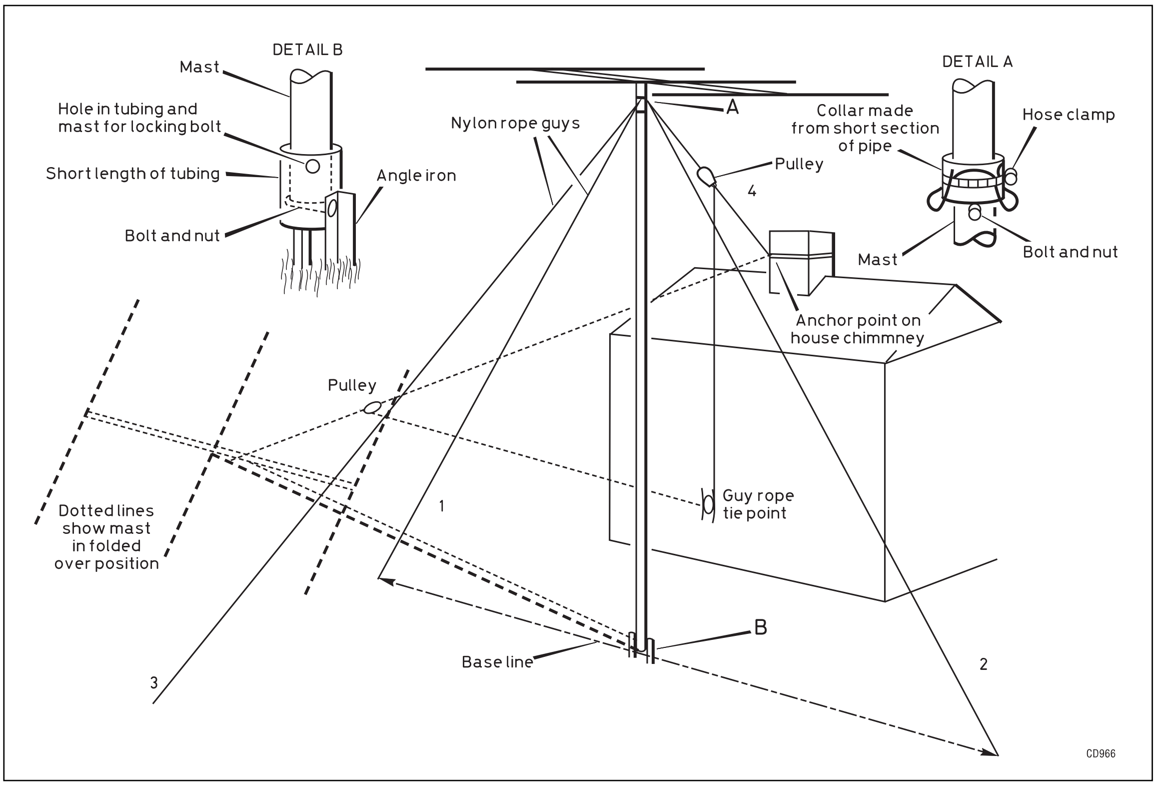


**Fig 13.38: Constructional details of the G2XK type of lightweight fold-over mast**

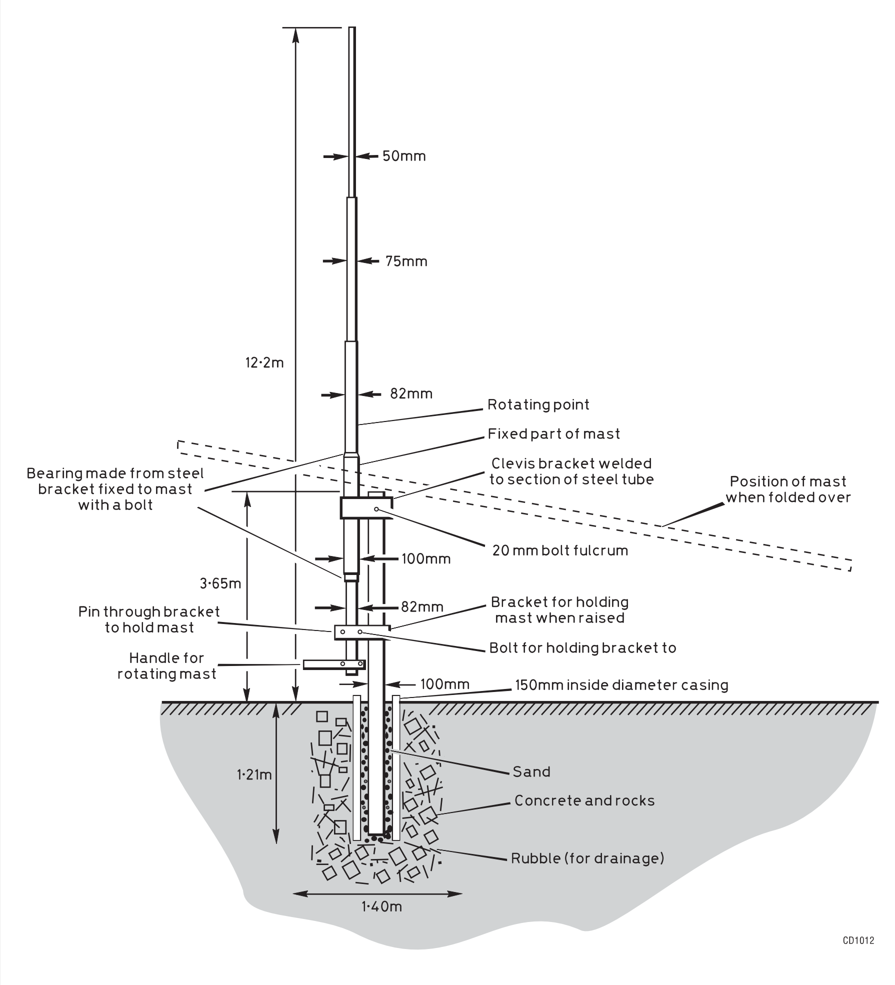


**Fig 13.39: Constructional details of the counterweighted fold-over rotatable 12 metre mast**

There is nothing new in this method of supporting, or raising and lowering masts using guy ropes. The military have used the method for many years for supporting wire fixed wire antennas.

The description that follows is of a similar mast; suitable for supporting a medium sized experimental beam antenna. No special tools or welding equipment are required to construct this structure and is an excellent support for experimental antennas provided the space for the guys is available. Do not use steel tubing for the mast of this design because it is too heavy. Aluminium scaffolding pole is not really suitable for this design of mast because of the weight/length ratio, although it could be used for short masts of up to 8 metre (25ft) high.

The layout is illustrated in Fig 13.38. The structure can be used with a fixed mast and rotator, or the mast can be rotated. In this case provision has to be made to allow the mast to rotate and be folded over. A minimum of four guy ropes is used.

The anchor point for guy wire 4 must be above ground level; the chimney of a nearby house is suitable with a lightweight structure. Guy ropes 1 and 2 are anchored along the baseline so that they retain the same tension when the mast is being erected or folded over. The length of guy rope 3 is adjusted so that it is under tension when the mast is in the vertical position. The original G2XK version used two sets of guy ropes but only one set is illustrated in Fig 13.38 for clarity.

This structure gains all its strength from its guys, so it is important that the guy ropes are strong and are connected securely, both at the anchorage and the top of the mast. Polypropylene rope (6mm diameter) is a suitable material for the guys, which should ideally be at 45 degrees to the mast. This angle can be reduced if space is limited but this increases the downward pressure on the mast in high winds and increases the chances of the mast buckling.

Commercial guy rope to mast bearings are available for the top of the mast, see Fig 13.30 and are recommended for this sort of application. The guys should be connected to the bearings with D-clamps.

If a commercial rotatable guy rope support bearing is unavailable, one can be constructed with a short length of steel tube, slightly larger in diameter than the mast. Very thick wire loops can be fixed to the tube using two hose clamps. The top of the mast is inserted into this tubing. A bolt and nut, through the appropriate point on the mast, holds the guy support collar in position. Detail A of Fig 13.38 illustrates this.

The guy anchorage can be constructed from a 1 metre (40in) or so length of angle iron, cut to a point one end and with a hole drilled in the other. This can be driven into the ground at 90 degrees to the angle of pull. The guy anchorage may need to be more substantial for very large masts and/or if the soil is light and sandy. The guy rope should be connected to the guy anchorage with a D-clamp. A pulley is required for the halyard to enable the mast to be hauled up; a good quality clothesline pulley is suitable.

The base pivot point comprises two lengths of angle iron, cut and drilled in a similar way to the guy anchorages. The two angle iron pieces are driven into the ground, with the holes aligned so that the pivot bolt can be fitted. If the design calls for a rotatable mast then a small section of tubing, whose internal diameter is slightly larger than the outside diameter of the mast, is pivoted to the angle iron. The mast fits inside this section of tubing and is free to rotate. Holes can be drilled through the base tubing and the mast to enable the structure to be locked on any particular heading. Detail B of Fig 13.38 shows how this is done. Lightweight sections of thin-wall tubing can be joined together using a short joining section, see Fig 13.27.

## Counter Weighted Fold-over masts

This type of support is heavier and requires more construction effort. Its main advantage is that guy ropes are not absolutely necessary. This design is based on a 18 metre (60 foot) tilt-over support designed by Alfred W.Hubbard K0OHM [12]. The original was designed to support a 3-element tri-band beam and a rotator. In this design, all sections of steel tubing of the mast were welded together. In the original design the foldover mast was partially counterweighted by filling the lower half of the tilt-over section with concrete! A pulley is used to manage the remaining 160kg (350 pound) pull.

The design of the base is interesting. It comprises a section of casing fixed in the ground with a concrete foundation. The gap

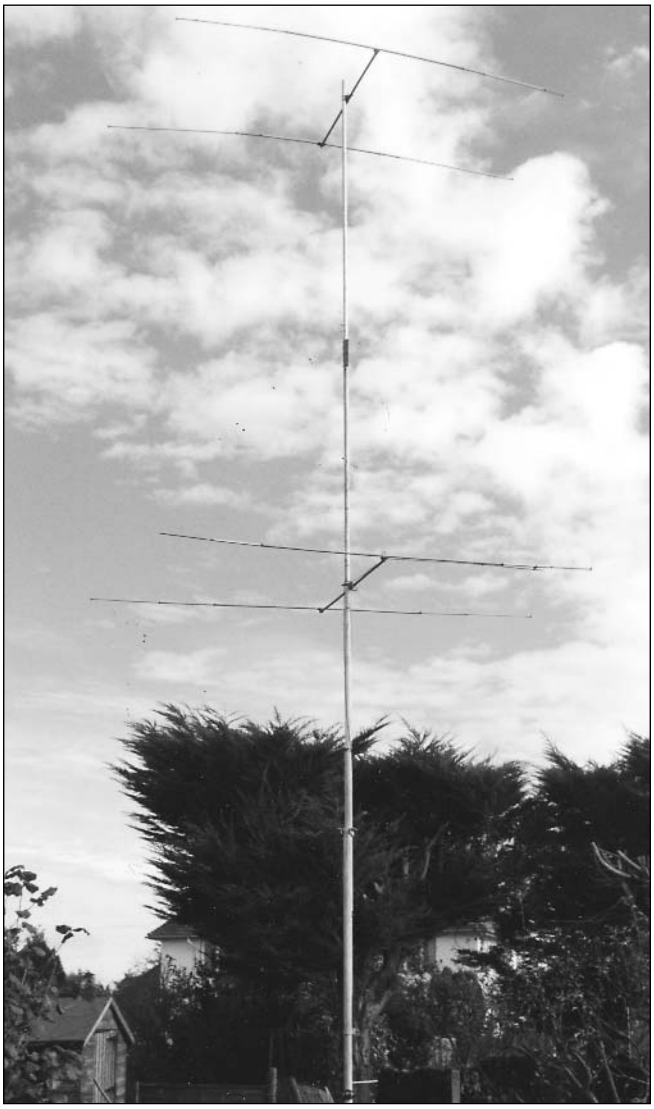


**Fig 13.40: 12m (40ft) version of the fold-over mast in upright position, supporting a 14MHz metal quad antenna**

**Fig 13.41: 12 metre (40ft) mast and 14MHz quad in the folded over position**

between the mast and the casing is filled with sand. This reduces the high-stress point at ground level that normally exists if the mast is set directly into concrete.

The sand acts as a buffer and allows the mast to flex within the base during high winds. The internal casing diameter should be around 5cm (2in) greater in diameter than the lowest section of the mast.

G3LDO built several of these masts, the largest of which were 18 metre (60 foot) high and supported an all metal quad. The mast and payload should not be fully counterweighted. A top weight imbalance of around 45kg (100 pounds), controlled with a winch will enable the momentum of the structure to be more easily managed.

### Medium size 12m (40ft) fold-over steel mast

The mast, described above, is too large for most suburban sites. The following is a description of a smaller version, but even this will require a garden at least 12m long. However the design can be scaled down if required

This mast is counterweighted with approximately 15kg (30lb) of top weight so a winch is not required. It takes about 15 seconds to raise the antenna mast into the vertical position. The mast is relatively lightweight; the top third of its length is 5cm (2in) diameter scaffolding pole. The whole mast is rotated manually using a handle fixed to the bottom of the mast.

The sections of steel tubing that make up the mast are telescoped into each other for about 30cm (12in) and secured by a bolt and nut. This allows the mast to be assembled, modified or repositioned much more easily than if the section was welded.

The detail of this mast can be seen in **Fig 13.39** and a more general views can be seen in **Figs 13.40 and 13.41**. At the time these photographs were taken, two sections of a tree trunk were used as counterweights. These weights have now been dispensed with by making the lower section of the mast out of solid 82mm steel rod.

Although these structures can be built single-handed the following are areas where some assistance would be of help.

- Inserting the lower half of the mast into the base casing. Two ropes are tied to the top of the lower section, using the holes drilled for the pivot bolt. The section can then be placed with the lower end over the base casing and the top supported on a pair of stepladders. The section can be raised using these ropes, at the same time the lower end is guided into the casing with a section of angle iron.

- Placing the clevis at the top of the mast to enable the bolt to be fitted and inserting the mast into the oversize piping used as the tiltable thrust bearing. These tasks can be eased by using a gin pole with a pulley and rope. The gin pole can be constructed from steel angle-iron and clamped to the mast with additional angle iron pieces or steel straps.

## Other Fold-over Masts

### Wooden masts

In the early days of amateur radio, wood was a very popular material for constructing masts and even beam antennas. These days this material is less popular because of the cost of quality seasoned timber and the lack of sensible fold-over designs that can carry the payload of a medium size beam antenna to a height of 10 to 15m. The selection of timber and weather treatment requires specialist knowledge, which is beyond the scope of this chapter.

### Commercial masts

There is a range of commercial masts available (see *RadCom* or the web for sources). Most of these masts have a lattice structure, with sections of the fold over lattice mast telescoping into each other. This design enables a fairly large mast to be erected into a relatively small garden.

## TREES AS ANTENNA SUPPORTS

If you have a tall tree in your garden, you may have a very good support for a wire antenna that does not require planning permission. As antenna supports, trees are unstable in windy conditions, except in the case of very large trees where the antenna support is well down from the top branches.

Tree supported antennas must be constructed much more sturdily than is necessary with stable supports. To this end, the preferred method is to use a halyard and pulley shown in **Fig 13.42**.

The use of a halyard with a mast is shown in **Fig 13.42(a)**. Here the halyard end can be lashed to a bracket. When a tree is used as the support a weight is used, see **Fig 13.42(b)**, to take up the movement of the tree. The endless loop is to allow greater control when raising and lowering the antenna.

## Fixing the halyard pulley.

If the point where the pulley is to be attached can be reached using a ladder then fixing it to a branch, pole or building is the easy bit. If you cannot reach the pulley fixing point then a line has to be thrown or propelled over the anchor point.

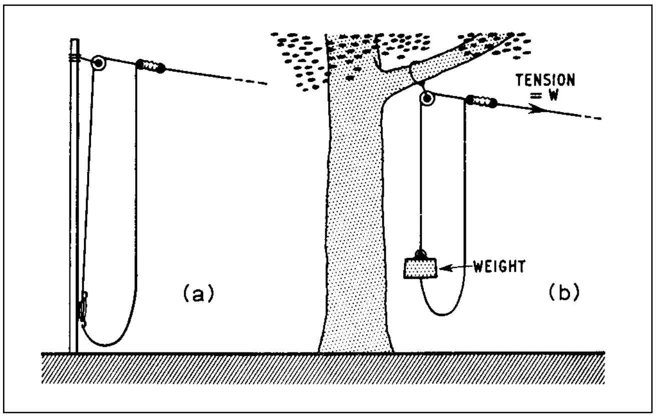


**Fig 13.42: Halyard connections to (a) a pole and (b) a tree. The weight is equal to the required antenna wire tension**

**Fig 13.43: An antenna support catapult launch pad. The catapult is held nearly upside down so that the line does not get caught up with anything when fired. It is advisable to gain proficiency with few practice runs in an open space before using it to secure an antenna support.**

A useful missile projector is the catapult as shown in **Fig 13.43**. A missile or weight must be used that will not cause damage or injury if things go wrong. The best object for this purpose is a squash ball or, as used in Fig 13.43, a plastic practice golf ball filled with wood filler.

The best sort of pilot line is strimmer cord. This comes in several thicknesses, the heaviest for heavy-duty petrol driven strimmers and the lightest weight for electric strimmers; the latter being the most suitable for the purpose. Strimmer line is very strong and resists kinking.

The line can be stretching out straight on the ground or better still, zigzagged left and right on the ground. If snarling of the line in a problem (due, say, to garden plants and bushes) try making a stationary reel by driving eight nails, arranged in a circle, through 20mm board. After winding the line around the circle formed by the nails, the line should reel off readily at lift-off. The board should be tilted at approximately right angles to the path of the shot.

If it is necessary to retrieve the line and start over again, the line should be drawn back very slowly; otherwise the swinging weight may wrap the line around a small branch, making retrieval impossible. This system can also be used to place an antenna support over a roof.

The pilot line can be used to pull a heavier line over the tree or roof. This line is then used to haul a pulley up into the tree after the antenna halyard has been threaded through the pulley. The line that holds the pulley must be capable of withstanding considerable chafing against the tree.

A metal ring, around 70 -100mm (3 to 4in) in diameter can be used instead of a pulley. The antenna support wire is just looped through the ring. This has more friction than a pulley but it will not jam.

## Safety

**Safety should be a primary consideration when erecting antenna masts.**

NEVER erect an antenna and mast that could possibly come in contact with electric power lines. Never rush this sort of work.

ALWAYS stop to consider the implications of the next move, particularly when dealing with heavy sections of steel tubing.

DO NOT use an antenna support structure that requires the joint efforts of all members of the local radio club to raise and lower it, although help in the construction stages is always welcome.

Fig 13.44: A compact two-element multiband beam

## WIND LOADING

The saying that “if you haven't had an antenna fall down then you don't build big enough antennas” might sound very smart but it is hardly good engineering practice. Bridge building engineers would hardly get away with it.

Most antennas are brought down by very strong winds so it is important to consider the effect of windloading of your antenna installation. While there are a couple of excellent articles on the subject [13] [14] a few suggestions are given here so that you can get some idea of the forces involved.

G3SEK [15] says that the round figures that stick in his mind are that at 100mph, every square foot of exposed area suffers a sideways pressure of 25 pounds; or that at 45-50m/s the wind force is about 150kgf/$m^2$ (kilograms force per square metre).

So how do you know how many square metres or feet your antenna installation is? To avoid any aerodynamics the best way is to simplify the parts of the elements to a 'flat slab' area. So that a pole 3m long and 50mm (.05m) diameter is a flat slab 0.15$m^2$.

### Assessing the Exposed Areas

This is where the calculations become simple. Take, for example, a compact HF beam mounted on the roof of the house shown in **Fig 13.44**.

This beam has two elements, which are 4.49m long and 25mm in diameter. The flat slab area of the elements is 4.49 x 0.025 x 2 = 0.2245$m^2$. The boom is 2.1m long and 0.035m diameter: 2.1 x 0.035 = 0.08$m^2$. The loading coils and spokes at the ends of the elements are complicated so they have been modelled as four cylindrical objects 0.3m long by 0.06m in diameter. This gives an area of 0.3 x 0.06 x 4 = 0.072$m^2$. The mast fixed to the chimney is around 1m long and 0.05mm diameter. This adds 0.05$m^2$. For the rotator, 0.15m x 0.13m = 0.02$m^2$ has been allocated.

This totals 0.225 + 0.072 + 0.05 + 0.02 = 0.367$m^2$, or for rough calculation 0.4$m^2$.

The boom has not been included because it would be end on to the wind if the beam were facing into wind. If the beam were to be rotated 90 degrees to the wind then the area facing the wind would be 0.08 + 0.06 + 0.05 + 0.02 = 0.21 or say 0.2$m^2$.

### Calculating the Wind Pressure

To work out the force acting on the antenna structure by the wind, see **Fig 13.45**.

This antenna, with a total area of 0.4m, the sideways force on this antenna with a 45m/s (100mph) wind, according to **Fig 13.45** is 128kgf/$m^2$ x 0.4 = 51kg. By turning the antenna so that the elements are sideways to the wind the area facing the wind is reduced to 0.2$m_2$ and the sideways force reduced to 10.3kg.

There are leverage forces that need to be taken into consideration with unsupported masts that extend above the supporting structure, such as a wall bracket, chimney bracket or guys on a mast. That is why an antenna should be fixed as close to the support or rotator as possible. If you have a Christmas tree of antennas turned by one rotator then a rotator cage is a must.

Of course, these calculations are a simplification of the real world. The wind comes in gusts and there is a lot of turbulence over the roof. Nevertheless, the method of estimating wind forces by G3SEK does give some idea of the forces that will be encountered and enable you to engineer the structure accordingly.

## FURTHER READING

'Comparing MININECS, A Guide to Choosing an Antenna Optimization Program', LB Cebik, W4RNL, Communications Quarterly, Spring 1994.

'Programs for Antenna Analysis by Method of Moments', RP Haviland. W4MB. *The ARRL Antenna Compendium*, Vol 4

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[3] *Radio Engineering*, 2nd edition 1937, F.E Terman

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[5] *The New MININEC (Version 3): A Mini-Numerical Electromagnetic Code.* J C Logan and J.W. Rockway. Naval Ocean Systems Centre, San Diego, California

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[7] ‘The Simplest Phased Array Feed System . . . That Works’, *The ARRL Antenna Compendium*, Vol 2

[8] ‘Eurotek’, Erwin David, G4LQI, *RadCom,* Nov 1999

[9] *Protection Against Atmospheric Corrosion*, Karel Barton, published John Wiley, 1976

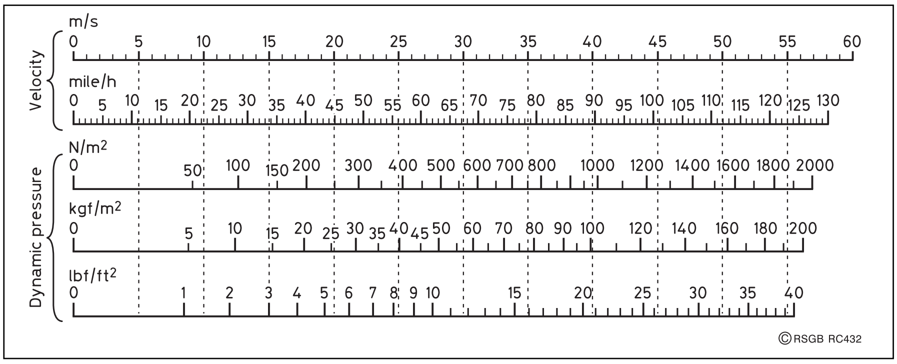

Fig 13.45: Conversion between wind speed and force per unit area

[10] ‘In Practice’, Ian White, G3SEK, *RadCom*, Mar 1995
[11] ‘In Practice’, Ian White, G3SEK, *RadCom*, Nov 1998
[12] 'The Paul Buyan Whip', Alfred W.Hubbard, K0OHM, *QST*, Mar 1963
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[15] ‘In Practice’ column, Ian White, G3SEK, *RadCom*, Jan,1995