Successful Wire Antennas

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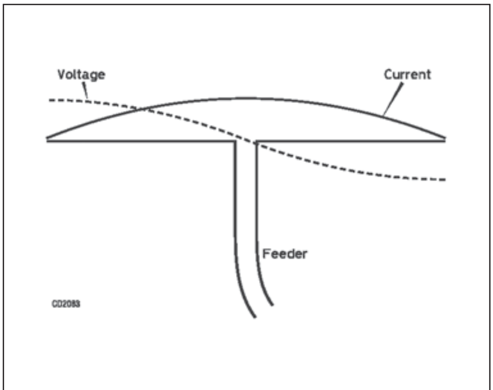
THE WIRE DIPOLE is a very effective antenna that can be constructed and installed very easily and for only a small cost. The half-wave version of the dipole has become the standard against which other radiating systems are judged and it remains as perhaps the most effective, yet simple, single-band antenna, and one which can virtually be guaranteed to perform well even when used in far-from-ideal situations.

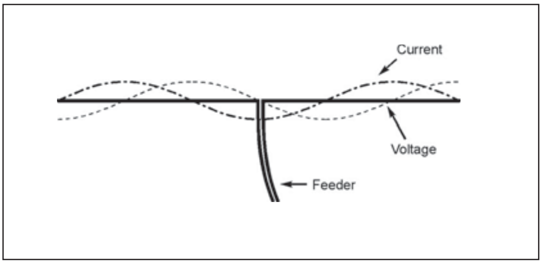
As the name suggests, it contains two legs or 'poles'. The most common form is the *half-wave* dipole, which (not surprisingly) is an electrical half-wavelength long. The basic format for a half-wave dipole along with the voltage and current waveforms can be seen in **Fig 3.1**. The voltage rises to a maximum at either end and falls to a minimum at the centre, whereas the current is at its minimum at the end and its maximum in the centre. Its feedpoint in the centre forms a low impedance point suitable for many sorts of feeder.

A dipole does not have to be a half-wavelength long. A three half-wavelength version can be seen in **Fig 3.2**. Again the points of voltage maximum are at either end and at a minimum in the centre. Likewise the current is at its minimum at either end and maximum in the centre.

DIPOLE LENGTHS

A resonant half-wavelength of wire will be somewhat shorter than its name implies. RF energy in free space (electromagnetic radiation) can travel at the speed of light, but when moving along a conductor it travels more slowly. At HF (between 3 and 30MHz) wires exhibit *skin effect*, i.e. most of the RF energy flows along the outer surface of the conductor. A practical half-wave antenna made from wire needs end supports; each end usually being terminated with an insulator. The capacitance between the ends of dipole and its supports, even when the supporting material is non-metallic, gives rise to *end effect*. This effect additionally loads the wire capacitively and contributes towards its shortening from the theoretical half-wavelength.





(Left) Fig 3.1: A basic half-wavelength dipole antenna with the voltage and current waveforms.

(Above) Fig 3.2: A three half-wavelength dipole.

Frequency	Length			
	With insulators		Without insulators	
(kHz)	(feet)	(metres)	(feet)	(metres)
1850	252' 11"	77.29	258' 5"	78.75
1950	240' 0"	73.33	245' 1"	74.71
3550	131' 10"	40.28	134' 8"	41.04
3750	124' 9"	38.13	127' 5"	38.85
7050	66' 4"	20.28	67' 10"	20.66
10100	46' 4"	14.15	47' 4"	14.42
14100	33' 2"	10.14	33' 11"	10.33
14250	32' 10"	10.03	33' 6"	10.22
18100	25' 10"	7.90	26' 5"	8.04
21100	22' 2"	6.77	22' 8"	6.90
21300	21' 11"	6.71	22' 5"	6.84
24940	18' 9"	5.73	19' 2"	5.84
28100	16' 8"	5.08	17' 0"	5.18
28500	16' 5"	5.01	16' 9"	5.11
29000	16' 1"	4.93	16' 6"	5.02
29500	15' 10"	4.84	16' 2"	4.93

Table 3.1: Lengths of half-wave dipoles.

The theoretical half-wavelength may be calculated from the expression:

Theoretical half wavelength (metres) = 150 / f (MHz)

or

Theoretical half-wavelength (feet) = 492 / f (MHz)

To take account of the end effect and the use of insulators, the length may be calculated by using either:

Antenna length (metres) = 143 / f (MHz)

or

Antenna length (feet) = 468 / f (MHz).

When using nylon rope it has been suggested that no insulators are required. In his book *HF Antennas for All Locations* (published by the RSGB), Les Moxon, G6XN, suggests that when no insulators are used a half-wavelength can be found by using either 478 / f (MHz) feet or 145.7 / f (MHz) metres.

A further factor which influences antenna resonant length is the diameter of the wire used for that antenna. The formulas above are for typical wire dimensions. Typical antenna lengths for the amateur bands from 160 - 10m, both when using insulators or nylon rope, are shown in **Table 3.1** above.

DIPOLE IMPEDANCES

A half-wave transmitting antenna, when energised and resonant, will have high RF voltages at its ends with theoretically zero RF currents there. This means that the ends of a half-wave dipole in free space will have an infinitely high impedance, but in practice in the real world there will always be some leakage from its ends and into the supporting insulators. This means that in reality the impedance at the dipole ends is close to 100,000Ω, a value which depends upon the wire or element thickness. At a distance of approximately one-sixteenth wavelength from either end it is 1000Ω, and at the dipole centre, where the current is greatest and the RF voltage is low, the impedance is also low.

If it were made from an infinitely thin conductor wire, our theoretical dipole in free space would have an impedance of about 73Ω at its centre. Such an antenna is impossible in the material world, and a practical half-wave dipole made from wire will have an impedance at its centre at resonance close to 65Ω. Antennas fabricated from tubing have lower values at their centres, of between 55 and 60Ω. These impedance values also depend upon the height of the antenna above ground, as will be shown later.

The very high values of self-impedance at the ends of a half-wave wire makes end-feeding difficult, and this is why breaking the wire at its centre and connecting the inner ends so formed to a low-impedance feedline makes a convenient and efficient coupling and match. Suitable feeder is available in the form of twin-lead or coaxial cable, which both have design impedances lying between 50 and 75Ω. These present a good match to dipole centres.

At exact resonance the impedance at the centre of a half-wave dipole is like a pure resistance. At any other frequencies the same dipole will have either inductive or capacitive reactance at its feedpoint. If the dipole is too short to be resonant the reactance is capacitive and when it is too long the reactance becomes inductive. In either case there will be problems in matching the 50 or 70Ω feeder to the dipole and if the reactances are great, there will be a high SWR on the feeder and considerable power loss.

ANTENNA Q

A half-wave antenna is something like a conventional tuned circuit where the Q, or 'Quality factor', is largely determined by the resistance of the coil. Losses in the capacitor used in the circuit are generally small and are not so significant in the determination of Q. A high-Q tuned circuit exhibits very sharp tuning (selectivity) and this is also the case when an antenna has a high Q.

Using thin wires lowers the bandwidth of a half-wave antenna, but not dramatically. However, short wires that are brought into resonance will exhibit high Q. The shorter the wire in terms of wavelength, the higher the Q. Small changes in the transmitting frequency away from the antenna resonances will give rise to a rapid rise in the reactance at the feedpoint.

Thicker wire will lower the Q, reduce resistive loss and make the half-wave dipole less frequency conscious. It is therefore best to ensure that such an antenna is made from the thickest possible wire consistent with such factors as the pull on the antenna supports, windage and sag.

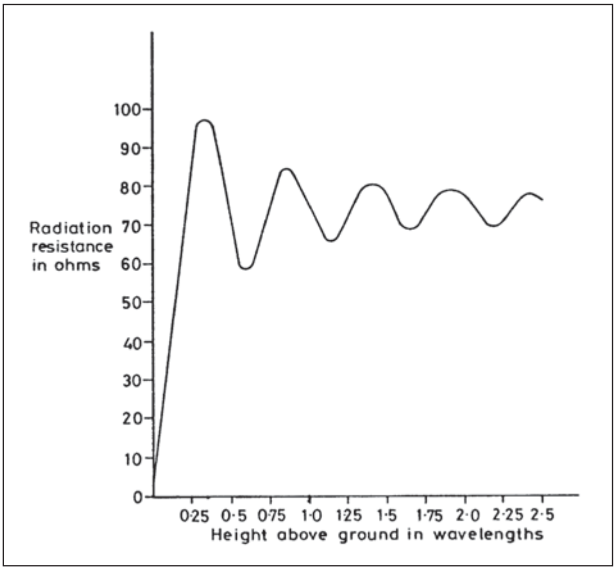


Fig 3.3: Radiation resistance of a half-wave dipole as a function of height above the ground (reprinted with permission of the American Radio Relay League).

DIPOLE HEIGHT

The height of a horizontal dipole above the ground as a ratio of its design frequency is important (see the standard curves of feed impedance against height in **Fig 3.3**). When below about half a wavelength high the radiation resistance at the feedpoint will be reduced, and down at a height of just one-tenth of a wavelength it will only be 25Ω. This means that a dipole fed

THE SLOPING DIPOLE

Horizontal half-wave dipoles require two end supports and it is not always possible to provide these in some awkward locations. In such situations a single support, preferably a non-metallic mast or a high point on a building, will suffice, and then the antenna can be arranged to slope down towards the ground at an angle lying somewhere between 30° and 60° (**Fig 3.14**). The sloping half-wave dipole should have its lower end at least one-sixth of a wavelength above ground, and its feeder should ideally come away from the radiator at 90° for at least a quarter of a wavelength. If coaxial feeder is used the braid should connect to the lower half of the antenna.

The performance of a sloping dipole is quite different from one of the horizontal variety and it can be good for long distance work. The radiation from a sloping dipole shows slant polarisation with both vertical and horizontal components according to the amount of slope. Its lower angle of radiation to the horizon can result in a little low angle gain over a horizontal dipole. This kind of gain is difficult to realise on the low bands in other ways, where for most amateurs multi-element Yagi beams are out of the question.

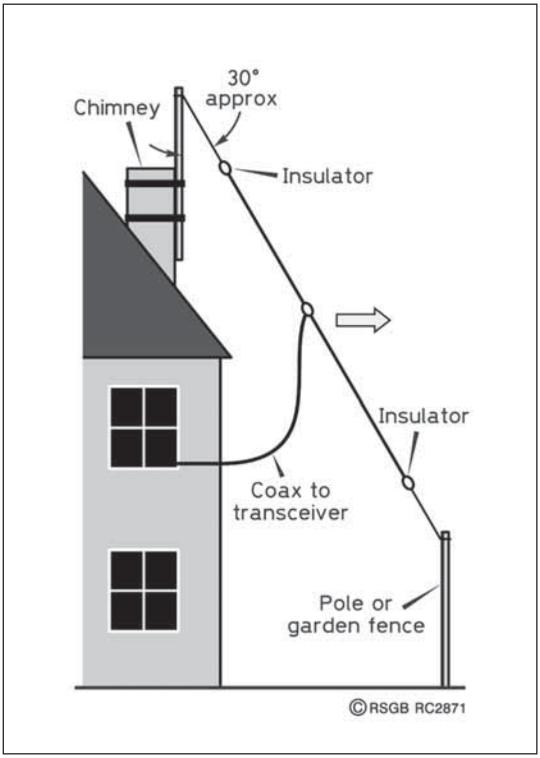


Fig 3.14: A half-wave sloping dipole which can be put up in a small space and which will be useful for long-distance working. Most of its low-angle radiation is towards the low end of the antenna but there is also considerable radiation at high angles in other directions.

There is some high-angle radiation from the sides of the sloping dipole but very little radiation from its high end. An actual plan of the horizontal radiation pattern resembles a heart with a null between its two upper lobes. This null corresponds with the high end of the sloping dipole. A disadvantage is of course that long-distance working will only be possible towards one direction, but this may be overcome by having a group of three or four ‘slopers’ suspended from a common central support, each with its individual feedline which may be selectively switched to the transceiver. (There are designs which involve the unused dipoles in such arrangements as reflectors to improve forward gain and front-to-back ratios, but their correct adjustment can be complicated.)

Slopers are ideal in many applications where a single support is available. Many people who have beams and towers, mount a sloper on the tower for one of the lower frequency bands, ensuring that the direction of maximum radiation is arranged towards the areas of the globe they want to contact, sometimes having two or more around the tower.

THE VERTICAL DIPOLE

A vertical half-wave dipole will radiate vertically-polarised signals all round, and much of the radiation will be at the low angles favourable for DX working. If a feed impedance of around 70Ω is required, the centre of this antenna must be around 0.45λ above the ground and so it is usually more convenient to arrange for a vertical *quarter-wave* antenna to be used, which can then have its feedpoint at or near ground level. A vertical dipole cannot be hung down from a metal mast or tower, and it should have its feeder come away from the radiator wire at right angles if the radiation pattern is to be preserved, which may present some problems. As a result, vertical half-waves are not often used by amateurs, although they can be practical on the higher-frequency HF bands. A practical design for vertical dipoles is given in the chapter on vertical antennas.

A 3λ/2 DIPOLE: THE 40M DIPOLE ON 15M

The dipole, when fed with coaxial cable, is basically a single band antenna. While this is true, there are a few ways that dipoles can be made to work on more than one band. One method is to parallel two or more dipoles for different bands together; another is to use traps. We will look at both of these methods later in this chapter. The simplest way, though, is to take advantage of the fact that the low impedance at the centre feedpoint of a dipole occurs not only when it is one half-wave long, but also when it is three half-waves long (and in fact all odd numbers of half-waves). We can take advantage of this where amateur bands have this same harmonic relationship, i.e. where one band has three times the frequency (or five or seven times, etc), and therefore one third (or one fifth or one seventh) of the wavelength of another band.

On HF, the best example of this is the relationship between 40m and 15m: the third harmonic of 7MHz is 21MHz. What this means is that a 40m dipole *should* also work on 15m. Unfortunately, life isn't quite that simple. As we have already seen, the end effect means that a half-wave dipole is physically about 5% shorter than its theoretical (electrical) half-wave length. However, when the same antenna is operating on its third harmonic, it becomes *fifteen* per cent shorter than the electrical length of a three half-waves antenna. What this means in practice is that it is actually resonant quite a bit higher in frequency than you might expect.

The way around this problem is to resonate the 40m dipole at the very bottom of the band, 7000kHz, or even make it somewhat longer still, so that the minimum SWR point is actually *below* the bottom of the band on, say, 6980kHz. On 21MHz you will find the minimum SWR point is nevertheless at the *top* of the band, around 21400 or 21450kHz.

Furthermore, *QST* Technical Editor Joel Hallas, W1ZR, points out (in the July 2009 *QST*) that the resonant impedance of a 3λ/2 dipole is above 100Ω, so it's not as good a match to 50Ω coax as is the λ/2 case.

The good news is that an external ATU or the internal automatic ATU in your rig should be able to reduce the

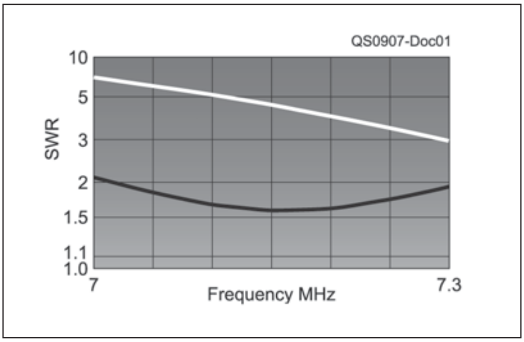


Fig 3.15: Comparison between the 40m (black) and 15m (white) *EZNEC* SWR plots of a 66ft high, 67.2ft long, 40m dipole (diagrams reprinted with permission of the American Radio Relay League).

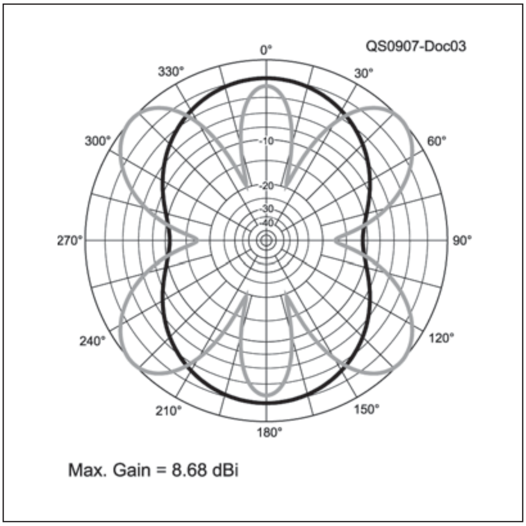


Fig 3.16: Comparison between the 40m (black) and 15m (grey) azimuth patterns of a 40m λ/2 dipole.

SWR to close to 1:1 at your operating frequency of choice in both the 40m and 15m bands.

Fig 3.15 shows a comparison between the 40m and 15m *EZNEC* SWR plots of a 66ft high, 67.2ft long, 40m dipole made of 14 gauge bare wire. In **Fig 3.16** note that the azimuth pattern of a 3λ/2 dipole is not the same as the usual λ/2 case. While different, the pattern can be useful and provides a bit of additional gain in its prime directions.

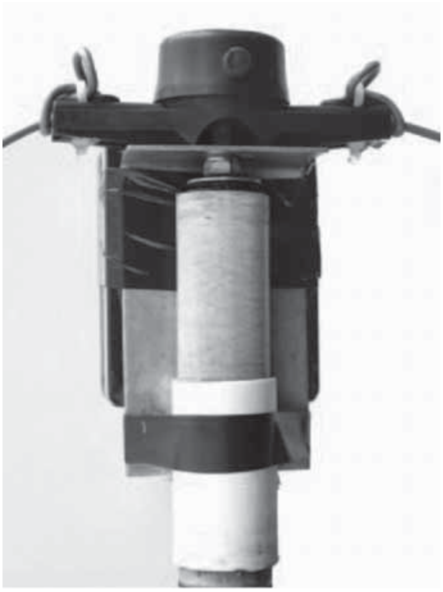
On HF there are a few other combinations of bands that have an odd harmonic relationship, for example an 80m half-wave dipole cut for the lower-frequency end of the band is five half-waves long on the 17m band, and seven half-waves long on the 12m band. (However, if the 80m dipole is cut for the SSB DX end of the band, around 3800kHz, its five and seven half-wave resonances will be well above the top end of the 18MHz and 24MHz bands respectively, and the SWR is likely to be very high on both bands.)

MOUNTING A WIRE DIPOLE ABOVE A ROTATOR

Most amateurs with masts and towers suspend their HF wire dipole or inverted-V dipole from a point below the rotator, leaving the beam free to rotate above. However, mounting a dipole on a mast extension *above* the beam is a much better option, provided the inverted-V angle can be made shallow enough to clear the beam as it rotates underneath. Another strong reason for mounting low-band dipoles above the beam is the extra height above ground, which makes them more effective – undoubtedly for DX, and often for more local QSOs as well. The problem with this 'over the top' approach is that the centre of the dipole must be able to pivot on the top of the mast, so that the mast and beams can rotate beneath it.

One successful solution to this problem was designed by Jan Fisher, G0IVZ, and taken up by Ian White, GM3SEK, in his 'In Practice' column in the April 2009 *RadCom*. The rotating mast for the HF beam is made from scaffold tubing, extended by a 1.5in fibreglass pole (an aluminium pole of that diameter probably couldn't handle the bending forces). The top of the extension pole is filled by a close-fitting

80m dipole over the top of a small HF beam.



Close-up of the rotating dipole centre with balun box to the rear.

hardwood plug, drilled 8mm through the centre and secured with epoxy.

G0IVZ's idea was to use a ready-made centre insulator that was originally designed for mounting a tubular dipole on the boom of a Yagi. The plastic moulding is strong enough to support a much longer wire dipole, simply tied on through the fixing holes as shown in the photograph. G0IVZ used the built-in terminal box to connect the dipole to the coax feedline, while GM3SEK, who has adopted a similar set-up, connected the two wire ends to the terminals on the balun box.

The main mounting hole of the centre insulator is drilled 8mm for an M8x100mm stainless steel screw which is the pivot pin for the whole assembly. In GM3SEK's version, the balun bracket is fixed to the bottom of the insulator with a nut, so those two parts rotate together. A large washer is added to spread the down-thrust, and the free end of the screw simply drops into the hole in the wooden plug. A later addition was a piece of white PVC waste pipe, taped to the bracket to prevent the bottom edge scratching the fibreglass. Below this fitting there has to be a rotation loop in the coax and of course there's the usual loop around the rotator itself.

THE FOLDED DIPOLE

Another form of dipole is the folded dipole, shown in **Fig 3.17**. It is often used as a part of more complex antennas such as Yagis, but it can also be a useful antenna on its own. It has the advantages that it has a higher impedance and a wider bandwidth than an ordinary dipole.

The 300Ω feed impedance is an important feature of a folded dipole. The power supplied to a folded dipole is evenly shared between the two conductors which make up the antenna, so therefore the RF current, I, in each conductor is reduced to I/2. This is a half of the current value (assuming that the same power is applied) at the centre of the common half-wave dipole, so the impedance is raised. By halving the current at the feedpoint yet still maintaining the same power level, the impedance at that point will be four times greater. This means that a two-conductor folded dipole will have a feed impedance of 280Ω, which is close to the impedance of 300Ω twin feeder. It can therefore be satisfactorily matched and fed with this feeder, and have a low SWR along the feedline.

If a third conductor is added to the folded dipole (**Fig 3.18**), the antenna current will be evenly split three ways and the impedance at the feedpoint will be nine times greater than the nominal 70Ω impedance of a simple dipole. Such a three-wire dipole with its feed impedance of 630Ω will make a good match to a 600Ω feeder. This feeder may be made from 18SWG wires which are spaced at 75mm (3in).

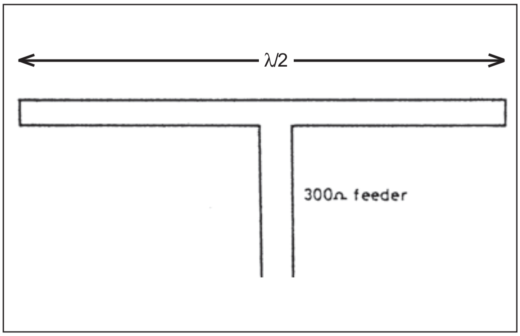


Fig 3.17: The basic two-wire folded dipole.

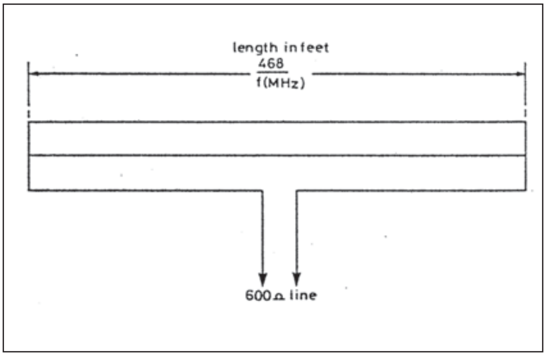


Fig 3.18: A three-wire folded dipole. If each wire is of equal diameter the total current will be shared equally between the three wires and the impedance at the feedpoint will be nine times that of a conventional half-wave dipole (9 x 70Ω = 630Ω), a close match to a 600Ω feedline.

4 Doublets

ONE CLASS OF antenna that is not as widely used as it might be is that of tuned feeder antennas. Using an open-wire tuned feedline as part of the overall antenna system enables multi-band operation to be achieved, although such an antenna - often called a *doublet* - does require the use of an ATU to ensure that there is a good match to the transceiver.

The key to tuned feedline antennas is naturally the feeder. As discussed in Chapter 2, these open-wire feedlines have a characteristic impedance which relates to the diameter of the wire used and the spacing between the feed wires. This impedance is important in many applications, but note that it is of no consequence when considering centre-fed antennas which use tuned lines exclusively.

Tuned feedlines operate on the principle that they are really a part of the antenna and have 'standing waves' along their lengths. Standing waves are a feature of most radiating wires but, if two such wires of equal length are closely spaced (in terms of wavelength) and fed in anti-phase, in theory they will not radiate (in practice they will radiate a very small proportion of the RF power applied).

THE BASIC DOUBLET ANTENNA

The basic doublet (**Fig 4.1**) is a probably the most useful simple multi-band antenna for amateur use. It is simple and yet effective, and requires no special earth or counterpoise arrangements. The only drawbacks are the requirement to use an ATU

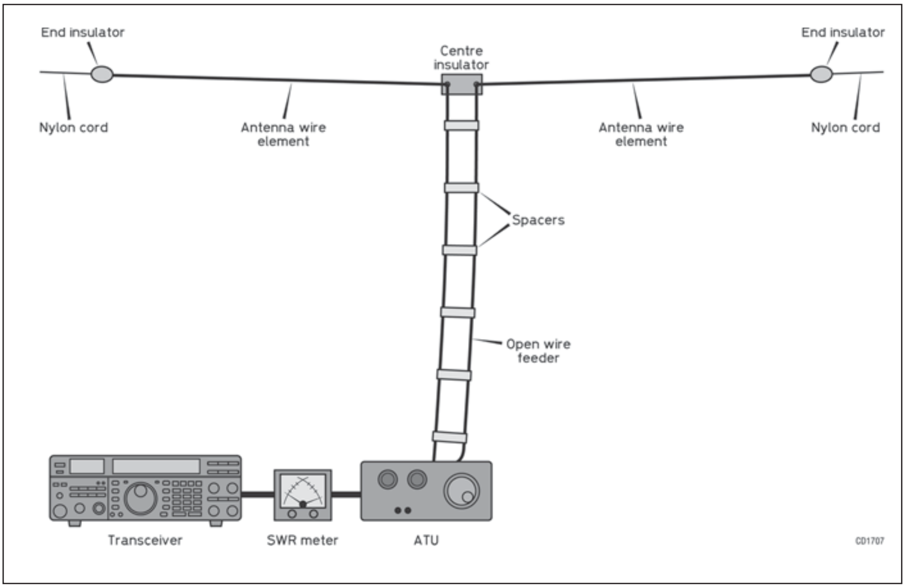


Fig 4.1: The basic doublet antenna.

and that the balanced feeder cannot be routed through the house.

The doublet is essentially a balanced system and each half of the top, plus each wire in the feedline, must be equal in length. The antenna top is not cut to resonate at any particular frequency (unlike the half-wave dipole), and almost any length may be chosen to suit an individual location.

The doublet can be used over a wide range of frequencies although as the frequency changes so the radiation pattern of the antenna will alter. A half-wavelength antenna has the maximum radiation at right angles to the axis or line of the antenna. As the electrical length of the antenna increases the phasing of the radiation from the antenna wire means that new lobes appear and grow. Examples of polar diagrams of a half-wave and a three half-wave radiator are shown in **Fig 4.2**.

When erecting an antenna of this nature there are no particular precautions to observe except that, due to possible problems with reactance making a good match difficult to achieve, certain combinations of feeder / top leg length should be avoided. These are summarised in **Table 4.1**. The table shows that when using doublet legs of 15.2m (50ft) together with 16.4m (54ft) of feeder there ought to be little difficulty with reactance on most amateur bands. There are of course many other combinations of top length and

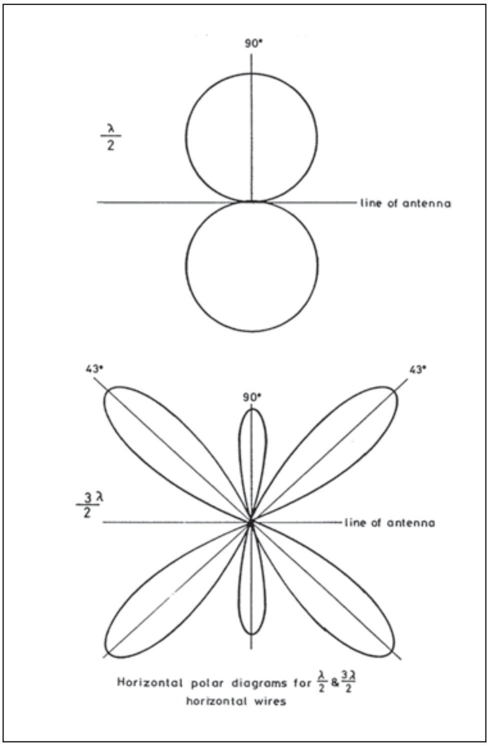


Fig 4.2: Horizontal polar diagrams for half-wave and three half-wave horizontal wires.

Band (MHz)	Lengths to be avoided (metres) (half the total top length plus feeder length)					
1.8 / 1.9	56.4m	93.7m	131m			
3.6	29.26m	48.8m	68.3m			
7	15m	25.14m	35.2m	45.26m		
10.1	10.5m	17.52m	24.53m	31.54m		
14.15	7.5m	12.6m	17.6m	24.2m	27.7m	32.7m
18.1	5.9m	9.9m	13.86m	17.83m	21.8m	25.8m
	29.7m	33.7m				
21.2	4.9m	8.2m	11.6m	14.9m	18.1m	21.5m
	24.7m	28.0m	31.4m	34.8m		
24.94	4.3m	7.1m	10m	12.8m	15.6m	18.5m
	21.3m	24.1m	27.1m	29.9m		
29	3.7m	6.1m	8.5m	11m	13.4m	15.8m
	18.3m	20.7m	23.2m	25.6m	28m	30.5m

Table 4.1: Lengths to avoid when designing multi-band doublets with tuned feeders.

Band (metres)	80	40	30	20	17	15	12	10	6	2
L1 end (2)	168	89.4	63.2	45	35.3	30	25.6	22.4	12.7	4.37
L2 centre (2)	65	34.7	24.6	17.5	13.7	11.7	9.97	8.72	4.95	1.70
L3 total size	467	248	176	125	98	83.3	71.2	62.3	35.4	12.2
L4 stubs	48.6	25.8	18.3	13	10.2	8.66	7.4	6.47	3.68	1.26
L5 height	120	64	45	32	25	21	18	16	10	10
Inductor (μH)	25.9	11.7	7.3	4.9	3.4	2.8	2.2	1.9	0.85	0.13
Gain (dBi)	11.4	11.4	11.3	11.2	11.1	11.0	11.0	11.0	11.4	10.9
Freq (MHz)	3.8	7.15	10.1	14.2	18.12	21.3	24.93	28.5	50.2	146

Table 4.3: Lengths (in feet) of an HGSW beam for 10 amateur bands.

insulators as shown. The lower ends of the two lines should be stripped and bent over and soldered together. The resultant active line length must be 13ft. The distance from the centre insulator to the ladder line should be 17.5ft. If you have a lot of wind in your area you might want to tie a 1oz lead fishing sinker to the bottom of each of the phasing lines. Alternately a string can be attached and tied to some secure point below the antenna. AL7KK says that he has had no problem with his phasing lines except that they curl slightly, which is not ordinarily a serious difficulty.

The antenna is completed by winding five turns of coax near the feedpoint into a 6in diameter coil and securing them with tie wraps. This acts as a cheap but effective choke balun.

EZNEC modelling results indicate that with the antenna at λ/2 high (32.8ft on 20m), the gain will be about 11.2dBi with a peak of the elevation lobe at 29°. Calculated azimuth, elevation and SWR plots at λ/2 height are shown in **Figs 4.14, 4.15** and **4.16** respectively. Even more gain is available, and more importantly lower elevation angles of the main lobe, with greater heights. For example at 3/4-λ, the peak elevation drops to 20°, and to 15° at 1λ.

Table 4.3 shows the lengths necessary to build an HGSW beam for all bands from 80 to 2 metres. The dimensions were scaled from the 20m model that was built and tested, while *EZNEC* was used to calculate the gain and inductor values.

THE G5RV ANTENNA

Louis Varney, G5RV, designed his famous G5RV antenna in 1946, but it was not until 1958 that he wrote about it in 'An Effective Multi-band Aerial of Simple Construction' (*RSGB Bulletin*, July 1958). He described it in greater detail, again in the *RSGB Bulletin*, in November 1966 ('The G5RV Aerial - Some Notes on Theory and Operation'). Finally, he wrote a further article, 'G5RV Multiband Antenna . . . Up-to-Date', published in *Radio Communication* in July 1984.

Louis Varney, G5RV, in 1998.

The G5RV antenna has achieved almost iconic status during the last half century, so it is perhaps worth looking at it in some detail. In this chapter we first look at the design and how it evolved, using Louis Varney's own words and the original diagrams which accompanied his articles. Then we take a 21st century look at the design, using computer analysis, a luxury that obviously Varney did not have in 1946, or even in 1984.

Louis Varney's original design, as published in 1958, is shown in the diagram opposite. Then, he wrote, "The aerial consists essentially of a 102ft flat-top split in the centre where a Pyrex type insulator is inserted, a 34ft long open-wire stub (spacing is unimportant) and sufficient length of 72 ohm coax or twin feeder to reach the transmitter. Alternatively, open-wire feeder may be employed from the centre of the aerial right back to the transmitter output or ATU." These two methods of feeding the antenna are shown in **Fig 4.17 (a)** and **(b)** respectively. It will be noted that what is shown in Fig 4.17(b) is simply a basic doublet with a 102ft top and open-wire feeder.

Describing the antenna's performance on each band, G5RV wrote that on 20m: "...the aerial really comes into its own. On this band it functions as a three half-wavelength aerial... Since the impedance at the centre is about 100 ohms, a satisfactory match to the 72 ohm feeder is obtained via the 34ft of half-wave stub. . . By making the height a half-wave or a full wave above ground at 14 Mc/s and then raising or lowering the aerial a bit at a time while observing the standing-wave ratio on the 72 ohm twin-lead or coax feeder by means of an SWR bridge, an excellent impedance match may be obtained on this band." The technique of matching an antenna by raising or lowering it seems to have been lost over the years!

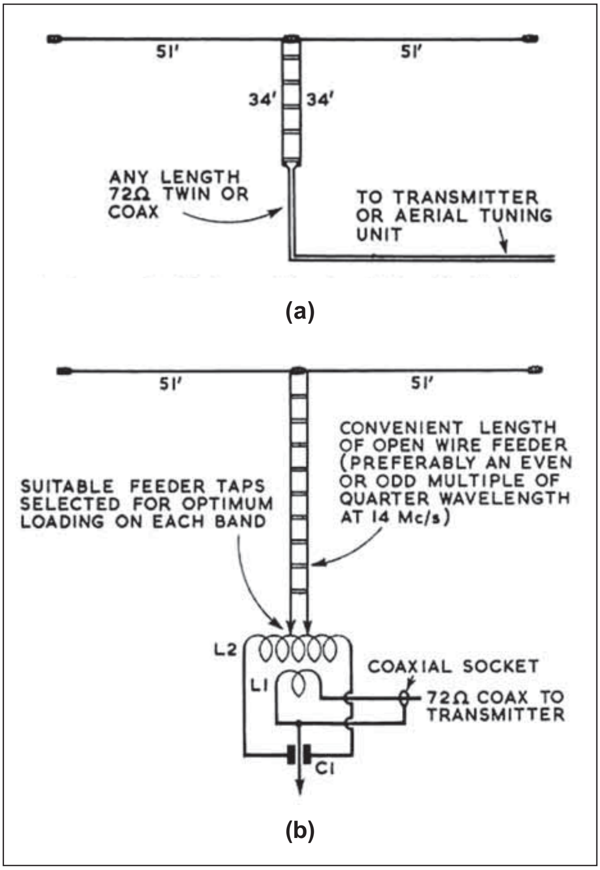


Fig 4.17: The two methods of feeding the G5RV antenna, as described by Lois Varney in his original 1958 article.

By 1966, 300Ω 'ribbon' feeder had become more widely available, and G5RV wrote, "A word about the matching stub is in order. If this is of open wire feeder construction (preferred because of lower losses, especially on 21 and 28 Mc/s) its length should be 34ft... but if 300 ohm ribbon is used, allowance must be made for the velocity factor of this type of twinlead. Since this is approximately 0.88, the actual physical length of the 300 ohm ribbon stub should be 29ft 6in. It should be born in mind that this matching stub is intended to resonate as a half-wave impedance transformer at 14 Mc/s, which was chosen as the design centre frequency for the G5RV aerial, thus giving a very good impedance match for a 75 to 100 ohm twin-lead or coaxial cable connected to the base of the stub." Thus it is clear that, although Louis Varney described the G5RV as a multi-band antenna, he optimised it for use on 20m.

G5RV went on to say, "An alternative arrangement to that of the matching stub and twin-lead or coaxial cable feeder is to use an 83ft length of open-wire feeder measured from the centre of the flat top to the terminals of the ATU." The specific length of 83ft (modified to 84ft in G5RV's 1984 article) was chosen because it "permits parallel tuning of the ATU on all bands from 3.5 to 28 Mc/s with very low feeder losses."

G5RV's 1966 article gave current distribution diagrams for the antenna on each of the five HF bands then allocated to amateurs. He also described the ATU designed for use with the antenna.

The problem of currents flowing on the outer of the coax was recognised by G5RV, for he wrote: "Although it may be very convenient to use a length of, say, up to 100ft of coax direct from the transmitter to the base of the matching stub, it must be remembered that such an arrangement will tend to produce currents which will flow in the outer conductor of the coax, causing unwanted radiation from the coaxial feeder. This may be avoided by the use of either 75 ohm twin-lead and a suitable ATU or the open-wire feeder and ATU as already mentioned. However, the use of a wide-band balun... would be preferable if coaxial cable is to be used. Nevertheless, in practice very satisfactory operation can be achieved by the simple use of coax direct from the transmitter to the base of the matching stub even though the VSWR may reach 10 to 1 or more on 3.5 Mc/s. This figure may be reduced to about 5 to 1 on 3.5 Mc/s by 'pruning' the coax. On the higher frequency bands the VSWR on the coax lies between 5 to 1 and 1.5 to 1, the latter figure applying to 14 Mc/s where, as explained above, the matching is very good."

This suggestion of using a balun was reversed in Louis Varney's 1984 article, in which he wrote: "In the original article describing the G5RV antenna, published in the, then, *RSGB Bulletin* November 1966 [Varney himself appears to have forgotten about the earlier 1958 article - *Ed*], it was suggested that if a coaxial cable feeder was used, a balun might be employed to provide the necessary unbalanced-to-balanced transformation at the base of the matching section. This was because the antenna and its matching section constitute a *balanced* system, whereas a coaxial cable is an *unbalanced* type of feeder. However, later experiments and a better understanding of the theory of operation of the balun indicated that such a device was unsuitable because of the highly reactive load it would 'see' at the base of the matching or 'make-up' section on most HF bands.

"It is now known that if a balun is connected to a reactivbe load presenting a VSWR of more than about 2:1, its internal losses increase, resulting in heating of the windings and saturation of the core (if used). In extreme cases, with relatively high power operation, the heat generated due to the power dissipated in the device can cause it to burn out. However, the main reason for not employing a blaun in the case of the G5RV antenna is that, unlike an astu [ATU] which employs a *tuned circuit*, the balun cannot compensate for the reactive load condition presented to it by the antenna on most of the HF bands, whereas a suitable type of astu can do this most effectively and efficiently." (Louis Varney used the term 'ATU' in 1958 and 1966, but in the August 1983 *Radio Communication* he had had an article published in which he argued the case that the device ought more properly be called an 'Antenna System Tuning Unit', or 'astu'. More accurate or not, the name did not catch on.)

Instead, he recommended the use of an 'HF choke', a device which these days is often referred to as a common-mode choke balun: "Under certain conditions, either due to the inherent 'unbalanced-to-balanced' effect caused by the direct connection of a coaxial feeder to the base of the (balanced) matching section, or to pick-up of energy

3.5MHz	Flat top plus about 17ft (5.18m) of the matching section forms a $\lambda/2$ dipole partially folded up at the centre. Reactive load.
7MHz	Flat top plus 16ft (4.87m) of the matching section functiuons as a partially folded-up collinear array with two half-waves in phase. Reactive load.
10MHz	Collinear array with two half-waves in phase. Reactive load.
14MHz	$3\lambda/2$ centre-fed long wire. Matching section functions as a 1:1 impedance transformer. Resistive load, approx 90Ω.
18MHz	Two full-wave antennas, slightly folded up at the centre, fed in phase. High impedance load, slightly reactive.
21MHz	$5\lambda/2$ long wire. High impedance load, virtually non-reactive.
24MHz	$5\lambda/2$ long wire with low resistive load of approx 90 - 100Ω.
28MHz	Two x $3\lambda/2$ long wires fed in phase. High impedance load, slightly reactive.

Table 4.4: G5RV antenna theory of operation on each of the HF bands (Source: 'G5RV Multiband Antenna... Up-to-Date', by G5RV, July 1984.)

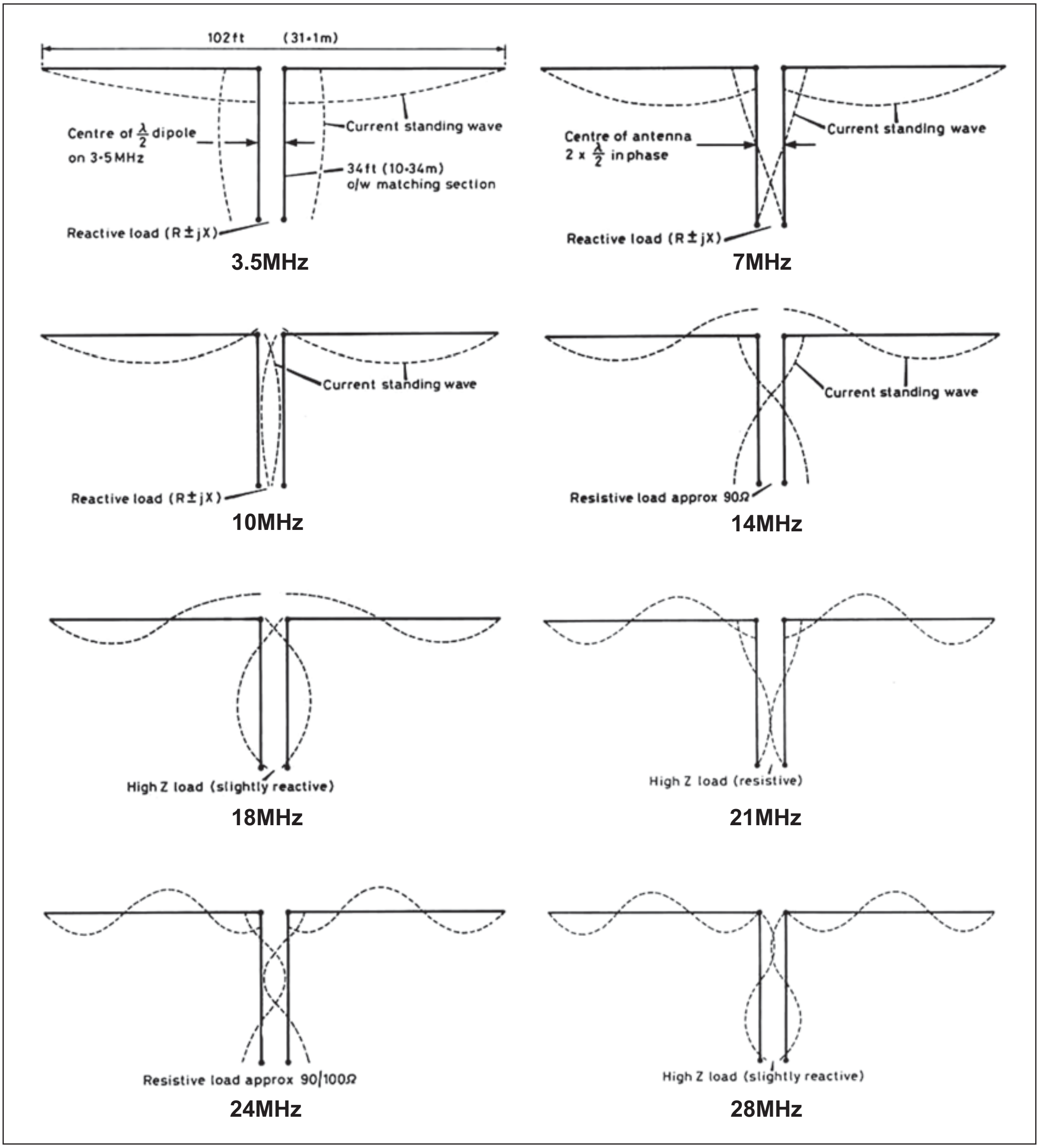


Fig 4.18: Current standing-wave distribution on the G5RV antenna and matching section on each of the HF bands. (Source: 'G5RV Multiband Antenna... Up-to-Date', by G5RV, July 1984.)

radiated by the antenna, a current may flow on the *outside* of the coaxial *outer conductor*. This is an undesirable condition and may increase chances of TVI to nearby TV receivers. This effect may be considerably reduced, or eliminated, by winding the coaxial feeder into a coil of 8 to 10 turns about 6in in diameter immediately below the point of connection of the coaxial cable to the base of the matching section."

By 1984, radio amateurs had been allocated additional bands at 10.1, 18.0 and 24.8MHz, and in his article 'G5RV Multiband Antenna . . . Up-to-Date', Louis Varney described the theory of operation on each of the HF bands, including the three new ones (**Table 4.4**). The current distribution on each band is shown in **Fig 4.18**.

For use in restricted spaces, Louis Varney wrote that, "because the most useful radiation from a horizontal or inverted-V resonant antenna takes place from the centre two-thirds of its total length, up to one-sixth of this total length at each end of the antenna may be dropped vertically, semi-vertically, or bent at some convenient angle to the main body of the antenna without significant loss of effective radiation efficiency." This would imply that the full-size G5RV could be fitted into a space just 68ft (20.72m) long, if 17ft of wire were to be dropped vertically at either end of the antenna.

HALF-SIZE G5RV

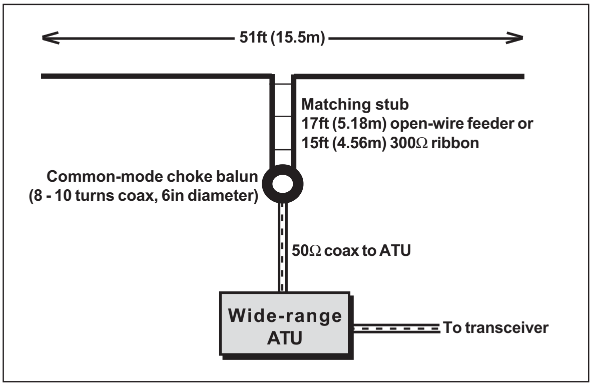


Fig 4.19: The Half-Size G5RV.

The Half-Size G5RV is shown in **Fig 4.19.** Writing in 1966, Louis Varney, G5RV, stated that, "It is quite possible to scale all wire dimensions (including that of the stub) down to exactly half-size and the resulting aerial will work from 7 to 28 Mc/s. Optimum performance and impedance matching will occur on 28 Mc/s, where the operating conditions will be as for the full-size version at 14 Mc/s."

In 1984 he added that by strapping the station end of the feeder (either balanced or coaxial) and feeding it via a suitable ATU using a good earth connection or a counterpoise wire, the half-size version may also be used on the 3.5 and 1.8MHz bands.

THE G5RV ANALYSED

Writing in the August 2010 *QST*, Joel Hallas, W1ZR, commented on three questions often asked about the G5RV antenna:

- What is the function of the usual 34ft section of window line or twinlead between the antenna and the coax?
- Should there be a balun or choke at the transition from the balanced line to coax?
- Should the SWR on the coax be a matter of concern?

G5RV wanted an antenna that would work well in certain directions on 20m, and that could also be used on all the HF bands, at that time just 80, 40, 20, 15 and 10m. *EZNEC* computer analysis, which of course was not available to G5RV when he designed the antenna, allows us to see the radiation pattern on 20m (**Fig 4.20**).

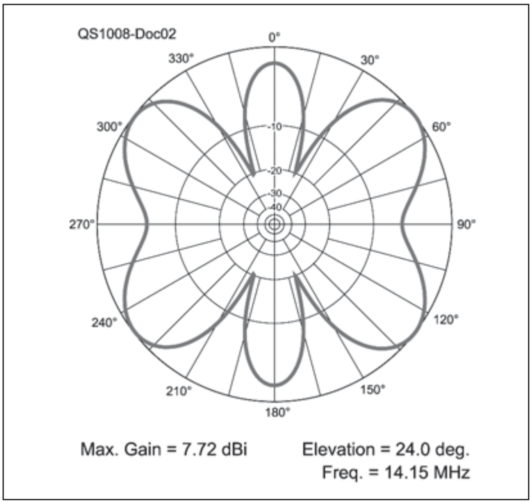


Fig 4.20: Azimuth pattern of G5RV antenna on 20m. At a typical height of 40ft, the peak take-off elevation is 24°. Note the sharp lobes perpendicular to the antenna, as well the broad lobes at other potentially useful angles. The gain at each is within a dB or two of the dual lobes of a half-wave dipole at the same height.

The section of balanced line, 34ft of open wire in Varney's article, transforms whatever the antenna impedance is to a different impedance at its bottom. To say that it provides a good match on all bands may be wishful thinking. On 20m it is a half-wave long and thus repeats the antenna impedance, as it does on 10m. The half-wave window line or twinlead that he used as a transforming section resulted in an impedance at the bottom on 20m of around 100Ω with some reactance.

Computer analysis also allows us to plot the 75Ω SWR from 3.5 to 30MHz (**Fig 4.21**). It shows that there are indeed multiple resonances; however, not many of them line up well with amateur bands.

The dimensions given by G5RV, and with a height of 40ft above ground, produce a 75Ω SWR of 6.5:1 on 3.7, 5.6:1 on 7.1, 2.4:1 on 14.2, 4.6:1 on 21.2 and 2.1:1 on 24.9MHz. Other bands are higher, typically at least 10:1.

A fundamental limitation of the design is that there are only three adjustments - the flat-top length, the height and the transforming section length. With those variables, you can probably find dimensions that will work on multiple, but not all, bands. Unlike trimming a half-wave dipole, the direction to go with each change is not obvious. W1ZR says he has never found a set of dimensions that resulted in acceptable SWR on all, or even most, bands.

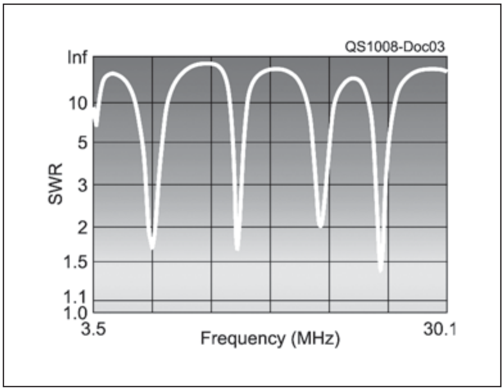


Fig 4.21: 75Ω SWR plot of Varney's original G5RV antenna design using a 34ft section of air-dielectric open wire line as transforming section. The resonances almost line up with some amateur bands, with a 1.7:1 SWR at the top of 20m.

The question about the importance of the SWR depends on the length and loss of the coax used, as well as the tuning range of the ATU used. A high SWR on the higher bands will result in significant loss for typical coax lengths. This makes the SWR at the radio look better than it really is, since the loss reduces the power that gets to the antenna and further reduces the reflected signal. This may explain why many think it has better SWR on multiple bands than it really does.

As with any balanced load to unbalanced line transition, the need for a balun depends on the amount of current that flows on the outside of the shield. This in turn depends on the ground impedance and the electrical length of the coax. Considering its use on multiple bands, it is likely that there will be some bands that have high shield currents and thus could benefit from a balun. At least one commercial manufacturer just slips multiple ferrite beads on the coax just below the transition with good results.

THE ZS6BKW ANTENNA

In 1982 Dr Brian Austin, ZS6BKW (now G0GSF), used some early computer modelling to optimise the G5RV antenna. By then, UK amateurs had access to three additional bands at 10.1, 18 and 24.9MHz, which were not available when G5RV designed his antenna, so operation was also considered on these bands. In 2007 G0GSF re-computed his design and came up with new dimensions for an antenna that presents a better than 2:1 SWR without the use of an ATU in the 40, 20, 17, 12 and 10m bands. It can also be used *with* an ATU on 80, 30 and 15m.

He wrote: "The configuration of the ZS6BKW is shown in **Fig 4.22**. The dipole radiator is L1, the series section impedance matching transformer (to give its formal name), with characteristic impedance of Z2, is L2 spaced twin-wire. The lower end of L2 presents an impedance, Z3, to the coaxial cable, Z4 (50Ω as is standard practice in all modern radio systems). A computer-based pre-

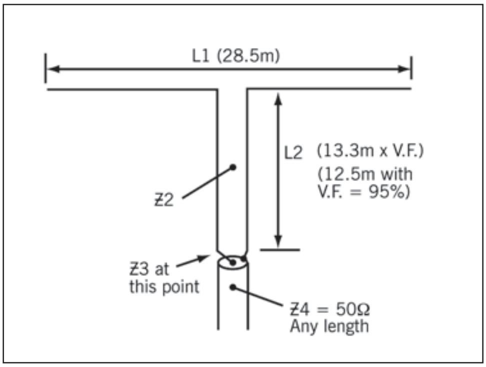


Fig 4.22: The ZS6BKW antenna as computed in 2007 by G0GSF (ex-ZS6BKW).

5 Verticals

AFTER THE DIPOLE, the vertical antenna in its various guises is probably the second most widely-used HF antenna today. Like the dipole, the basic quarter-wave vertical is simple to make and can almost be guaranteed to work with minimal 'pruning' required, provided it is made well and certain guidelines are followed. However, while a horizontal dipole is often easy to mount 'in the clear', a vertical, ground mounted in a typical garden for example, is liable to be screened by nearby objects such as buildings and trees. As a result its performance in typical urban or suburban locations can sometimes be disappointing. Furthermore, a quarter-wave vertical needs a ground plane, usually in the form of radial wires, to work properly, and a less than adequate ground connection can also lead to disappointing results. Nevertheless, a simple quarter-wave vertical wire *can* work well, and in certain circumstances *extremely* well, as we shall discuss later in this chapter.

There is a tendency to think that because a vertical wire takes up virtually no space at all, it is an ideal antenna for those with very limited space. Unfortunately, this is usually not the case. Because quarter-wave verticals require radial earth wires, a quarter-wave vertical antenna system can take up at least as much space as a horizontal dipole for the same frequency band. In the ideal case, quarter-wave long radials will extend in all directions and the vertical radiator would therefore be in the centre of a square a half-wavelength long by a half-wavelength wide. Nevertheless, it *is* possible to make certain compromises without affecting the performance too greatly and, provided you are prepared to put in the ground work (literally), verticals can be very effective antennas, even for those with limited space for antennas.

THE QUARTER-WAVE VERTICAL

The most basic vertical antenna is the quarter-wave. In this configuration one connection from the feeder is taken to the quarter-wave vertical radiating element, and the other is taken to ground. In this way the ground provides the 'image', or other half of the antenna, as shown in **Fig 5.1(a)**. As such the ground connection is an integral part of the antenna system as a whole, and upon its effectiveness rests the efficiency of the whole antenna. In fact this is true for any antenna of this nature that uses the ground for one of its connections.

In view of the fact that one of the connections from the feeder is taken to ground, this type of antenna is an unbalanced antenna. Accordingly it can be fed directly using unbalanced feeder, such as coax, without the need for a balun.

The impedance at the point where a resonant quarter-wavelength vertical conductor meets the ground is about 36Ω - half of the feed impedance at the centre of a resonant half-wave dipole. The current along the quarter-wave vertical antenna is at its maximum at its base and therefore the greatest radiation will take place at this point - see **Fig 5.1(b)**. The radiation will be vertically polarised and in the example illustrated will have equal field-strength levels in all directions.

Much of its radiation will be at low angles to the horizon when above a good ground, and this makes the vertical antenna very attractive for both short-distance (ground wave) and long-distance communications on the lower-frequency bands.

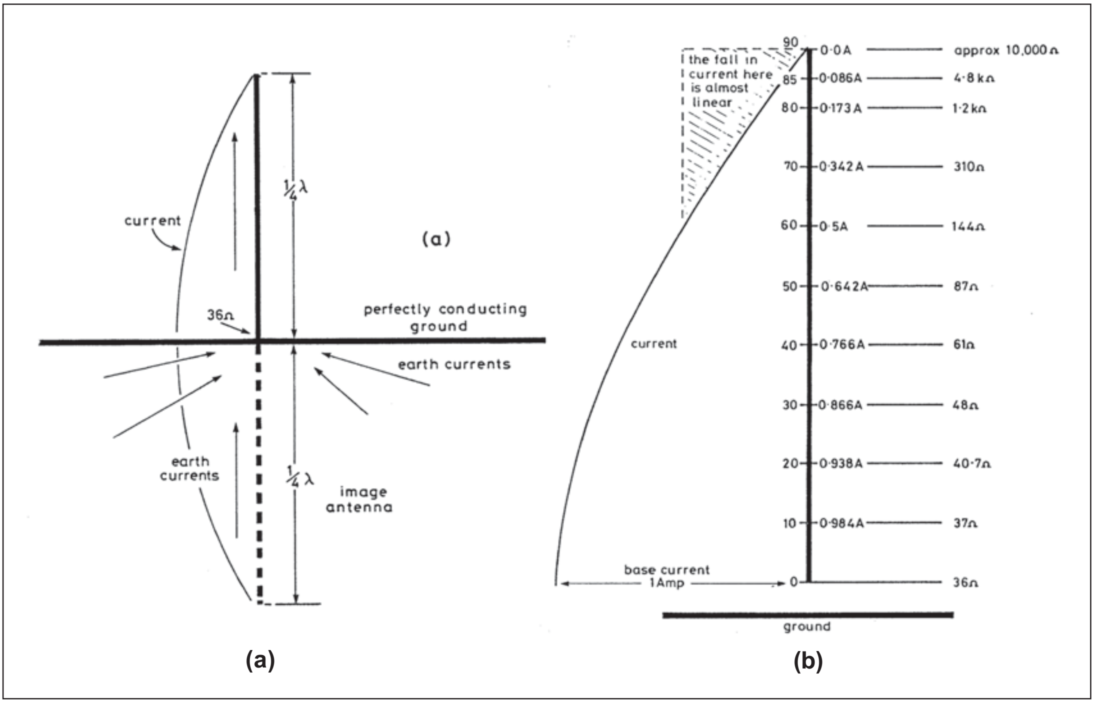


Fig 5.1: (a) The basic quarter-wave vertical antenna positioned over perfect ground, showing its earth image. Most of the earth return currents flow through the ground in the vicinity of the antenna. (b) A representation of a quarter-wave vertical antenna over perfect ground which is energised by a signal with a base current of 1A. The RF current at 10° points along its length is shown and also the impedance at these points. There is a rapid fall in current towards the top of the antenna and the impedance therefore rises greatly there. It is interesting to note that the fall in current over the final 30° of this antenna is almost linear.

The polarisation of an antenna when used for long-distance work does not matter, for the effects of refraction in the ionosphere etc will inevitably induce changes in polarisation.

In order to be able to gain the most from a vertical antenna, the ground system that is used with it must be efficient. One solution is a mat of buried wire extending to at least a quarter-wavelength and possibly a half-wavelength from the base of the antenna but for most practical situations this may not be possible. The antenna will still work with several buried radial (the more the better). Ground systems were discussed in Chapter 1 and there is more on wire radial systems later in this chapter.

As an alternative to the ground-mounted vertical it is possible to elevate the antenna and use a ground plane system, in which case the ground plane wires should be resonant, a quarter-wave long. Raising the antenna in height allows it to take advantage of the 'height gain' available.

Fig 5.1(a) represents a simplified and 'ideal' quarter-wave vertical antenna. The ground is shown to be a perfect conducting medium, a condition which can only be realised when it is replaced by a sheet of metal which has dimensions that are large relative to the length of the antenna or by a large body of salt water. The ground, if it is a perfect conductor, will behave like an electrostatic shield and provide an 'image' antenna a quarter-wave below the radiator. This image completes the missing half of a half-wave antenna, and earth return currents will be induced in the ground.

SHORTENED VERTICALS

It is seldom possible or convenient to erect a full-sized quarter-wave vertical for the lower-frequency bands, although such antennas are often used on the higher frequencies. For the lower frequency bands it is often necessary to look at ways of physically reducing their length. In **Fig 5.2(a)** the full quarter-wave is in the vertical plane and is shown to be bottom fed (impedance 36Ω). **Figs 5.2(b), (c)** and **(d)** show reducing lengths of the vertical antenna sections and corresponding increases in the lengths of the horizontal components. The total height of the antenna is therefore lowered and in (d), where only 25% of the quarter-wave is vertical, the antenna is only 0.06-wavelength above ground.

The three 'bent' quarter-wave antennas shown in (b), (c) and (d) are called 'inverted-L' antennas, and they are very popular arrangements when mast height is limited. As the vertical part of an inverted-L is reduced in length, the proportion of the radiated power at low angles and in the vertical plane also diminishes. The horizontal top section will then contribute more of the total radiation, this radiation being horizontally polarised and at high angles to the horizon. This high-angle radiation is a result of the antenna being close to the ground.

An inverted-L similar to that shown at (c), where the vertical and horizontal portions are equal in length, should give useful vertically-polarised radiation at low angles for both DX work and also local working within the ground wave range. The high-angle radiation from its top horizontal half will be effective for short range communications.

In **Fig 5.2(e)** the top half of the quarter-wave is dropped down towards the ground.

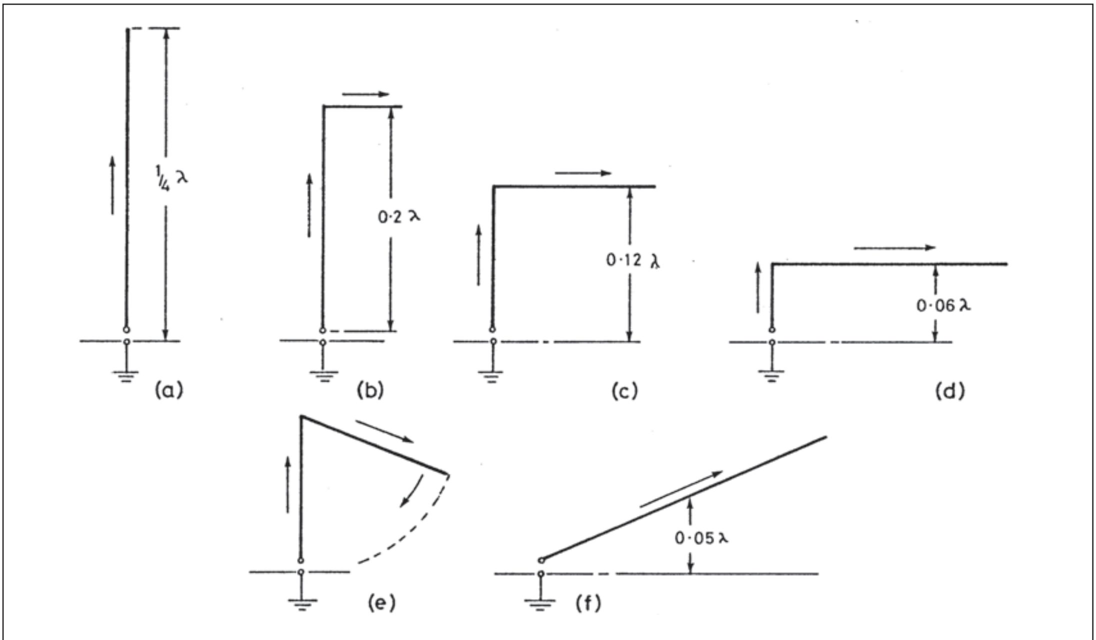


Fig 5.2: The vertical quarter-wave can have a proportion of its length bent horizontally as shown in (b), (c) and (d). When this is done the antenna is called an 'inverted-L'. As the proportion of the vertical section falls the vertically polarised radiation at low angles also falls, the horizontal top giving horizontally polarised high-angle radiation. The example shown at (d) will have most of its radiation at very high angles and will only be suitable for short to medium distance working. It will also have a much reduced ground wave. Bending the top of the inverted-L down (e) will mean that the antenna currents in the two sections will then tend to be out of phase and begin to cancel. At (f) the sloping wire will behave almost like a length of unterminated open-wire feeder.

- It doesn't matter if the vertical section is not fully vertical; for a given support height it *may* be advantageous to have a longer 'semi-vertical' section by sloping it slightly away from the truly vertical;
- Finally, and perhaps most obviously, ensure the vertical section is as high as possible.

The results could not have been more different between the two inverted-Ls and are perhaps counter-intuitive, with the shorter antenna working better on 160m than 80m and the longer one working better on 80m than 160m.

FISHING FOR DX: G0GBI FISHING ROD INVERTED-L

This antenna idea was described by Glenn Loake, G0GBI, in the July 2010 *RadCom*. It builds on the popular use of a fishing rod as a support for a wire vertical or inverted-L by utilising fishing reel and line as well, as shown in **Fig 5.15**. The basic principle is to use a fishing rod and reel to loft a weighted, non-conductive leader line to the top of a tree. The weight should cause the line to hook over a branch and head for ground level. The other end of the line is permanently attached to a 132ft (40.2m) length of

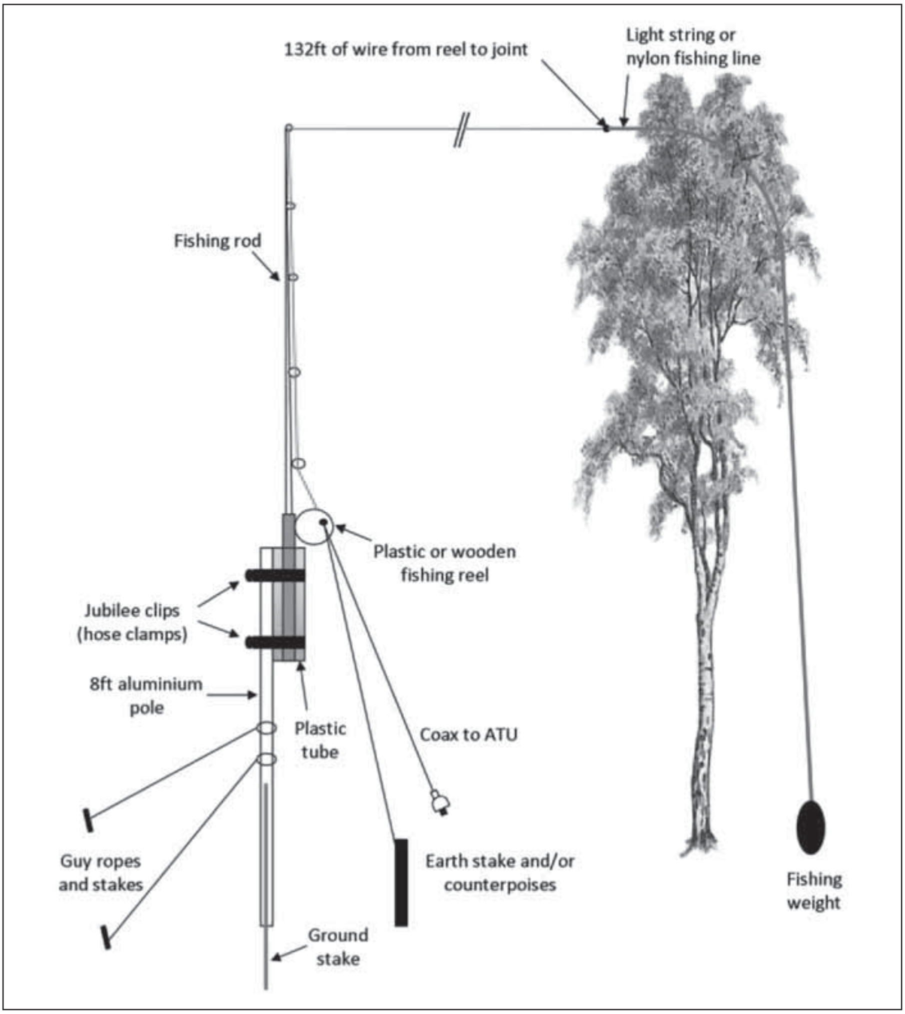


Fig 5.15: General arrangement of the fishing rod antenna system.

Left: The rod support: note how the tube protrudes an inch or so above the support pole.

Below: Attaching the feed (the antenna was not deployed at this point, which is why the antenna wire is not visible).

The completed fishing rod inverted-L, showing the support pole, sleeve, reel and rod.

wire that acts as the antenna element. A stand for the fishing rod plus a couple of guys and some wiring completes the set-up.

The parts are quite easy to obtain. When the antenna is dismantled it fits easily into a car. The only long piece is the aluminium support tube, which could be cut in half and then sleeve joined. It should take less than 10 minutes to erect once a suitable tree has been selected.

None of the parts are terribly critical, so the following is just a guide. You will need a *beach caster* type fishing rod. G0GBI used a telescopic one, but any kind about 8 - 10ft long will do (though you should avoid the conductive carbon-fibre types). You will also need a centre pin type plastic or wooden fishing reel; a commercial fly reel will be fine. Make a connection point in the side of the reel by putting a bolt through it or remove the reel winder knob and put a bolt in its place. Use a solder tag to connect one end of a 132ft piece of thin wire; any wire can be used provided it is thin enough to fit comfortably on the spool with space to spare. Next, attach about a 60ft (20m) length of light string or nylon fishing line to the other end of the wire. A solder tag at the end of the wire provides a handy attachment point. Wind the string on to the reel on top of the wire.

The rod support is constructed from a length of aluminium tube, approximately 8ft (2.5m) long and 1.5in (37mm) diameter, although the dimensions are not at all critical. Attached to the support is a piece of PVC pipe of a suitable diameter to take the bottom of

	Length	
Band	**(m)**	**(ft in)**
160m	39.5m	129'6"
80m	20.5m	67'5"
40m	10.5m	34'8"
30m	7.4m	24'4"
20m	5.3m	17'4"
17m	4.1m	13'7"
15m	3.5m	11'7"
12m	3.0m	9'10"
10m	2.7m	8'9"

Table 5.5: Suggested counterpoise lengths.

the fishing rod. The pipe is about 16in (40cm) long and does not need to be a tight fit to the rod. The plastic pipe can be attached to the support rod using two jubilee clips (hose clamps), as shown in the photo. A piece of steel reinforcing bar about 4 - 5ft long is used as a ground stake.

The final parts to make are the feed and counterpoise. The prototype used a 10ft (3m) length of RG58 coax with a PL259 plug on one end. The other end had an alligator clip on the centre conductor to connect to the end of the antenna wire. The counterpoise length in metres is calculated as 75/frequency (MHz), which allows a bit of extra length for trimming. **Table 5.5** gives suggested values for the mid-point of the HF bands, though you may well find that trimming these by 5% or so will be better. A single counterpoise wire per band was used, although more would probably be better.

To deploy the antenna you need to know how to beach cast a fishing rod. If you don’t, please find someone to teach you otherwise you could injure yourself or others. Select a suitable tree and make sure that there are no people or animals nearby that could be hurt when you cast the leader. Trees beside footpaths are particularly prone to people walking near them, and folk tend to get upset if you hit them with flying lead. Respect the wildlife that may be in the tree - after all it’s their home!

Thread the leader through the rod loops (just like a fishing line) and attach the weight to the end of the leader. Let a good bit of slack off the reel, ensuring it doesn't tangle. Don't try to cast straight off the reel or a ‘bird's nest’ (tangle) will result. Beach cast towards the top of the tree. With luck the weight will carry the leader over a high branch and fall to the ground. Pull the leader over the branch so that the end of the antenna wire is several feet from the leaf canopy. Tie off the leader at the base of the tree. Go back to the rod and pay out the antenna wire as you walk away from the tree. When the wire is fully extended, set up the ground stake, slip the rod support over it and then put the rod in the top of the support. If the antenna wire is a bit saggy then you can go back to the tree and tighten it by pulling on the leader.

Depending on the stoutness of the ground stake and the weight of the antenna wire, you may find it necessary to use some guys to keep the rod support upright. Finally, connect the feed to the bolt on the reel and arrange your counterpoise.

Another method of feeding the antenna is to put an automatic ATU on the ground at the base of the antenna with a wire connected to the driven element. The ATU earth can then be connected to the counterpoise or even just to an earth stake. G0GBI says that if it is windy the SWR will vary alarmingly as the tree sways about, but in practice he has not had any real problems. He uses a small LDG auto tuner.

REMOTELY TUNED INVERTED-L

If an automatic ATU is available, a practical remotely tuned multiband inverted-L is a possibility. See **Fig 5.16**. As with any inverted-L, the vertical section should be as long as possible. A good overall length to aim for would be about 86ft, although this is not critical since the antenna system is brought to resonance with the ATU. For multiband use, a length of around 65ft should be avoided as this would be close to a half-wave on 40m and thus would present a high impedance to the ATU and might therefore be difficult to match.

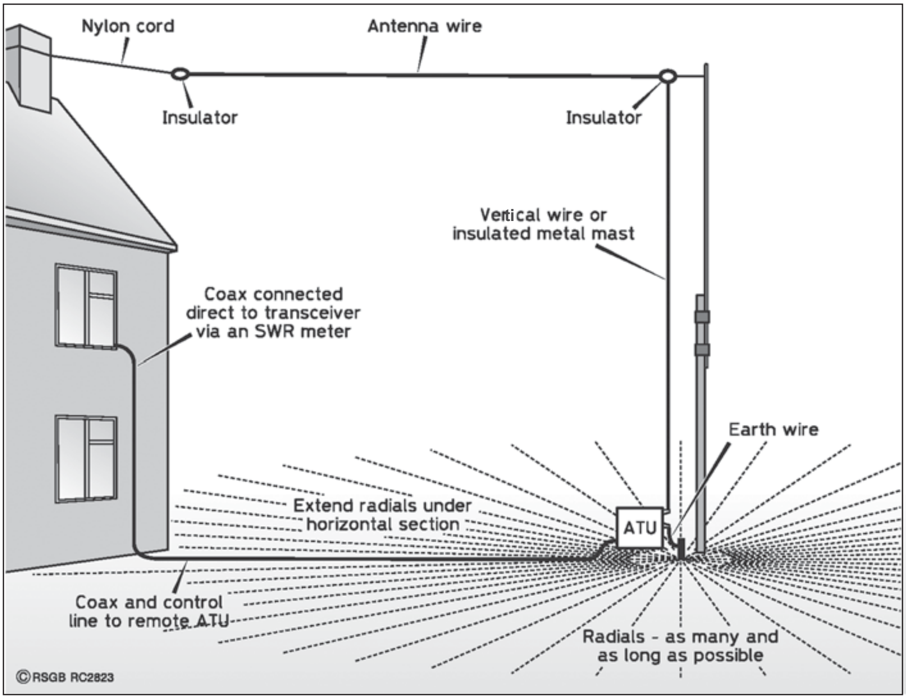


Fig 5.16: Remotely tuned multi-band inverted-L.

160M INVERTED-L PERFORMANCE

Amateurs who wish to operate on the 160m band, but only have a limited space for antennas, often use an inverted-L. It is arguably the best 'compromise' antenna for 160m if you are short of space. But just *how* well does it work? In the May 2008 *QST*, Al Christman, K3LC, described computer simulations of several different configurations of 160m inverted-L antennas. The height of the vertical section of the radiator and the length of the radials are varied in 20ft intervals from 30 to 90ft. The complete *QST* article includes calculated data for input resistance, peak forward gain, SWR bandwidth, efficiency, front-to-back ratio and front-to-side ratio for each case. Here, we present an edited summary of this study.

For those who do not have access to a support high enough to hold up a full-size 160m monopole the choice is straightforward - either use a shortened monopole with base, centre or distributed loading, or use a full-size $\lambda/4$ antenna with the vertical portion going to the top of an available support and the rest extended horizontally to a second support, as shown in **Fig 5.17**. While either technique can be used, the second provides for efficiency and bandwidth approaching that of a full-size monopole. The loaded antenna has lower radiation resistance, resulting in more of the transmit power being lost in the resistance of an imperfect ground, and generally has nar-

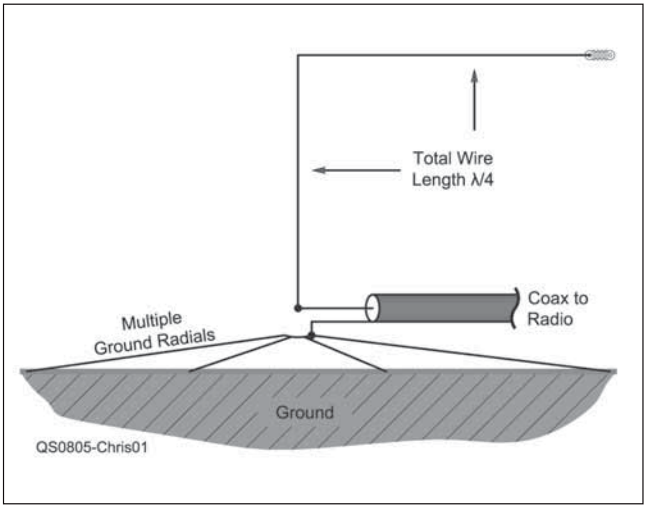


Fig 5.17: The configuration of an inverted-L antenna (diagrams reprinted with permission of the American Radio Relay League).

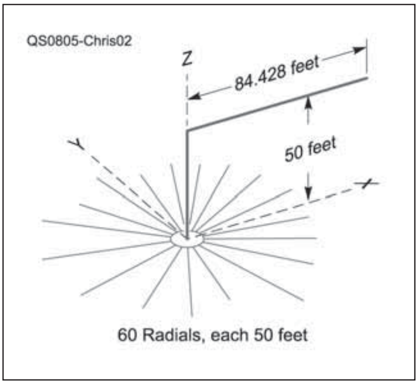


Fig 5.18: This inverted-L antenna uses a ground screen composed of 60 buried radials, each of which is 50ft long. The height of the vertical section of the radiator is 50ft, and the horizontal portion has a length of 84.428ft, which resonates the antenna at 1830kHz.

rower bandwidth (unless the losses are *so* high that it starts acting like a dummy load). The only downside of the inverted-L is that it requires a second support and has some directivity - but perhaps that can be used to advantage.

All of the antennas described here were modeled using *EZNEC/4* with a double precision calculating engine. Unlike other *EZNEC* versions, this version of the software is capable of simulating vertical antennas with radials buried in real ground. The soil was assumed to be 'average' (conductivity of 0.005 siemens per metre, dielectric constant of 13). The radiator (both vertical and horizontal portions) is made from 12 gauge copper wire and the radials modelled with 16 gauge copper wire. The number of radials was fixed at 60 because it is well known that it is important for a vertical antenna to have a good ground system. Tapered segment lengths were used for all wires, in accordance with the most conservative NEC modelling guidelines. The inner segment of each radial is about 1ft long, and slopes downwards from the base of the vertical element (at exactly H = 0) to its ultimate burial depth of 3in; the remaining length of the radial is completely horizontal.

The height of the vertical section of the inverted-L radiator was initially set at 30ft, using 60 buried radials that were also 30ft long. The length of the horizontal portion of the wire was then adjusted in order to resonate the antenna at a frequency of 1830kHz, after which all of the important performance data was collected. Next the length of the vertical section was progressively increased to 50, 70 and finally 90ft, with the tuning and measurement process being repeated each time. This entire sequence was then carried out again, as the length of the buried radials was increased in succession from 30 to 50 to 70 to 90ft.

Fig 5.18 shows what the antenna looks like when the height of the vertical section is 50ft, and the 60 buried radials are also 50ft long. In this case, the horizontal portion of the inverted-L had to be cut to a length of 84.428ft to achieve resonance (input reactance close to zero) at 1830kHz.

Modelling results

The resulting elevation-plane radiation pattern, in the plane containing the inverted-L, is given in **Fig 5.19**. Notice that maximum gain is actually directed *opposite* to that of the horizontal section of the radiating element; if you want to beam the strongest

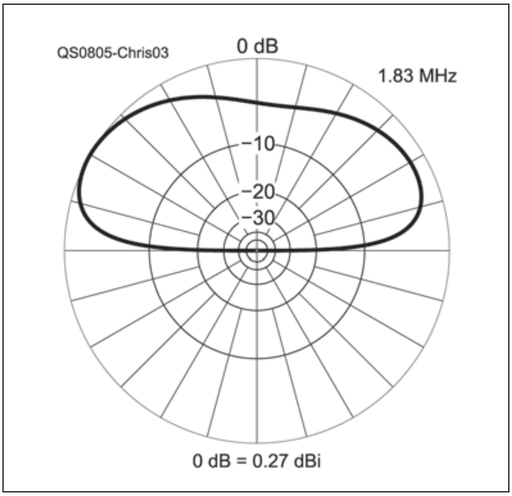


Fig 5.19: This is the elevation-plane radiation pattern of the antenna shown in Fig 5.18, in the plane containing the inverted-L wire. The front of the main lobe is directed towards the left, opposite to the position of the horizontal section of the radiator element. The peak gain is 0.27dBi at 30.1° take-off angle, and the front-to-back ratio is 1.42dB.

signal to the north-east, the horizontal portion of the L must extend towards the south-west. However, the front-to-back and front-to-side ratios are modest for all of the designs studied here, and are always less than 3dB.

Table 5.6 displays the input resistance at resonance for the various inverted-L configurations. We can see that, if the length of the radials is held constant, making the antenna taller will increase the magnitude of the input resistance. In contrast, if the height of the radiator is fixed, making the radials longer causes the input resistance to fall because the ground loss resistance is lower.

Table 5.7 shows how the maximum gain of the antenna and its corresponding take-off angle (TOA) vary with the length of the radials and the height of the vertical section. Notice that, for 30 and 50ft radials, making the antenna taller always yields more gain, at least for the range of heights discussed here. However, with 70 and 90ft radials, an element with a height of 70ft is actually a bit better than one that is 90ft tall.

When it comes to elevation angles, increasing the height of the antenna always produces a lower TOA, for radials of any particular length. For example, an element height of 30ft generates maximum gain at an elevation angle of 38.4° (on average) versus a typical TOA of 30.5° for a height of 50ft. Increasing the antenna height to 70ft drops the TOA to about 27.1°, while a height of 90ft results in a peak elevation angle of 25°.

The bandwidth capability of each antenna is listed in **Table 5.8**. These values were determined by calculating the standing wave ratio as a function of frequency, with the input resistance at resonance used as the reference impedance. If the radial length is fixed, making the antenna taller always increases the SWR bandwidth. On the other hand, for a given radiator height, making the radials longer always reduces the bandwidth.

Height (feet)	**30**	**50**	**70**	**90**
Radial Length (feet)	**Input Resistance (Ω)**			
30	19.15	25.43	33.52	40.99
50	14.72	21.35	29.43	36.81
70	12.29	19.16	27.17	34.43
90	11.02	17.97	25.86	32.99

Table 5.6: Input resistance for inverted-L antennas at resonance, as a function of radial length and antenna height. In each case, the ground screen is composed of 60 radials in 'average' soil (see text). The horizontal portion of the wire radiator is trimmed to resonate the antenna at 1830kHz.

Height (ft)	30	50	70	90
Radial Length (ft)	Gain (dBi) and Take-off Angle (Degrees)			
30	–1.77 @ 38.4	–0.41 @ 30.6	–0.01 @ 27.2	+0.11 @ 25.0
50	–0.82 @ 39.3	+0.27 @ 30.1	+0.51 @ 27.2	+0.55 @ 24.7
70	–0.21 @ 37.9	+0.66 @ 30.1	+0.82 @ 26.5	+0.81 @ 25.2
90	+0.16 @ 38.0	+0.89 @ 31.3	+1.01 @ 27.4	+0.99 @ 24.9

Table 5.7: Peak forward gain and corresponding take-off angle for inverted-L antennas, as a function of radial length and antenna height. In each case, maximum gain occurs in the plane containing the radiating element, and is oriented opposite to the direction of the horizontal portion of the L.

Efficiency and other data

EZNEC has the ability to estimate the average gain of an antenna and compare this with a theoretical lossless antenna operating in a lossless environment. Its average gain (over all angles of elevation and azimuth) is exactly 1, or 0dB, and its efficiency is therefore 100%, while an antenna whose average gain is -3dB must have an efficiency of 50%. **Table 5.9** provides a compilation of the efficiencies of our inverted-L antennas, based on the computer-predicted values for their average gain.

If the antenna height is held constant, we can see that making the radials longer always increases the efficiency. This intuitively makes sense because we expect a larger ground screen to reduce losses in the system. If the length of the radials is fixed at either 30 or 50ft, making the antenna taller always improves the efficiency. The story changes, though, if longer radials are installed. For 70ft radials, maximum efficiency is achieved when the height is 70ft (a height of 90ft works almost as well, followed by a height of 50ft). If the length of the radials is 90ft, a 70ft vertical again performs best, but now the 50ft tall element takes second place, with the 90ft vertical in third position. Notice that the inverted-L with the highest efficiency of all those tested (39.4%) uses 90ft radials in combination with a 70ft vertical section. In contrast, the worst antenna (which uses 30ft long radials and a 30ft tall vertical element) is roughly half as efficient (19.8%).

Fig 5.19 showed that the inverted-L did not have a significant amount of directionality in the azimuthal plane and this was true for all the antennas analysed.

Height (ft)	30	50	70	90
Radial Length (ft)	2:1 SWR Bandwidth (kHz)			
30	57	74	97	119
50	44	62	86	106
70	36	55	78	99
90	32	52	74	94

Table 5.8: 2:1 SWR bandwidth for inverted-L antennas, as a function of radial length and antenna height. In each case, the reference impedance for the SWR is the input resistance value given in Table 5.6.

Height (ft)	30	50	70	90
Radial Length (ft)	Efficiency (%)			
30	19.8	28.2	30.8	31.6
50	25.2	33.3	34.9	35.0
70	29.5	36.7	37.6	37.2
90	32.7	39.1	39.4	38.8

Table 5.9: Efficiency of the various inverted-L antennas, as a function of radial length and antenna height. In each case, the efficiency is calculated from the average gain of the antenna, as given by *EZNEC*. (Note that the efficiency of a full-size $\lambda/4$ vertical, calculated by this method, is only 40.6% - see text.)

For purposes of comparison, a full-size λ/4 vertical was also modelled, using 60 λ/4 (134.368ft) radials buried in average soil. A height of 130.826ft was required to obtain resonance at 1830kHz. The resulting input resistance was 38.25Ω. The gain was 1.15dBi at 21.8° take-off angle, the 2:1 SWR bandwidth 109kHz and the efficiency 40.6%. It is interesting to see that the performance of this antenna is not significantly better than that of the best inverted-L designs in our study, although it is much taller and has a much larger ground system.

Computer models are imperfect representations of the real world, and cannot possibly include all of the features that are actually present, such as buildings, vegetation, other conductive objects, irregularities in the terrain, non-uniformity of the ground constants and other local parameters. However, it is hoped that the information in this study will be helpful to those who are considering the use of an inverted-L on topband.

G3PJT 160M T-VERTICAL

The simple vertical T antenna shown in **Fig 5.20** is often recommended for 160m use because of its low angle of radiation. One of its principal advantages is that its dimensions are more realistic than those of a full-size 160m vertical. However, most of the recommendations on making a vertical T are somewhat casual, usually couched in terms like "for 160m use your doublet with the feeders strapped together, fed against ground via your ATU". Such a nonchalant approach is unlikely to lead to the best results. An article by Bob Whelan, G3PJT, in the July 2009 *RadCom* suggests a better way.

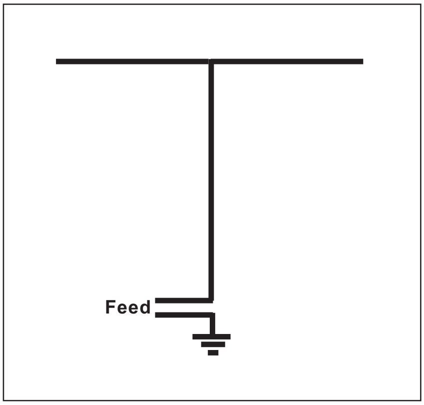


Fig 5.20: Basic T antenna.

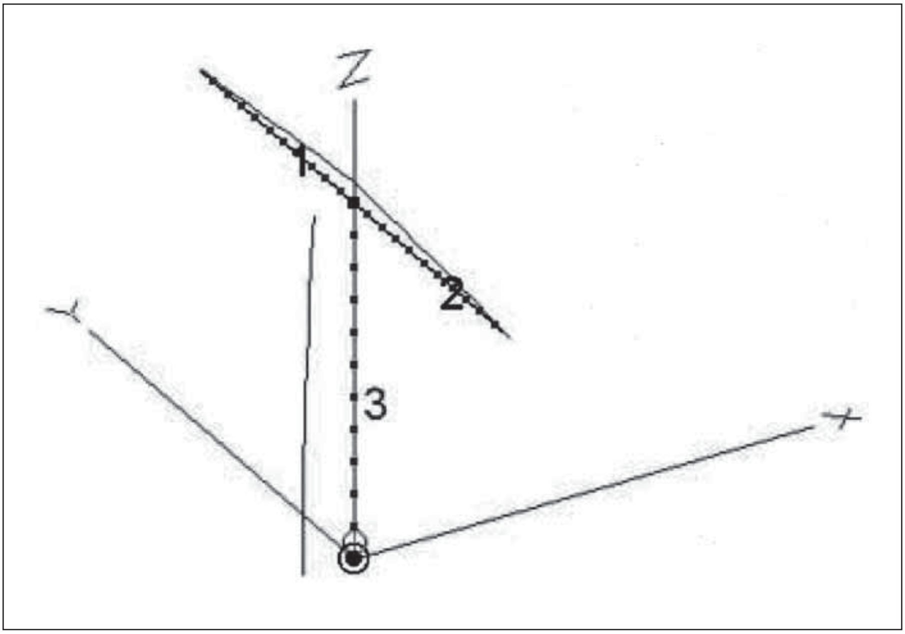


Fig 5.21: Modelling the T antenna in *EZNEC*.

A T antenna erected at a typical height of between 10 and 20m and having a span of 30 to 40m will have a feed impedance R ± *j* X of between 4 - *j* 190Ω and 23 + *j* 150Ω. These impedances not only mean that some sort of antenna tuning unit will be required to match to 50Ω coax but also that losses due to ground quality and the system as a whole need to be minimised.

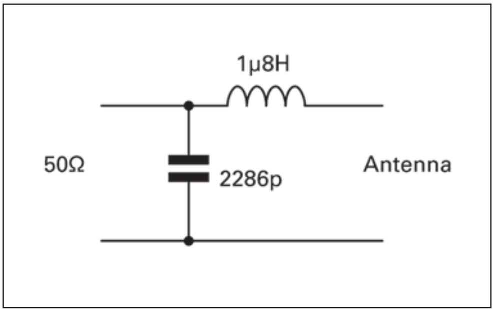


Fig 5.22: L matching section.

To put this in a practical perspective, G3PJT's doublet was 17m high with a span of about 30m. Modelling this using *EZNEC+* (**Fig 5.21**) showed that at 1820kHz an impedance of around 11+*j* 16Ω could be expected, to which an estimate of other losses needed to be added. The *TLA* program showed that such an impedance would need a L section shunt C of 2286pF and series L of 1.8µH to the antenna, as shown in **Fig 5.22**. (*TLA* is the ARRL Transmission Line Advanced program, bundled with the *ARRL Antenna Handbook*, available from the RSGB Bookshop and ARRL.) However, when G3PJT matched the antenna with this network, he found that a shunt C of 2850pF alone gave an excellent match at 1820kHz. Such a simple arrangement is very low loss.

So much for the theoretical calculated impedance, but what was the *actual* impedance of the antenna? G3PJT used the program l_network.exe (by R J Edwards, G4FGQ (SK), available at http://zerobeat.net/G4FGQ/index.htm) to perform the inverse calculation from *TLA*. This showed that his T antenna impedance was more like 14+ *j* 22Ω, which of course includes all the losses. This indicated that his ground loss was only around 3Ω, which seemed very low, but it did raise two questions: (a) what is the range of antenna impedances that only require a shunt capacitor to match to 50Ω?, and (b) what would be the dimensions of such a T antenna?

TLA calculated that 5+ *j* 14Ω, 10+ *j* 19Ω, 20+ *j* 24Ω and 30+ *j* 24Ω would fill the

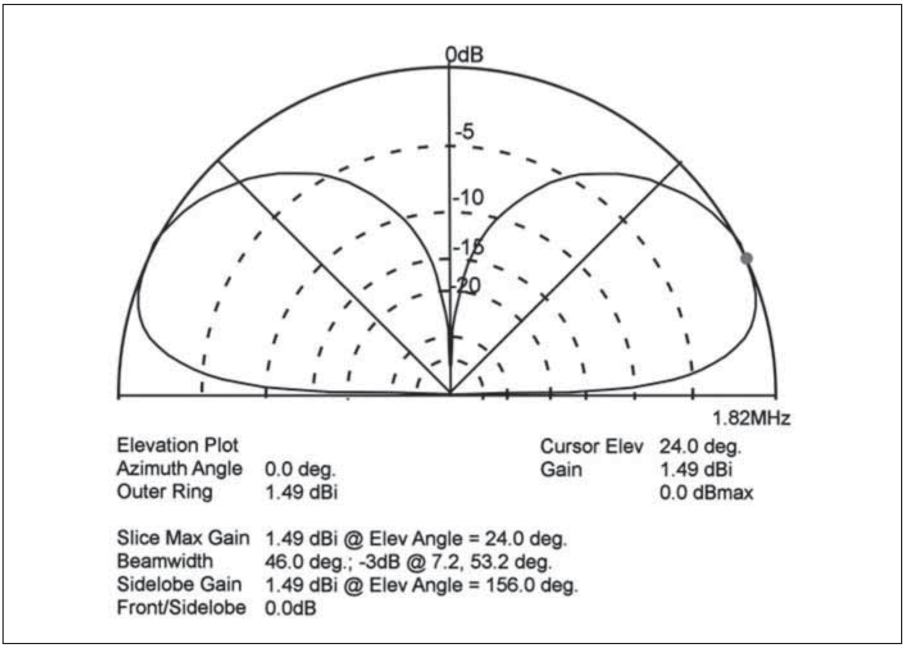


Fig 5.23: G3PJT's T antenna elevation radiation pattern.

Height (m)	Span (m)
11.0	50.0
17.5	34.0
23.0	23.4

Table 5.10: Suggested dimension for a T antenna requiring only a shunt capacitor to match to 50Ω.

bill. To use these values as the basis in *EZNEC* you need to insert a load that is representative of your earth loss. In G3PJT's case, based on the above, he estimated this at about 5Ω and so inserted a 5Ω load in *EZNEC*. Modelling his own antenna in *EZNEC* (**Fig 5.23**) showed that its performance was pretty good, with maximum gain 1.49dBi achieved at an elevation angle of 24°.

More modelling suggested the T antenna dimensions given in **Table 5.10** for an efficient and simple match. These dimensions may need to be adjusted to trim the antenna to the frequency desired. Of course, ground losses will affect these values too and should be minimised. If you want to have a very efficient and simple matching arrangement as well as an effective DX antenna on 160m these dimensions are the ones to go for.

THE FOLDED VERTICAL ANTENNA

One of the problems with an ordinary vertical antenna is the relatively low radiation resistance that can lead to low values of efficiency, especially when the earth connection is poor. This can be overcome to a degree by using a folded vertical antenna. By using a length of 300Ω ribbon as a 'half-folded dipole' or 'folded unipole', the radiation resistance of the antenna is raised to a value in the region of 80 -150Ω, depending on configuration and height. This means that even when used with an average earth system the antenna will have an efficiency of around 40%.

The version described here uses a shortened 300Ω ribbon section to which is added a length of single wire. To calculate the length of the ribbon needed, an electrical quarter-wavelength at the desired frequency must be multiplied by the velocity factor of the ribbon used (slotted ribbon has a velocity factor of 0.87). This

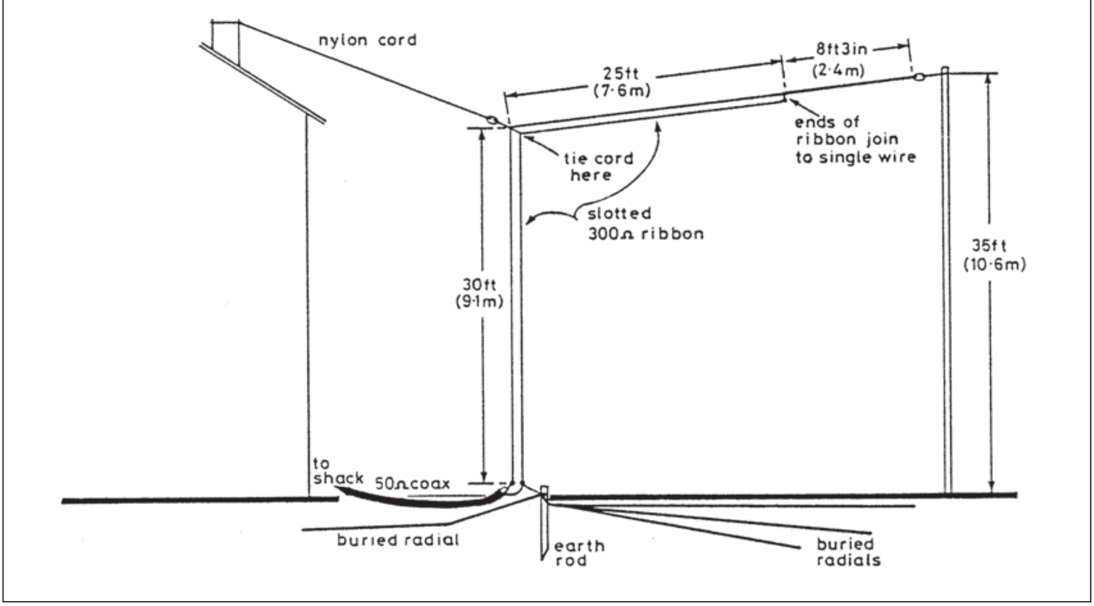


Fig 5.24: The folded vertical antenna which uses 300Ω ribbon for most of its length. The use of the 'folded dipole' principle raises the feed impedance of this antenna from around 15Ω to four times this figure. A reasonable match can be obtained with 50Ω coaxial feeder.

length is less than a quarter-wave, and it must have an additional wire connected at its end to make it up to be an electrical quarter-wavelength. This technique is very similar to that used when constructing folded half-wave dipoles from 300Ω ribbon (see Chapter 3).

The folded antenna illustrated in **Fig 5.24** is designed for 3.7MHz operation and it only needs 10.6m (35ft) high supports. The efficiency of the antenna is proportionally higher than a single wire vertical because the length of its vertical section is increased as a proportion of the total quarter-wavelength. A minimum of six buried radial wires, each being at least a quarter-wavelength long, are recommended for a suitable earth system, although with the limitations of many garden plots this may not be achievable. For a given length of wire, it is better to use many shorter radials than fewer longer ones. Versions of this antenna may be scaled up or down for use on other bands.

The step-up of feed impedance brought about by using this folded dipole technique allows the use of a 50Ω coaxial feeder. The greater distance between the vertical part of this antenna and any buildings etc, the more effective the antenna will be for low-angle long-distance communication.

THE QUARTER-WAVE SLOPER

Sloper antennas have become popular as low-band antennas that can be erected alongside an HF beam on a tower. Although sloping dipoles as described in Chapter 3 are very similar, these slopers comprise a single section and are usually classed as a form of vertical antenna. They provide a little directivity and can be erected very easily, making them an ideal antenna for many stations.

The quarter-wave sloper or 'half-sloper' antenna is really half of an inverted-V dipole. A quarter-wave antenna is normally arranged to be bottom-fed, which means that the maximum radiation is at the base of the antenna. By inverting the feedpoint of a quarter-wave as shown in **Fig 5.25(a)**, the position of the current maximum and therefore the greatest radiation can be moved to the top of the antenna.

The 'ground' against which slopers are fed is usually the metallic mass of the support tower, although for this to be as efficient as possible, a good low resistance ground at the foot of the tower remains important. The slope angle, 'L', of a half-sloper is usually 45°, and its maximum radiation is in the direction of the wire away

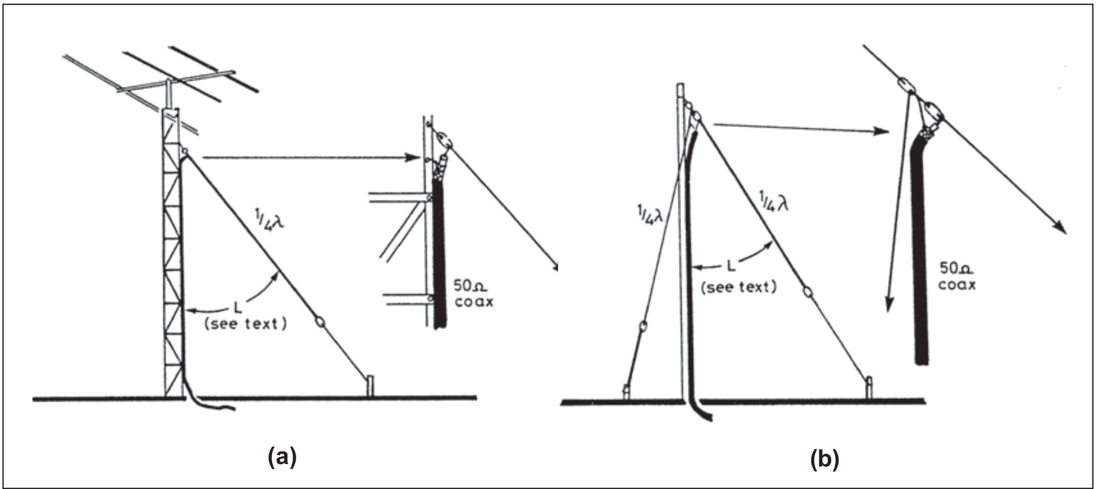


Fig 5.25: (a) A quarter-wave sloper antenna used with a metal tower; (b) Using a quarter-wave-length of wire which is almost vertical to replace the metal tower. The feed impedance of the sloper depends upon several variables, one being the angle 'L'.