15 Practical HF Antennas

This chapter addresses the practical construction of HF antennas and ATUs. Because the scale and range of HF antennas is so extensive the chapter is confined to the description and construction of the more commonly used antennas

END-FED WIRE ANTENNAS

The Simple End-Fed Antenna

The simplest of all HF antennas is just a length of wire, one end of which is connected directly to a transmitter or antenna tuning unit (ATU). An example of such an antenna is shown in **Fig 15.1**.

Connecting an antenna directly to the transmitter is often discouraged because of the close proximity of the radiating element to house wiring and domestic equipment. This undesirable feature is aggravated by the fact that wild excursions of feed impedance can occur when changing operation from band to band. Also, good matching can sometimes be difficult to achieve. Choice of wire length may alleviate this problem and is discussed in detail later, see Matching and Tuning. An inverted L antenna, as shown in Fig 15.1 is often referred to as a Marconi antenna.

However, the end-fed antenna is simple, cheap, and easy to erect; suits many house and garden layouts and is equally amenable to base or portable operation.

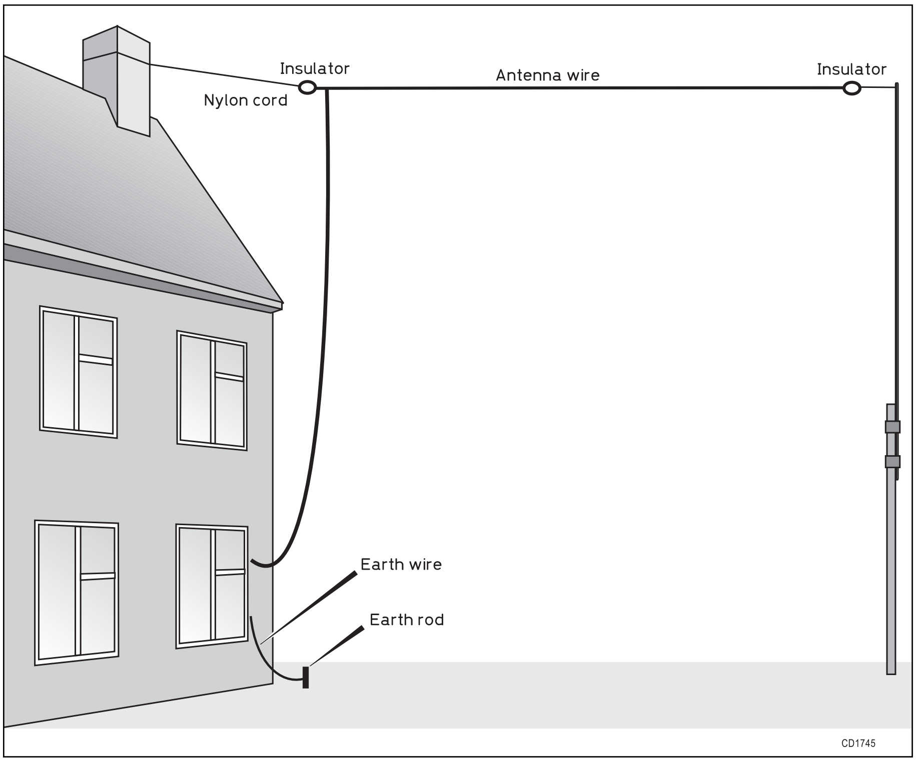


Fig 15.1: The end-fed antenna, the simplest of all multi-band antennas

Remote End-Fed Antenna

Having the antenna feedpoint remote from the shack (**Fig 15.2**) can circumvent the disadvantages of bringing the end of an antenna into the shack. Locating the long-wire antenna feedpoint away from the house minimises EMC problems on transmit on receive (electrical noise). Furthermore, it reduces the unpredictable effect on the antenna caused by possible conduit, wiring and water pipe resonances.

The disadvantage of this arrangement is that the ATU is some distance from the transceiver, and this can be rather inconvenient when it comes to making adjustments. Methods of overcoming this problem is discussed in detail later, see Matching and Tuning

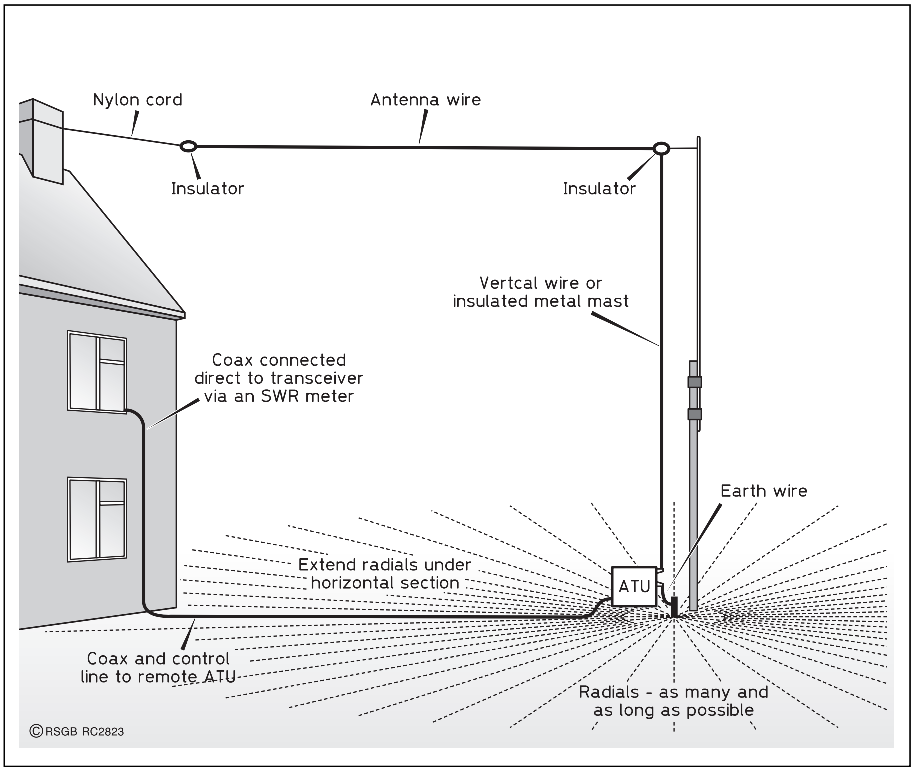


Fig 15.2: A remotely fed long wire antenna arrangement. The ATU can be either preset or automatic and may require a control cable in addition to the coaxial cable feeder

WARNING: Protective Multiple Earthing (PME)

Some houses, particularly those built or wired since the middle 'seventies, are wired on what is known as the PME system. In this system the earth conductor of the consumer's installation is bonded to the neutral close to where the supply enters the premises, and there is no separate earth conductor going back to the sub-station.

With a PME system a small voltage may exist between the consumer's earth conductor, and any metal work connected to it, and the true earth (the earth out in the garden). Under certain very rare supply system faults this voltage could rise to a dangerous level. Because of this supply companies advise certain precautions relating to the bonding of metal work inside the house, and also to the connection of external earths.

WHERE A HOUSE IS WIRED ON THE PME SYSTEM DO NOT CONNECT ANY EXTERNAL (ie radio) EARTHS TO APPARATUS INSIDE THE HOUSE unless suitable precautions are taken.

A free leaflet *EMC 07 Protective Multiple Earthing* is available on request from RSGB.

The Importance of a Good RF Earth

For an end-fed antenna to operate efficiently a good RF earth is required. The resistance of this connection is in series with the radiation resistance of the antenna so it is important to get the ground resistance as low as possible if you want an efficient end-fed antenna. A poor RF earth can result in a high RF potential on the metal cases of radio equipment. Furthermore, the microphone, key or headset leads are also 'hot' with RF so that RF feedback and BCI problems occur. Additionally, the circuitry of modern communications equipment can be electrically damaged in these circumstances.

Using Real Earth

In practice a good RF earth connection is hard to find and is only practicable from a ground floor room. The problem with the 'earth stake' is that ground has resistance and the lead connecting the earth stake to the radio has reactance.

Many ways have been tried to reduce the ground resistance. In general, the more copper you can bury in the ground the better. An old copper water tank, connected to the radio with a short length of thick copper wire, makes a very good earth. An RF earth can also be made from about 60 square metres of galvanised chicken wire. This is laid on the lawn early in the year and pegged down with large staples made from hard-drawn copper wire. The grass will grow up through the chicken wire and as if by magic the wire netting will disappear into the ground over a period of about two months. In the early stages, the lawn has to be cut with care with the mower set so that it does not cut too close and chew up the carefully laid wire netting.

Low band DXers tend to use buried multiple radials; many wires radiating out from the earth connection. The rule seems to be the more wires the better. These types of direct connection to earth can also provide an electrical safety earth to the radio equipment in the shack.

Artificial Earths

If you operate from an upstairs shack, engineering a low-impedance earth connection at ground level using the method described above will probably be a waste of time. The reason for this is that the distance up to the shack is a significant fraction of a wavelength on the higher HF bands and above. At frequencies where this length is near one or three quarters of a wavelength, the earth connector will act as an RF insulator, which is just the opposite of what is wanted, see **Fig 15.3(a)**. This is bound to happen in one or more of our nine HF bands.

On the other hand, if the lead resonates as a half-wave, (a situation that is likely to arise on any band above 10MHz), it may act as a good RF earth. However, it also has a high-voltage point halfway down which may couple RF into the house wiring, see **Fig 15.3(b)**, because electrical wiring within the wall of a house is generally perpendicular. In other words, although an earth wire from the radio in an upstairs shack to an earth stake will provide a safety earth its usefulness as an RF earth is unpredictable.

The favoured method of obtaining a good RF earth is to connect a quarter-wave radial for each band to the transceiver and ATU earth connector, then running the free ends outside, away from the transceiver. Because the current at the end of the wire is zero and the impedance is high it follows that at a quarter wave inward, where it connects to the transceiver, the RF potential is zero (the impedance is low). The problem is where to locate all these radials; such an arrangement will require some experimenting to find the best position. Radials can be bent or even folded but the length may have to be altered to maintain resonance. The radials are best located outside the house in the horizontal plane to reduce coupling into the electrical wiring. If

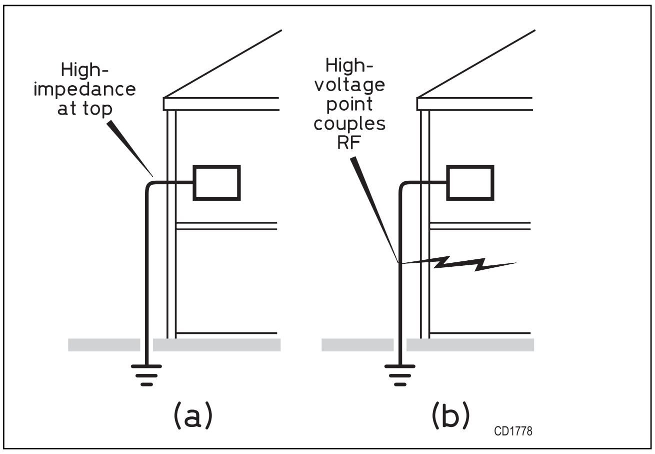


Fig 15.3: Why RF ground leads from upstairs seldom work. (a) Ground lead with quarter-wave resonance (or odd multiple) is ineffective; very little current will flow into it. (b) Ground lead with half-wave resonance (or multiples) will have high-voltage points which couple RF into house wiring

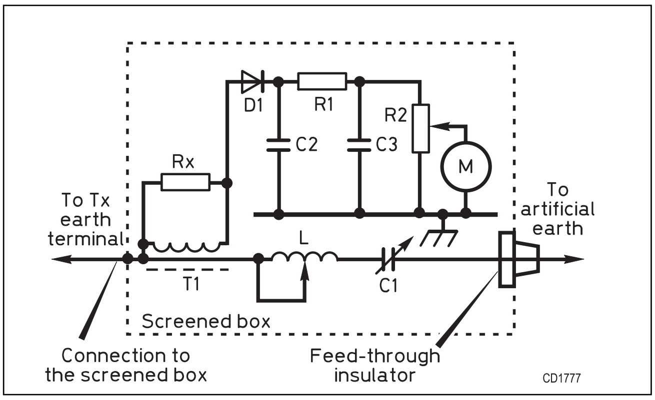


Fig 15.4: SM6AQR's earth lead tuner. T1 = Amidon T-50-43 ferrite toroid; the primary is simply the earth lead through the toroid centre; secondary = 20t small gauge enamelled wire. L = 28µH rollercoaster or multi-tapped coil with 10-position switch; see text. C1 = 200pF or more air variable, >1mm spacing, insulated from panel and case. C2 , C3 = l0nF ceramic. D1 = AA119; R1 = 1k; R2 = 10k pot, Rx see text. M = 100µA or less

the radial(s) are used indoors (say, round the skirting board) use wire with thick insulation with several additional layers of insulating tape at the ends where the RF voltage can be fairly high when the transmitter is on.

The best way to check resonance of a radial is to connect it to the radio earth, make a loop in the radial and use a dip meter to check resonance. If such an instrument is unavailable then use an RF current meter and adjust the radial length for maximum current.

Alternatively, one single length radial can be tuned to place a zero RF potential at the transceiver on any band by inserting a LC series tuning circuit between the transmitter and the radial. Such a units are commercially available, which have, in addition to the LC circuit, a through-current RF indicator which helps tuning the radial or earth lead to resonance (maximum current).

Or you can make one yourself. The unit designed by SM6AQR [1] and shown in **Fig 15.4**, uses a 200-300pF air spaced tuning capacitor with at least 1mm plate spacing; the capacitor and its shaft must be insulated from the tuner cabinet. The inductor is a 28μH roller coaster. Alternatively, a multi-tapped fixed coil plus with as many taps as possible could be used.

The tuning indicator consists of a current transformer, rectifier, smoothing filter, sensitivity potentiometer and DC microammeter. The 'primary' of the current transformer is the artificial earth lead itself; it simply passes through the centre of the T1 ferrite toroid, onto which a secondary of 20 turns of thin enamelled wire has been wound. Rx, the resistor across the T1 secondary, should be non-inductive and between 22 and 100 ohms; it is selected such that a convenient meter deflection can be set with the sensitivity control R2 on each required frequency and for the RF power used.

A separate electrical safety earth should always be used, in addition to the RF earth described above.

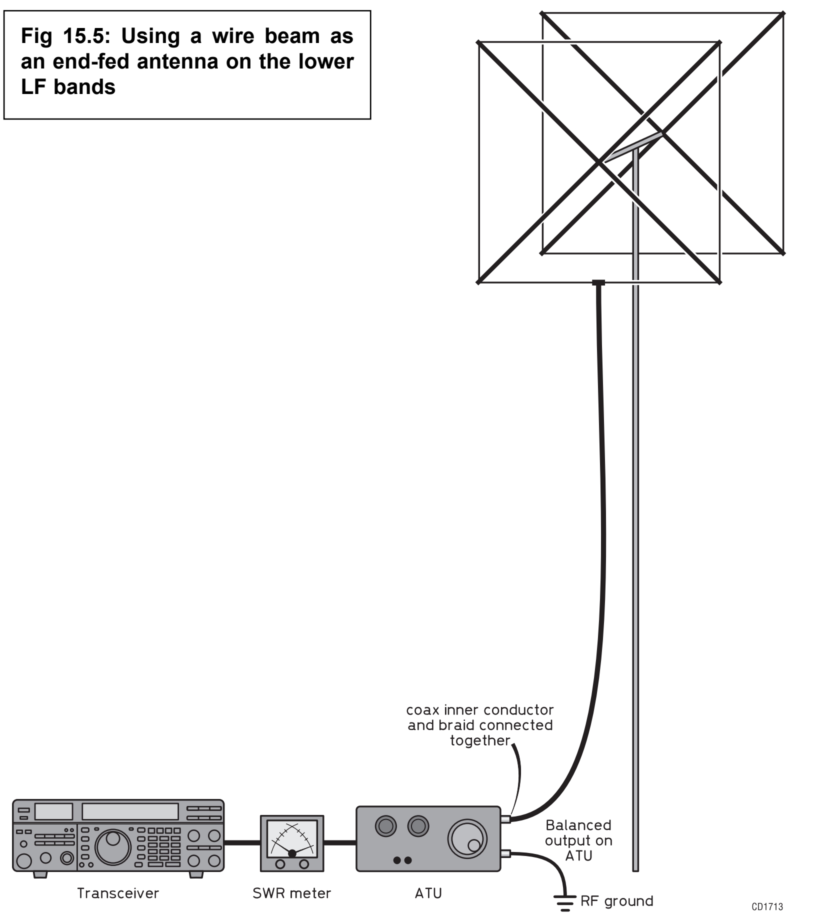
Using an Existing HF Wire Beam on the Lower HF Bands

A wire beam such as the quad, or any of those, described later, can be used as an end-fed antenna as shown in **Fig 15.5** provided the HF beam and mast are fairly close to the shack.

In this case, the coaxial cable is used as the antenna conductor rather than as a feeder. The inner conductor and the braid of the coax is shorted together using a PL259 socket with a shorting link and connected to the ATU. The beam itself forms a top capacitance which, provided the coaxial cable is reasonably clear of obstructions and not fixed to the tower, makes a very effective lower HF frequency antenna.

Other antennas can be used in this way. A dipole for 20 metres can be used on the lower frequency bands by connecting the coax to the ATU, as already described, so that the dipole forms a capacity top. As with all end fed antennas a good RF earth is required.

Fig 15.5: Using a wire beam as an end-fed antenna on the lower LF bands



CENTRE FED WIRE ANTENNAS

The Centre-Fed Dipole

Of all antennas the half-wave dipole is the most sure-fire, uncomplicated antenna that you can make and does not require an ATU. A centre fed antenna does not require connection to an earth system to function. In its basic form it is essentially a single band, half-wave balanced antenna (although normally fed in the centre with unbalanced coaxial cable). The current and voltage in one half of the dipole is matched by those values in the opposite half about the centre feed point, see **Fig 15.6**. The

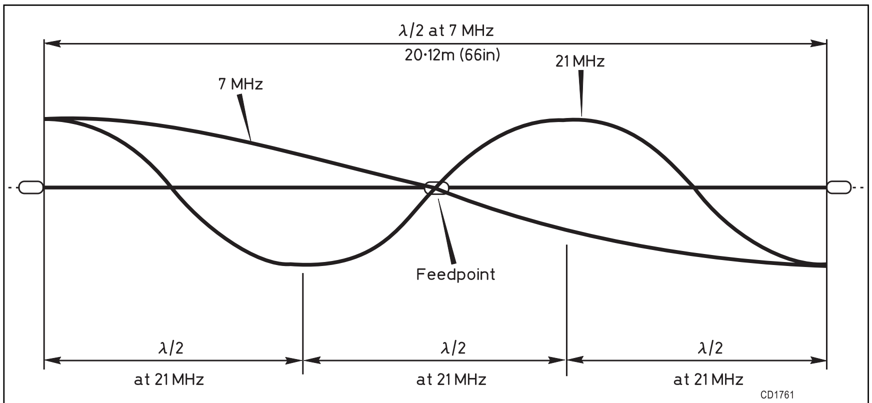


Fig 15.6: The voltage distribution on a 7MHz half-wave dipole. The coaxial cable is connected to the antenna at a point where the feed impedance is low (where the voltage is low). The 7MHz dipole will also have a low impedance at the centre on the third harmonic, at 21MHz

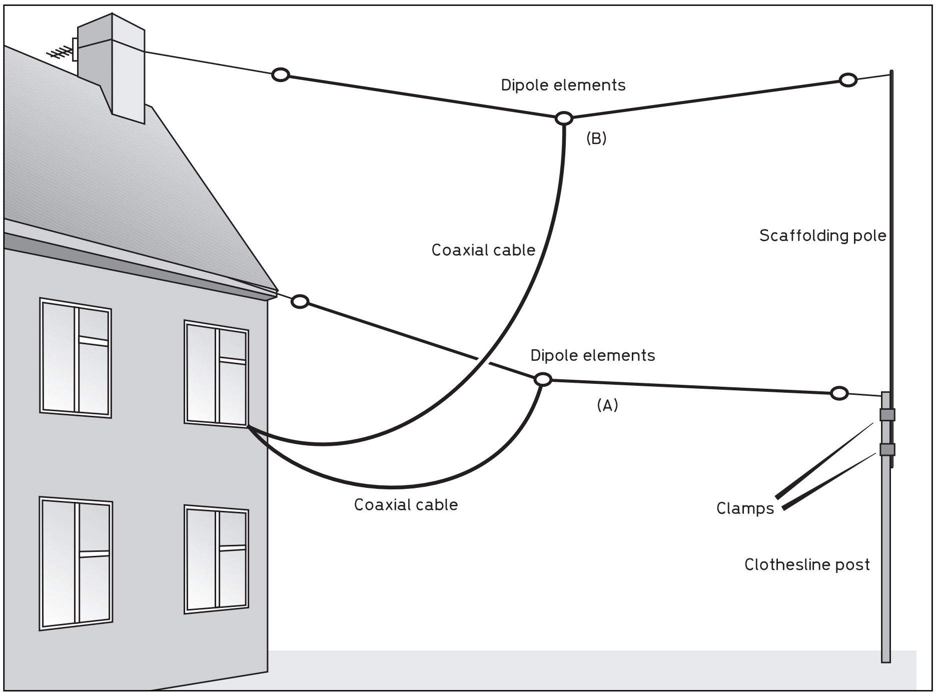


Fig 15.7: Antenna (a) shows a quick fix installation for a dipole. With the minimal effort the dipole height (b) can be raised substantially

halfwave dipole will also present a low feed impedance on its third harmonic so a 7MHz dipole will be close to resonance on 21MHz.

In most cases, the dipole is better than 95% efficient and because it has a low impedance feedpoint it can be connected the transceiver via a length of 50ohm coaxial cable without the need of an ATU. The elements can be bent, within reason, to accommodate space restrictions.

A practical dipole antenna for the higher HF bands is shown in **Fig 15.7**. It can be strung out between the house eaves and an existing clothes line post which would give the antenna an average height of around 4metres (15ft). As can be seen by the elevation radiation pattern (**see Fig 15.8**) the antenna is most effective for signals having a high angle of radiation, which would make it suitable for short skip contacts. With very little effort, the antenna can be raised to an average height of, say, 8 metres (23ft), see Fig 15.7, resulting in a much lower angle of radiation as shown in Fig 15.8. This would make the antenna much more suitable for DX contacts.

The above comments regarding height apply to any horizontal antenna.

There are various methods of connecting the coaxial cable to the antenna - two of these are shown in **Fig 15.9**. Both these arrangements take the strain of the coax from the connections. Also by having the ends of the cable facing downwards assists in preventing water entering the coax cable. It is still important to

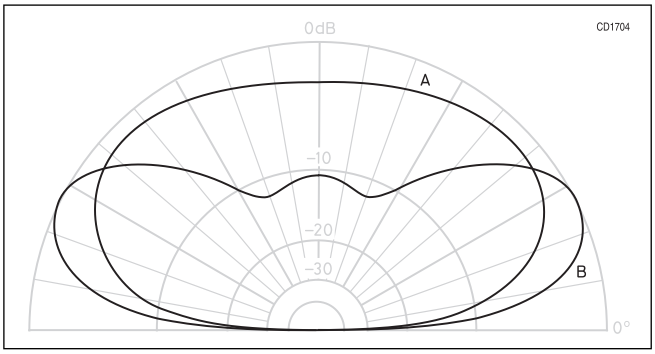


Fig 15.8: Elevation radiation pattern for a dipole at different heights above ground, see Fig 15.7. (a) is for a dipole around 4m high. (b) Is from the antenna at 8m. Path L indicates a 2dB increase in signal strength of (b) compared with (a) for low angle DX signals. Path H indicates a 2dB decrease in signal strength of (b) compared with (a) for high angle short skip non-DX signals

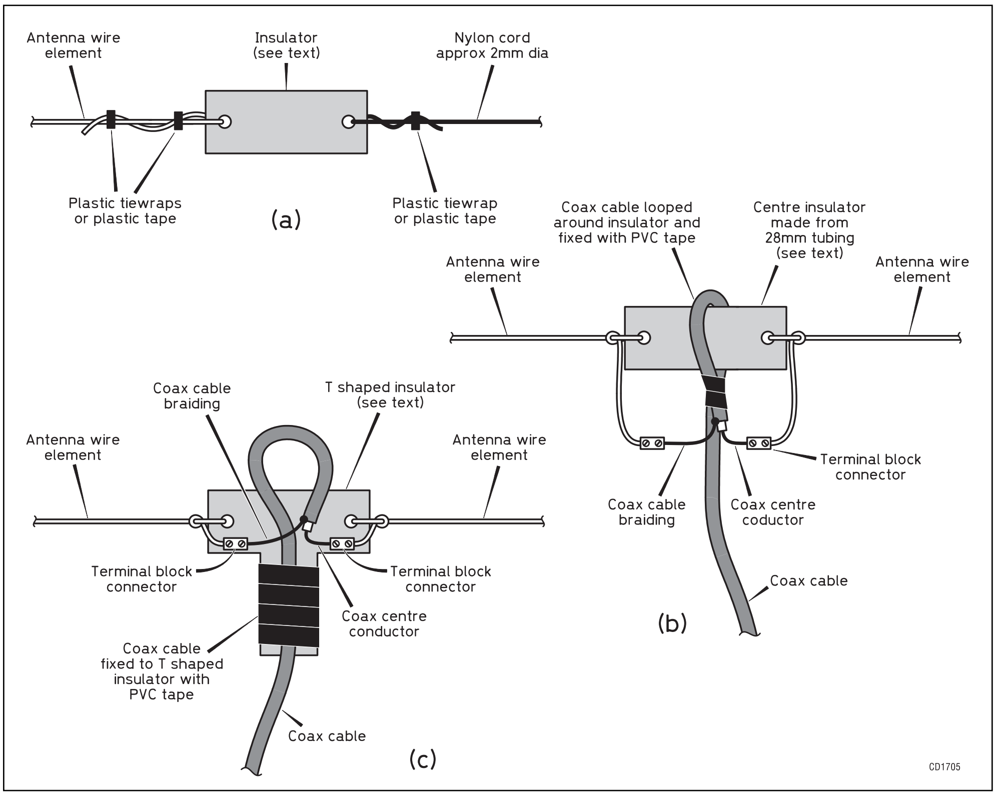


Fig 15.9:(a) A convenient arrangement for constructing a dipole so that the element lengths can be adjusted to make the element longer than shown in Table 15.1. The excess is taped back along the element. (b) Method of connecting coax cable to the centre of the dipole using a short length of tubing or a dog-bone insulator. (c) Method of connecting coax to the centre of a dipole using a specially constructed T insulator. A sealant should be used to prevent water ingress at the exposed coax end

Table 15.1: Wavelengths and half-wavelengths, together with resonant lengths for dipoles relative to frequency for the HF bands. (' = ft, " = in). The dipole lengths * are calculated for a wire diameter of 2mm. The dipole lengths # are calculated for a tube diameter of 25mm

Freq: MHz	λ Metres	λ Ft/in	λ/2 Metres	λ/2 Ft/in	Dipole Metres*	Dipole Ft/in*	Dipole Metres #	Dipole Ft/in #
1.83	163.82	537'6"	81.91	268'9"	80	262'	-	-
1.9	157.78	517'8"	78.89	259'10"	77	260'7"	-	-
3.52	85.17	279'5"	42.58	139'8"	41.56	135'10"	-	-
3.65	82.13	269'6"	41.07	134'9"	40.08	131.6"	-	-
7.02	42.7	140'1"	21.35	70'0"	20.76	68'2"	-	-
10.125	29.61	97'2"	14.8	48'7"	14.4	47'2"	14.2	46'7"
14.05	21.34	70'0"	10.67	35'0"	10.35	33'11"	10.20	33'5"
14.20	21.11	69'3"	10.55	34'10"	10.24	33'7"	10.09	33'1"
18.1	16.56	54'4"	8.28	27'2"	8.03	26'4"	7.88	25'10"
21.05	14.24	46'9"	7.12	23'5"	6.9	22'8"	6.78	22'3"
21.2	14.14	46'5"	7.07	23'3"	6.86	22'6"	6.73	22'1".
24.94	12.62	39'6"	6.31	19'9"	5.82	19'1"	5.70	18'8"
28.05	10.69	35'0"	5.34	17'6"	5.18	17'0"	5.05	16'7"
28.4	10.56	34'8"	5.28	17'4"	5.1	16'8"	4.99	16'4"
29.5	10.16	33'4"	5.08	16'9"	4.9	16'1"	4.80	15'9"

seal the junction against the ingress of water, using either self-amalgamating tape or a non-corrosive sealant.

The dipole can be supported using 2mm or 3mm nylon rope with 'dogbone' insulators at the ends of the elements. The method of connecting the antenna element to the insulator, shown in Fig 15.9, allows the dipole element length to be adjusted for minimum SWR.

Do not use egg insulators and wire as element end supports - the end capacity of such an arrangement can cause some very unpredictable results if the antenna is supported by wire.

The dipole is described as a half wavelength antenna. In practice the dipole length is slightly shorter than half a wavelength because of end-effect. A true wavelength on 7.02MHz is 42.7m and a halfwave 21.35m. A halfwave dipole for the same frequency will be 20.78m (68ft, 2in)

Dipole dimensions for each amateur band are shown in the **Table 15.1**, where the wire lengths have been calculated using EZNEC (see Antenna Fundamentals chapter) and assume the use of 2mm diameter wire and an antenna height of 10m (33ft).

Table 15.1 gives the equivalent wavelengths and half wavelengths for given frequencies in metric and imperial units. Half wavelengths for centre fed dipole or vertical antennas, described earlier, are also given in metric and imperial units and are calculated using EZNEC.

Most antenna books use the formula 143/f (MHz) = L (metres) or 468/f (MHz) = L (feet). This gives a close enough approximation on the higher frequency bands but may be a bit short for the lower bands. For example, the formula gives a dipole length of 40.6m for 3.52MHz while EZNEC calculates a length of 41.42m for the same frequency.

Remember, these are total lengths and the wire has to be cut in half at the centre to connect the coax and that the gap in the centre is part of the whole dipole length. You also need to be aware that around 160mm (6in) at each end of each half of the dipole elements is required to connect them to the centre insulator and the end insulator.

When a larger diameter conductor is used for the antenna element, the length has to be reduced by an amount known as the K factor (based on the length to diameter ratio). For example, the calculated length for a dipole for 21.2MHz is 6.86m, or 22'6". If the conductor diameter is increased from 2mm to 25mm (1 in), the total length should be reduced to 6.73m (22'1").

This can influence the design when making a vertical antenna with the top element of 25mm diameter tube and the lower element(s) of wire. You should use the appropriate column for determining the length. Remember that these figures are for a half-wave antenna. For a ground plane antenna on 21.2MHz the top quarter wave 25mm diameter section should be 6.73/2 = 3.36m. The lower wire radials are 6.86/2 = 3.43m.

In practice tubular elements are best constructed using different diameter telescopic sections. This makes it easy to adjust the length on test for minimum SWR.

The 80 and 160 metre dipoles are quite long and should be made of hard drawn copper wire to reduce stretching and sagging due to the weight of the antenna and the coaxial cable.

The feed point impedance of a dipole at resonance can vary either side of the nominal 75 ohms, depending on height above ground, the proximity of buildings and any electromagnetic obstacles, together with any bends or 'dog-legs' in the wire. As a result, an SWR of 1:1 is not always possible when the antenna is fed with 50 ohm coaxial cable.

Because the dipole is a balanced symmetrical antenna, ideally it should be fed with balanced two-wire feeder. However, because almost all transmitters use a 50 ohm coaxial line antenna socket, coaxial cable is almost universally used to feed the dipole antenna. Connecting unbalanced coaxial cable to a balanced antenna does not normally affect the performance of the antenna provided the unbalanced current (antenna current) on the coaxial line is kept to a minimum. This can be done by making sure the coaxial line is not a multiple of an electrical quarter wavelength and that the coax line comes away from the antenna element at as close to 90 degrees as possible.

Antenna currents on the line, which can cause the line to radiate (and lead to EMC problems) should not be confused with SWR. A high SWR on transmission line does not cause it to radiate.

A balun can also be used to reduce these antenna currents, see Transmission Lines chapter.

The dipole antenna normally requires two supports and this may be a problem at some locations. The solution may be to mount the antenna so that it is vertical or sloping. A dipole with the centre feedpoint fixed on a single mast, with the ends sloping towards the ground, (inverted V) is a common configuration.

The Ground Plane Antenna

When a dipole is mounted vertically, it has become common practice to call the top element of the antenna a 'vertical' and the lower one a 'counterpoise'. The terminology is derived from an antenna that was once quite popular called the Ground Plane. This antenna comprises a vertical element with a counterpoise made from four wires called radials as shown

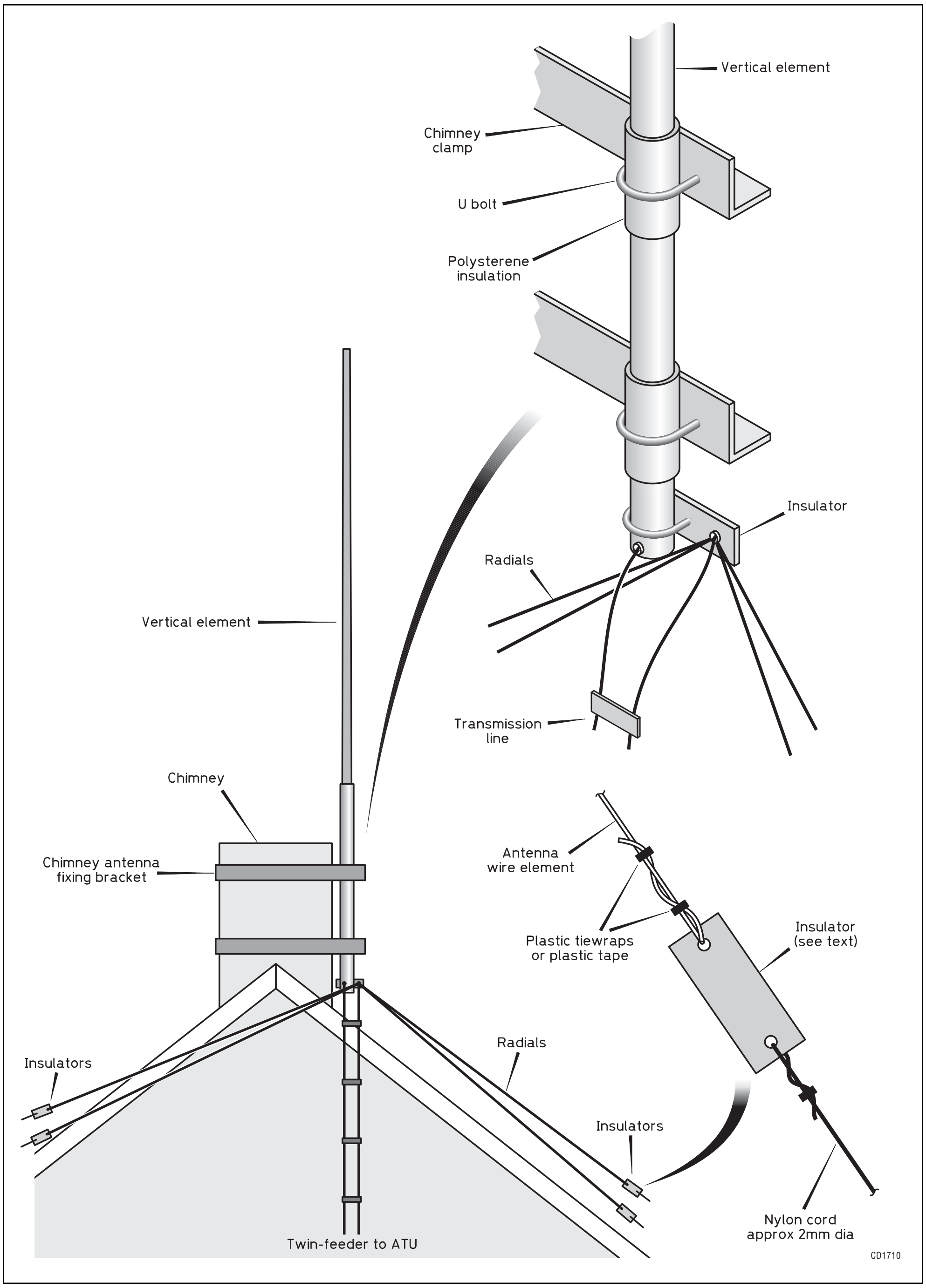


Fig 15.10: The ground plane antenna. It can be used as a single band resonant antenna, fed with coax cable; with the centre of the coax being fed to the vertical element and the braiding connected to the radials. The antenna can also be used as a multi-band antenna fed with open wire line as shown. The lengths of the elements are shown in Table 15.1

in **Fig 15.10**. The radials are made to slope down from the feedpoint although the angle is not critical. If the radials are at 90 degrees to the vertical element the feed impedance is around 30 ohms; with the radials sloping down at around 45 degrees the feed impedance is around 45 to 55 ohms (depending on height), which is a good match for coax cable.

The vertically orientated antenna is often cited as having a good low angle of radiation. From the graphic data obtained from EZNEC, this appears to be true (see **Fig 15.11**). The elevation plot shows a ground plane antenna whose feedpoint is only 0.2 wavelengths above the ground, which equates to 3m (9ft) on 21MHz. It has a very deep vertical null but the maximum gain is only 0.45dBi.

If the 21MHz groundplane is raised so that the feedpoint is 10m above the ground the antenna has two elevation lobes, one at 12 degrees (1.4dBi) and the other at 38 degrees (2.6dBi), with a deep vertical null, similar to the vertical dipole shown in Fig 15.11.

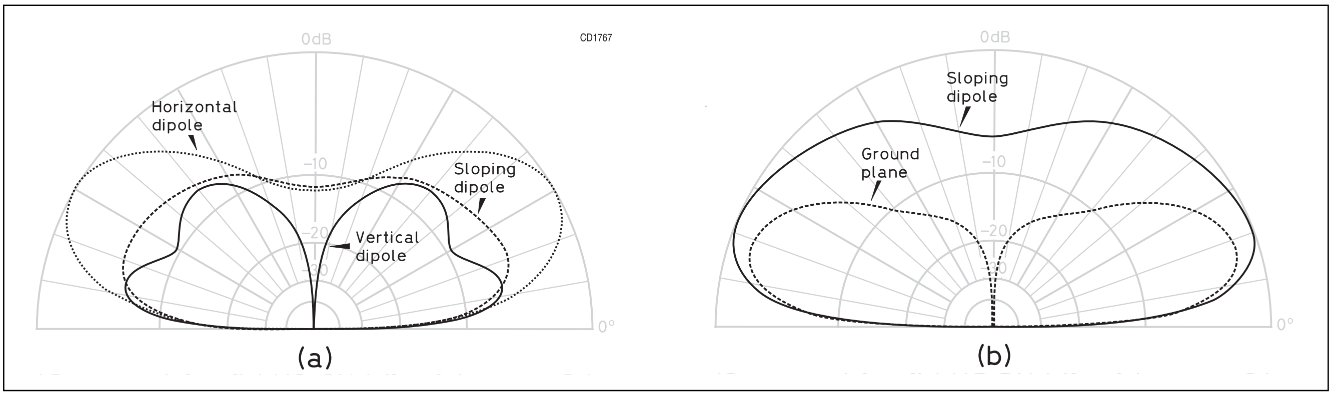


Fig 15.11: Elevation polar diagrams of different orientations of dipoles, and the ground plane 0.2 wavelengths high at the feedpoint

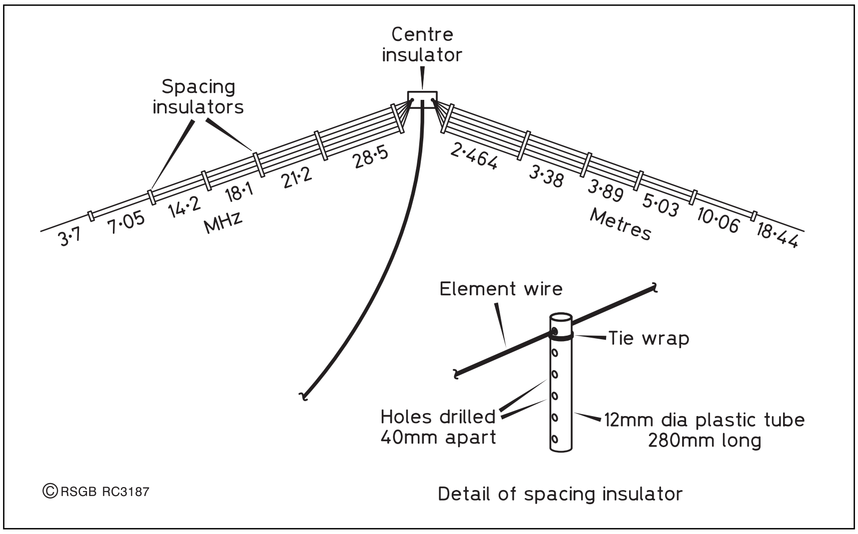


Fig 15.12: Multiband parallel dipoles. The detail shows the larger spacers to accommodate 6 wires. The outer spacers are progressively shorter with holes drilled for 5, 4, 3 and two wires respectively. The 24MHz dipole is not shown but the lengths are 2.84m (9ft 4in)

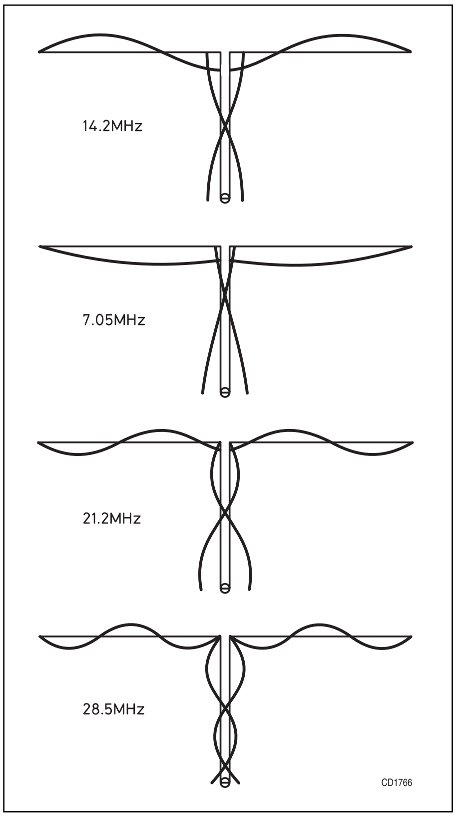


Fig 15.13: Showing the current distribution on a G5RV antenna at 14MHz; and on 7, 21 and 28MHz.

Multi-Band Centre Fed Antennas

While the resonant dipole is a very efficient antenna, which can be connected to the antenna socket of the transceiver without an ATU, using separate dipoles for each of the bands can result in a mass of wires in the back yard. Solutions to the multiband problem include using dipoles in their fundamental and harmonic modes, parallel dipoles, trap dipoles, the multiband doublet using tuned lines and the multiband doublet with an ATU.

Most multiband systems can be improved using an ATU so it is probably a good idea to invest in one, or build one. It is basic RF technology and does not date like computers, or even modern transceivers.

Parallel Dipoles

If you wish to operate on several of the HF bands and you don't have an ATU, parallel dipoles may be the answer. The design shown in **Fig 15.12**. enables all the wires of the multiple dipole to be held together in a tidy fashion. This arrangement uses the lowest frequency dipole to support the higher frequency dipoles using spacing insulators made from 11mm plastic electrical conduit. The antenna is best configured as an inverted V with the weight of the centre insulator and the 1:1 balun mounted on a suitable mast or pole. Low centre band SWRs are possible if some time is spent tuning each dipole. This can be achieved by arranging the ends of the elements so that they are clear of their support insulators by about 200mm. The dipole lengths can be reduced or increased by folding back the end and securing with plastic tape.

The resonance of these dipoles can be interactive - when you adjust one it effects the resonance of the other so be prepared to have to re-resonate elements.

The G5RV Antenna

Newcomers (and some old-timers) often regard the G5RV antenna as a panacea to the multi-band antenna problem. Louis Varney, G5RV, designed his antenna over 40 years ago, primarily to give a clover-leaf pattern and a low feed impedance on 20 metres. The G5RV has a top of 102ft (31.27m), a total of three half wavelengths on 20 metres, which is fed in the centre.

The feed impedance on 20 metres is low because the feedpoint is at the centre of the central halfwave section. The midband resonant feed impedance at that point is around 90 ohms and a 34ft (10.36m) matching section of open-wire feeder is used as a 1:1 transformer, repeating the feed impedance at the other end, as shown in **Fig 15.13**.

Because of this, the lower end of the matching section can be connected to a length of 75 ohm coaxial cable as a convenient way of routing the feed to the transmitter in the shack (see **Fig 15.14**).

In addition, the antenna is presents low impedances on other bands, which were within the impedance range of earlier amateur radio transmitters with pi-output variable tuning and loading; thus the antenna could be connected directly to the transmitter without an ATU. This represented quite an advantage over routing open line feeder into the shack.

However, for the G5RV to work the top dimension must be around 31.27m (102ft) and the dimensions of the of the matching section shown in Fig 15.14 are only true for open wire feeder. If 300-ohm ribbon or slotted line is used, the length must be adjusted to take account of the velocity factor (multiply 10.36m - 34ft - by the velocity factor).

In addition, the G5RV geometry cannot be altered by, for example, converting it into an inverted-V or bending the ends to fit into a small available space, without modification to the length.

On the 10, 18 and 28MHz bands the feed impedances are likely to be fairly wild. Modern all-solid state amateur band transceivers have transmitter output stages that can be damaged when operated with high SWR on the feed cable to the antenna, or they have an ALC circuit that reduces power in some proportion to SWR. It is obvious that an ATU between the low-impedance feeder and the transceiver is required.

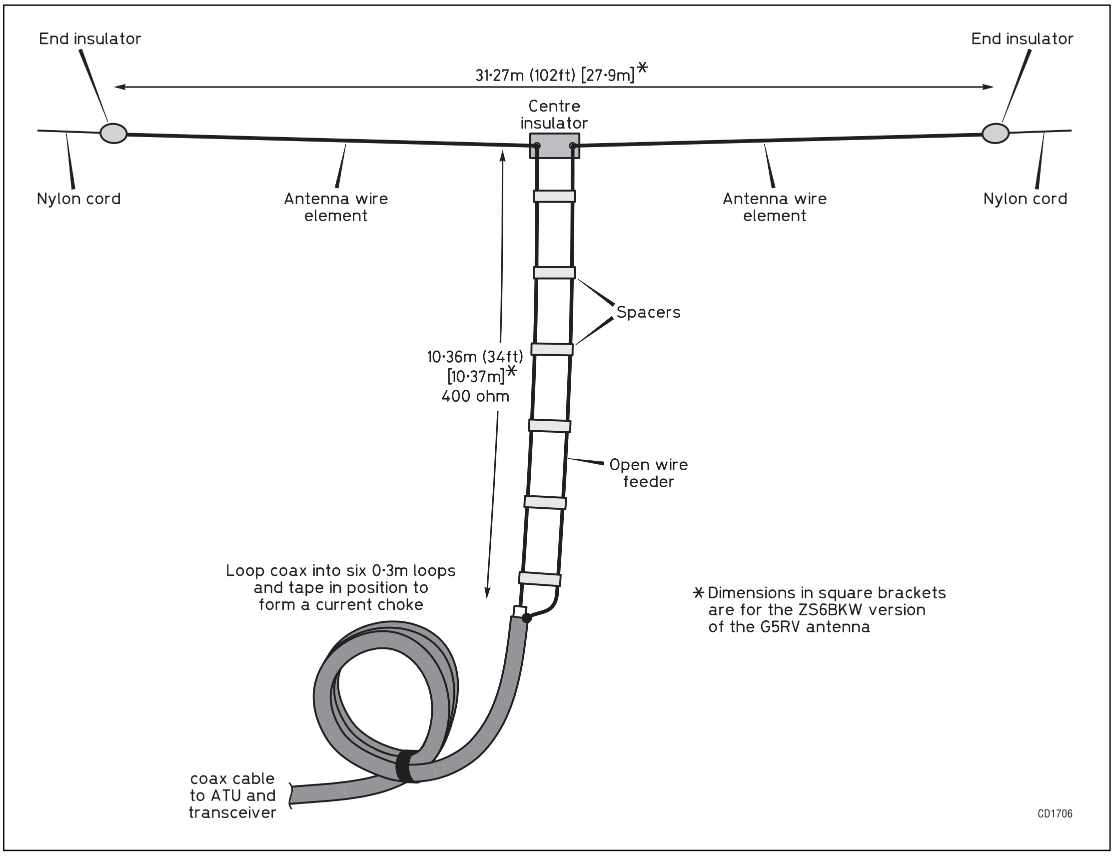


Fig 15.14: Construction of the G5RV antenna. The dimensions shown in square brackets are for the ZS6BKW version - see text

ZS6BKW developed a computer program to determine the most advantageous length and impedance of the matching section and the top length of a G5RV-type antenna. He arranged that his antenna should match as closely as possible into standard 50-ohm coaxial cable and so be more useful to the user of modern equipment. The G5RV antenna total top length of 31m was reduced to 27.9m, and the matching section was increased from 10.37m (ignoring the velocity factor). This matching section must have a characteristic impedance of 400-ohms, and it can be made up from 18SWG wires spaced at 250mm (10 in) apart. The ZS6BKW gives improved impedance matching over the original G5RV, but still cannot be used without an ATU with modern solid state PA transmitters.

Some amateurs have reported that they get very low SWR readings on all bands. If you have consistently a low SWR using this antenna, it is possible that a test of the coaxial cable from the transmitter to the bottom of the open wire matching section might be in order, see Transmission Lines chapter.

G2BDQ notes [2] that many amateurs use the G5RV antenna with success, and that he prefers the use of either open-wire or

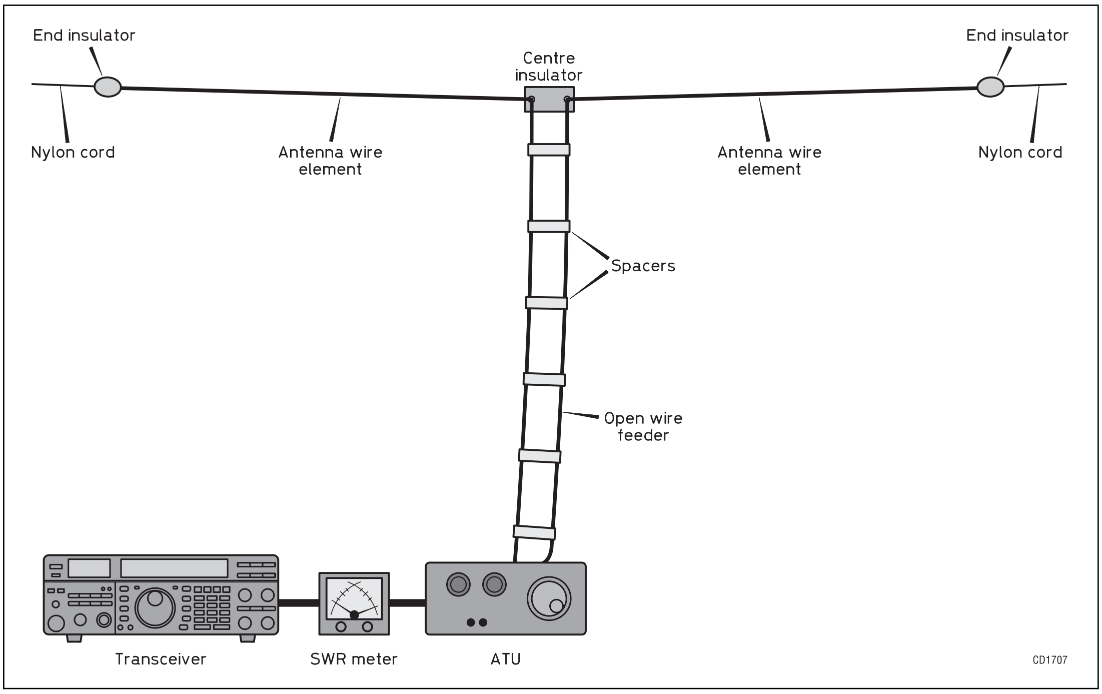
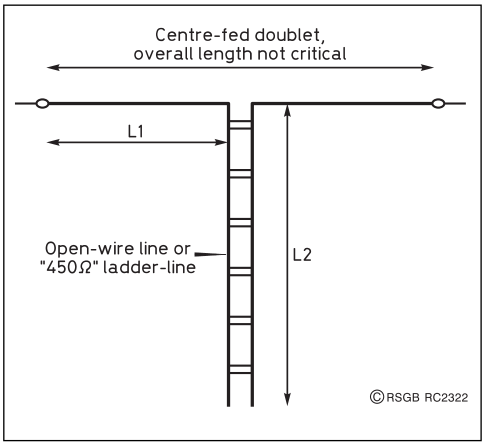
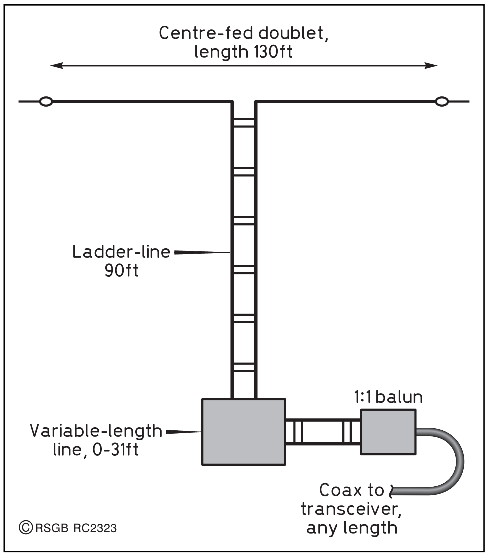


Fig 15.15: The tuned open-wire dipole using a tuned transmission line. If you are short of space the antenna could be cut for 3/8 of a wavelength on 7MHz and it will tune all bands from 7 to 28MHz. The real advantage of this antenna is that the dipole length is not critical, because the tuner provides the impedance match throughout the entire antenna system, whatever the dipole length may be

Fig 15.16: The HF Multi-band doublet fed with ladder line can have a wide range of feed impedances. To estimate the impedance, measure half the length of the doublet L, plus the electrical length of the feedline L2, (allow for velocity factor of L2)





(right) Fig 15.17: W6RCA's line-length switcher makes his 39.62m (130ft) doublet cover all eight HF bands with no ATU. Optimum dimensions will depend on local factors, but you can always change the line length to compensate

300-ohm ribbon to feed the horizontal top. With an ATU, such a feed will result in high-performance, all-band working

G5RV mentions [3] that the most efficient feeder to use is the open-wire variety, all the way down from the centre of the antenna to the equipment, in conjunction with a suitable ATU for matching. He added that by using 25.6m (84ft) of open-wire feeder the system will permit parallel tuning of the ATU on all bands; which brings us to the Open-Wire Tuned Dipole.

The Open-Wire Tuned Dipole

This antenna, also known as the Tuned Doublet or Random-Length Dipole is very simple, yet is a most effective and efficient antenna for multiband use. It is fed with open wire tuned feeders, as shown in **Fig 15.15**, and an ATU is used to take care of the wide variations of feed impedance on the different bands.

This antenna should be at least a quarter wavelength long at the lowest frequency of operation, where it radiates with an effectiveness of approximately 95% relative to a half wave dipole.

However, the feed impedance of such a short antenna results in SWR values of around 300:1 on 450-ohm line. While the antenna is quite efficient the impedances at the end of the tuned feeder will be outside the matching range of the average commercial ATU using a toroid balun to provide a balanced feed to the tuned feeders. A doublet with a length of about 3/8 wavelength on the lowest frequency would overcome this problem. This is halfway between quarter wave and half wave and will work very well if you can't erect a full half wave on 80-metres. A 3/8 wavelength dipole has an effectiveness greater than 98% relative to a half wave dipole, and the SWR values are far easier to match, being in the region of 25:1 on 600-ohm line, 24:1 on 450-ohm line, and 25:1 on 300-ohm line.

A 3/8 wavelength dipole at 3.5MHz is approximately 30m (100ft) long, which means that any length from 27m (90ft) to 30m will make an excellent radiator on all HF amateur bands, 80 through 10 metres, including the WARC bands.

If you don't have room for a 27m length of straight wire for operation on 80 metres, a 3 to 5m (10 to 16ft) portion of each end may be dropped vertically from each end support. There will be no significant change in radiation pattern on 80 and 40 metres. However, there will be a minor change in polarisation in the radiation at higher frequencies, but the effect on propagation will be negligible. Bear in mind that twin wire feeder can be affected by the close proximity of metal objects such as windows or guttering. If this presents difficulties bringing twin feeder into the shack then the Comudipole, described later, may be a solution.

The W6RCA Multi-Band Doublet

Many antenna designs feature combinations of doublet length and feedline length resulting in a convenient impedance (one easily matched by a transceiver's internal auto-ATU) at the bottom of the feedline for a few bands, but never all of them. Hence the need for an ATU with the open wire tuned multi-band dipole described above.

The following describes a more radical approach by Cecil Moore, W6RCA, and described in [4]. His solution to the problem covers all the HF bands from 3.6 to 29.7MHz with no ATU at all. This is achieved by changing the length of the 450-ohm tuned ladder-line - and this is much more practical than it looks at first sight. The line length is adjusted for each band, so that the current maximum always coincides with the bottom of the feedline. The feed impedance at this point is then by definition low and non-reactive, and in practice the SWR is usually low enough that you can use a 1:1 choke balun, straight into coax and the transceiver. With reasonable lengths for the doublet and the permanent part of the feedline, you can always achieve an acceptable impedance match.

The requirement is that the physical half-length of the doublet L1 (see **Fig 15.16**), plus the total electrical length of the feedline L2 (allowing for the velocity factor v) must be an odd multiple of a quarter wavelength on each band:

$$L1 + L2 \times v = n\,\lambda/4$$

where n is 3, 5, 7 etc

From these calculations, it is obvious there are several possible solutions. The W6RCA arrangement is shown in **Fig 15.17**, with a 39.62m (130ft) centre-fed doublet and 27.5m (90ft) of 450-ohm ladder-line. The doublet is approximately a half-wave at 3.5MHz and a full-wave at 7MHz, and the 27.5m (90ft) feedline brings the current maximum to the bottom at 7.2MHZ. The big practical advantage of this combination is that all the other bands can be matched within a relatively small range of additional feedline length. The longest additional length required is 9.5m (31ft) for 3.6MHz, which extends the feedline to an electrical half-wavelength.

All other bands require a line extension somewhere between zero and 9.5m, so W6RCA built a variable-length switcher shown

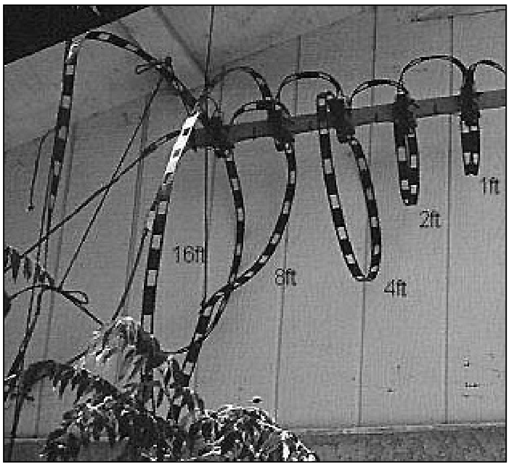


Fig 15.18: Practical line switcher. The horizontal rail holds the five pairs of DPDT relays. W6RCA points out that, with hindsight, it makes more sense to start with the 2.44m (8ft) and 4.88m (16ft) loops at opposite ends of the wooden rail that holds the relays. Band changes can also be achieved manually by using plug-in lengths of line for each band

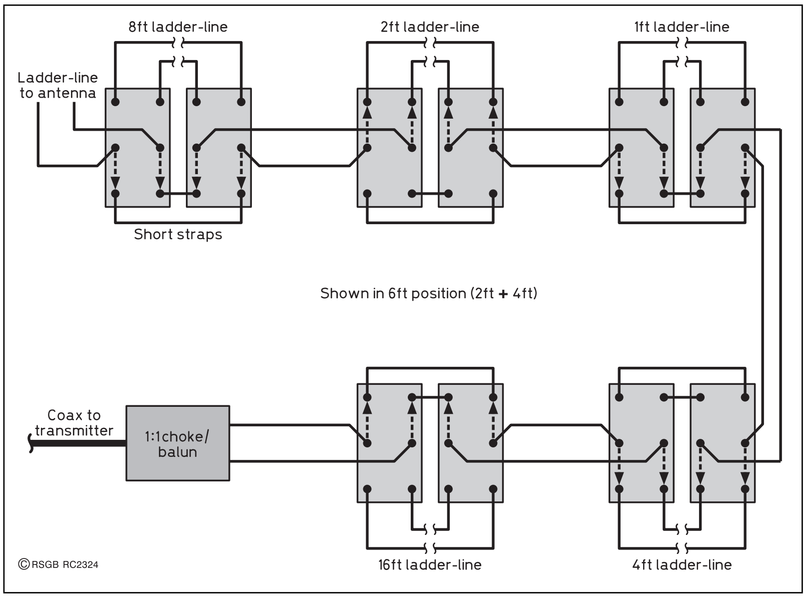


Fig 15.19: More details of W6RCA's line switcher, which uses five pairs of surplus DPDT relays. A suitable 1:1 choke balun is described in the Transmission Lines chapter

in **Figs 15.18 and 15.19**. This consists of 300mm (1ft), 600mm (2ft), 1.22m (4ft), 2.44m (8ft) and 4.88m (16ft) loops of line, which can be individually switched in or out using DPDT relays, giving any length from zero to 9.5m in 300mm steps.

W6RCA found he could cover all amateur bands from 3.6 to 29.7MHz with a SWR of better than 2:1:. The optimum dimensions will depend on a number of local factors. These include antenna height, earth properties, the use of other doublet configurations such as an inverted-V or inverted-U, and the exact type of feedline. So-called '450-ohm' ladder-line varies considerably in characteristic impedance, velocity factor and quality (conductor diameter and insulation) between different brands; hence the need to experiment.

A battery-powered tuneable SWR analyser is the perfect tool for the job of experimenting with line lengths and it should used via the 1:1 balun. You can easily make temporary splices in ladder-line using screw connectors - or just twisting the wires together. The first step would be to increase the permanent length of line by say a metre from the recommended length, then trim the feeder so that the SWR minimum occurs around 7.05MHz. You may find that the same length works well enough for 21MHz and 24.9MHz too. Next, determine the maximum extra length needed to tune all the way down to 3.5MHz with an acceptable SWR. This extra length should not be much more than 9.5m, and the optimum lengths for all the other bands will all be shorter than that.

Unfortunately, the popular 32m (102ft) G5RV-style doublet is not very well suited to this arrangement, because it requires a much wider variation in the feedline length. If you're stuck with a 102ft 'flat-top', W6RCA recommends adding a 4.6m (15ft) vertical 'drop wire' at each end, and then you're back to the much more convenient situation of Fig 15.18. For a shorter doublet covering 7 - 29.7MHz, a 20.12m (66ft) doublet and a 18.3m (60ft) feedline is a good starting-point, again with a 0 - 9.5m variable section. Note also that the system can still be used as a shortened dipole on the next band below, but you will require an ATU and there may be significant losses in the ATU and feedline due to the very low impedance.

After the initial experiments, you can think about a more permanent arrangement. You don't have to build the complete line switcher. Practical solutions range from a fully manual system to a fully automatic system linked to the transceiver's 'band data' output (ideal for HF contesting in the single-antenna section). For occasional visits to certain bands, you could insert the necessary lengths of feedline using 4mm banana plugs and sockets (the silver-plated variety can be used permanently outdoors).

It wouldn't be difficult to string something along a wooden garden fence, so long as the loops of line are suspended clear from other lines, metallic objects or the ground.

The 1:1 balun is worth a brief mention. It's important to use a balun, because any low-impedance path to ground from either side of the feedline is likely to result in very strong unbalanced radiation from the feedline itself. This is a consequence of the 'odd quarter-wavelength' principle used in selecting the feedline length. A suitable choke balun is described later.

The Comudipole (Coaxial Cable Fed Multi-band Dipole)

In many locations, there are problems of bringing open wire feeder into the shack, particularly for apartment dwellers. One solution for a multi-band antenna was first described by Ton Verberne, PA2ABV [5] is the Comudipole.

The arrangement was used to feed an inverted-Vee dipole of about 2 x 19m mounted on the roof of a five-storey apartment building from a second floor shack. The antenna is not that much different from the tuned open wire dipole arrangement shown earlier. However, bearing in mind that twin wire feeder performance can be affected by the close proximity of metal objects such as metal structures and windows, the twin feeder is brought down to a point where it is still clear of metal objects. At this point it is connected to a 4:1 coaxial balun and there a length of RG-213 coax led to the shack where an L-network takes care of matching to the transceiver.

The comudipole overcomes the problem of running twin line feeder into the shack because the balun can be located outside the shack.

In practice the balun can be placed anywhere along the transmission line section from the antenna to the ATU as shown in **Fig 15.20**. However, the feeder system should consist of as

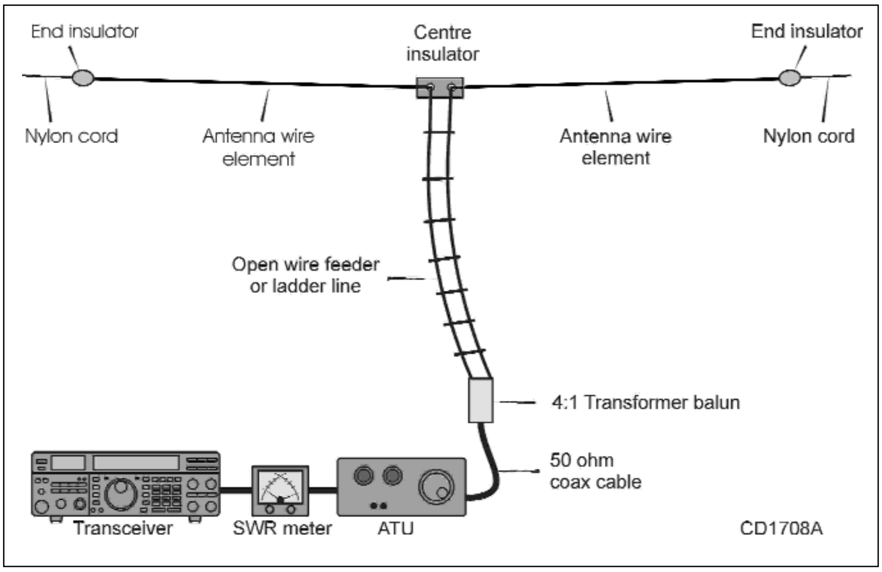


Fig 15.20: The Comudipole feed arrangement for a multiband doublet antenna

much twin wire feeder or ladder line as possible because the losses on such line with a high SWR are much lower than with coax cable. If you are restricted to a short dipole antenna, say less than 15m (45ft), then a 1:1 balun might be more appropriate, see the G3TSO ATU and balun described below.

MATCHING AND TUNING

Many of the antennas described so far may require some degree of impedance transformation before they can be connected to the station transmitter. A unit for providing this transformation is normally called an ATU (Antenna Tuning Unit) or Tuner. As the function of the unit is to match the impedance presented by the antenna system to 50 ohms, AMU (Antenna Matching Unit) might be a more accurate description, but "ATU" is much more commonly used.

There are three different antenna arrangements that may need coupling to the transmitter:

* Wire antenna fed against earth.
* Antenna fed with coaxial cable
* Antenna fed with twin-line feeder or ladder line

Matching the End-Fed Antenna

There are two aspects of the end-fed antenna, which need to be considered. The first is matching the transmitter to the range of impedances encountered at the end of wire antenna on the different bands. The other is an effective and efficient RF earth or ground, which was discussed earlier.

An end-fed antenna has traditionally been designed to resonate on one lower band in the HF spectrum, say a quarter wavelength on 80m where the feedpoint will be around 50 ohms. At a half wavelength on 40m, the input impedance will rise to a high value, presenting a voltage feed to the source. The next band, 30m, will fall in the vicinity of current feed again at three-quarter wavelength and present a fairly low impedance. The next move to 20m will once more encounter a high impedance and then through an off tune 17m to another high at 15m. The sequence continues with extra complications in that odd multiples of one wavelength will show generally increasing impedance with frequency whereas even multiples of wavelength (the halfwave points) will show decreasing impedance on the higher bands.

Fig 15.21 illustrates resistance and reactance plotted against electrical length from below $\lambda/4$ to $3\lambda/4$ and beyond. It can be seen that dramatic changes begin to occur as the $\lambda/2$ (half-wave) resonant point is approached. These changes are repeated at multiples of $\lambda/2$.

In spite of these wide variations of antenna feed impedance on different bands the transceiver can be matched to the antenna using a suitable ATU, which is described later.

The selection of an optimum antenna length was described in detail by Alan Chester, G3CCB [6], although this was done to meet the limitations of a wideband matching transformer system.

In Fig 15.22, wire length is shown against each of the nine HF bands, including 160m. The heavy lines indicate areas where impedance excursions might fall outside the matching capabilities of many ATUs. These lengths were calculated by G3CCB from the lower band edge frequency in each case and no corrections were made for the 'end effect' on a real antenna.

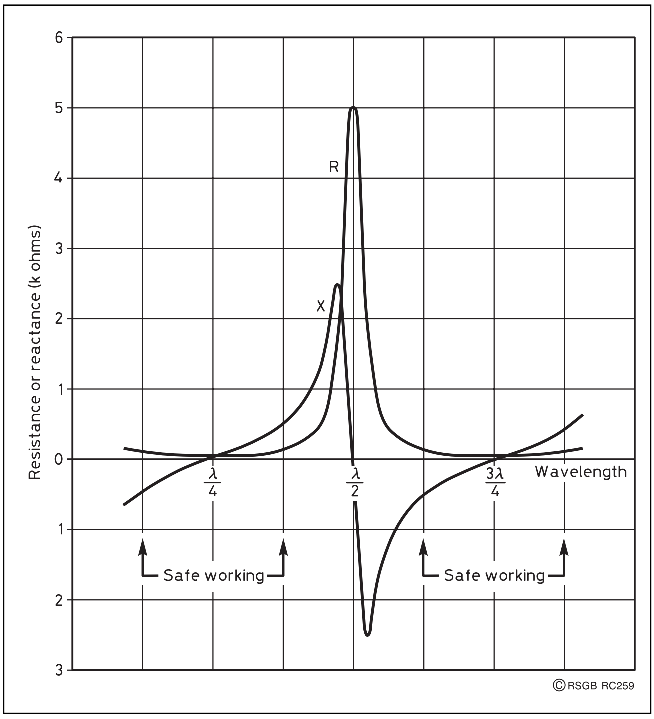


Fig 15.21: End-fed Impedance characteristics of a wire from one-quarter wavelength to three-quarter wavelengths. Values of impedance that are more easily matched using a commercial ATU are designated 'safe working'

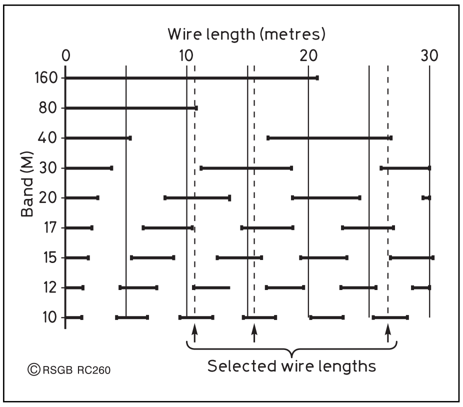


Fig 15.22: Antenna wire lengths, showing high impedance lengths for various bands

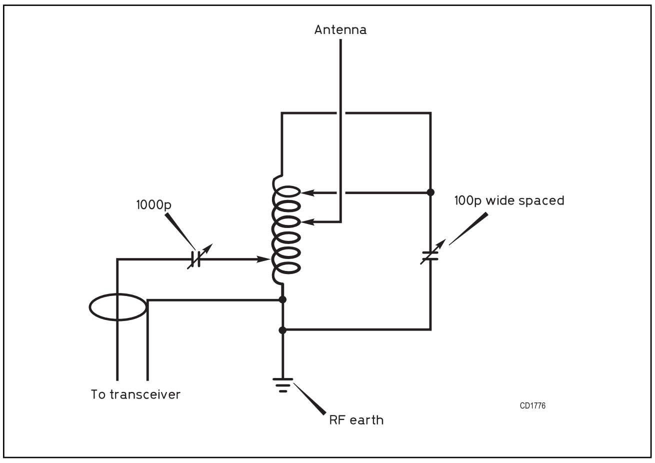


Fig 15.23: A circuit diagram of an ATU for a multiband end-fed antenna. Ideally, to match a whole range of impedances of an end-fed antenna, the coil should be tapped every turn. In practice, a limited number of coil taps can preset and selected using a clip or a switch. The three coil taps and the capacitor settings have to be changed for each band

To use the chart shown in Fig 15.22, a perpendicular straight edge is dropped from the horizontal axis and moved along until a clearest way through the gaps between the extreme impedance sectors is found. There is a minimum antenna length shown which depends on the band in use. This restriction, which may be of interest to those operating from a restricted size site, can be overcome by using a loading coil - this is described later.

In practice the ATU design shown in **Fig 15.23** gets rather complicated when multiband operation is required. Ideally, to match a whole range of impedances with all the various lengths of wire that may be encountered, the coil should be tapped every turn. There are three sets of taps to be adjusted for each band. In practice, coil taps can be adjusted on test then fixed so that they can be selected using a switch or relay.

A Remote Controlled ATU

L B Uphill, G3UCE, devised a remote controlled ATU (**Fig 15.24**) with an end-fed antenna that has proved satisfactory on all the HF bands. It sits in a rear porch and is connected to the shack by 10m of coaxial cable, plus an 8-way multicore cable for remote control of the relays. Other suitable places to house an ATU may be used, such as the garage, outside shed, conservatory or greenhouse. Even mounting it on a post in the garden is feasible, provided the assembly is weatherproofed. A good RF earth or a counterpoise close to the ATU is necessary.

Once set up this ATU provides instant selection of preselected settings. It will, however, need several hours to set up and so should be sited in an accessible position.

The ATU has been tested with several different lengths of antenna from 18m (60ft) to 61m (200ft). Some antenna wire lengths were more difficult than others to get all six bands working, and the best turned out to be 30m (100ft) and 40m (132ft). Around 40 turns are required if 160m is the lowest band to be used; if 80m is the lowest frequency then 20-25 turns are sufficient.

A junk box coil may be used provided the turns are of a reasonably heavy copper wire. The wire spacing should allow the use of an instrument-type crocodile clip with narrow jaws to be clipped to any turn during setting-up, without shorting an adjacent turn. If a suitable coil is not available then a 40-turn coil can be wound on a 190mm (7.5in) length of 45mm diameter plastic pipe using 14 to 16SWG tinned copper wire. Fasten one end to a nut and bolt, and wind tightly using a similar thickness of string as spacing until 40 turns are wound on. Anchor the other end to a nut and bolt and carefully remove the string spacer. Apply 3 or 4 strings of adhesive, such as superglue, across the turns to hold them in place.

The capacitors used are 100pF air spaced types for the higher frequency bands and 500pF 500V working mica presets for the lower bands. A capacitor may not be required for 160m, where a direct connection is made from the coax to the coil.

The relays are 12 volt types and are not critical, provided the contacts can carry about 5A AC. A small control box with a 2-pole, 6-way Yaxley switch controls the relay switching in the shack. One pole switches the relays and the other pole switches small LED indicator lamps to show which band is selected. An 8-core miniature, screened cable is used to connect the ATU to the shack. With six bands to select, this will leave two wires spare and these are used to switch the transmitter on and off via the CW socket during adjustments from the ATU end.

The setting up procedure is as follows: Starting with the lowest frequency, tune up the transmitter on a dummy load to the centre of the band, connect the feeder, energise the appropriate

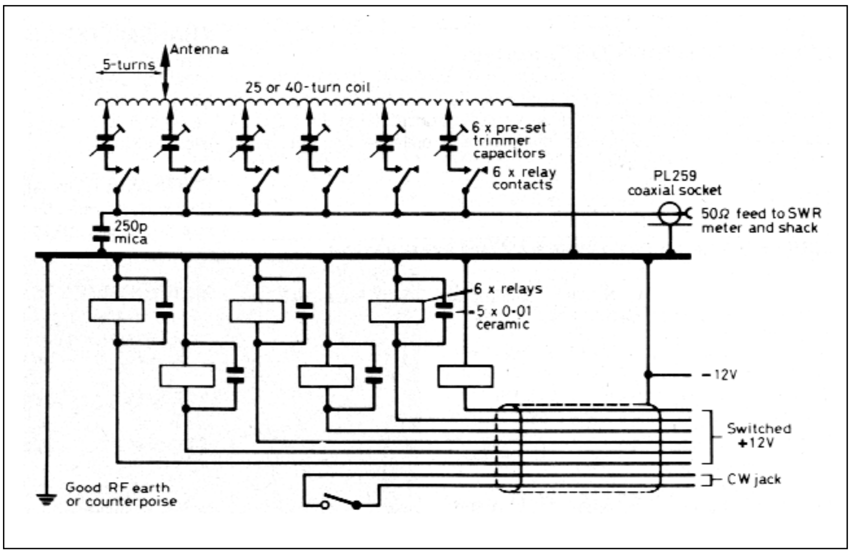


Fig 15.24: The G3UCE remote-controlled ATU

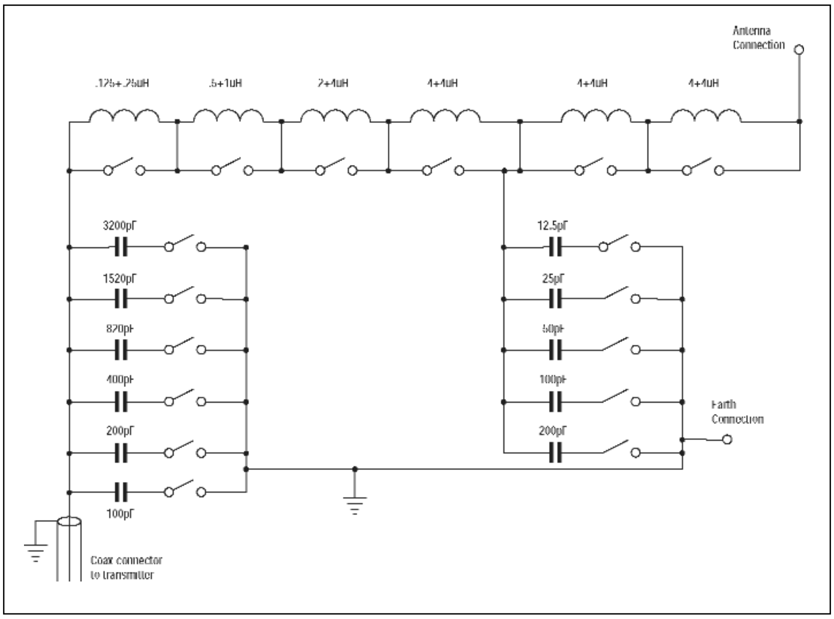


Fig 15.25: Simplified diagram of the SG-235 ATU. The Pi section inductor (the section between the two capacitor banks) is actually made up of eight inductors, while the inductors (top right) are switched in for short antennas. Switching relays are controlled by a SWR/microprocessor circuit (not shown)

relay, and pass a small amount of RF to the ATU. An SWR meter must be inserted at each end of the feeder. Find a tapping on the coil, working from the aerial tap where the SWR reduces, and adjust the appropriate capacitor until a combination is found which gives the lowest SWR (ensure that the transmitter is switched off whilst manually adjusting the tapping point, to prevent the possibility of RF burn to your fingers).

Now check the shack SWR meter and if both are similar readings, the top can be soldered permanently in place on the coil. Now carry on to the next lowest frequency, remembering to switch in the appropriate relay. On the highest frequencies, (15, 12 and 10m) the tap should not need to be more than four or five turns from the antenna.

When all the bands have been satisfactorily set up, no further alterations must be made to the antenna length or the earth system or all adjustments will need to be repeated.

Commercial Remote Control ATUs

An automatic ATU provides the most satisfactory method of feeding a remote antenna.

As with all modern automatic ATUs, adjustment of the inductors and capacitors in the matching network is accomplished using relays. These relays are controlled via a microprocessor using an embedded tuning algorithm, which in turn receives SWR and impedance samples from an RF head.

The construction of an automatic tuner is beyond the scope of this chapter, however the G3XJP PicATUne automatic ATU design can be found at [7]

The SG-235 is quite a robust unit, said to be capable of handling 500W, and is obviously the big brother of the SG-230, a simplified version of which is shown in **Fig 15.25**. From this we can see that the SG-235 is a Pi-network although if one of the banks of capacitors were switched out it would be an L network.

On the left hand side of Fig 15.24 are the capacitors associated with the low impedance 50-ohm input from the transmitter. This bank of capacitors, with a total capacity of over 6000pF, can be switched in or out with relay contacts with a resolution of 100pF. On the antenna side of the ATU a total of nearly 400pF can be switched in with a resolution of 12.5pF. These capacitors are made up of groups of series/parallel capacitors to obtain a safe voltage working.

Additionally, these capacitors are switched using four sets of relay contacts in series for both switching voltage working and to reduce stray capacitance. The Pi section inductor (the section between the capacitor banks) is actually made up of eight inductors having a total inductance of 15.75µH and a switching resolution of 0.125µH. Antennas shorter that a quarter wavelength, which present low and capacitively reactive impedances are taken care of using four 4µH inductors (top right) that can be switched in or out to load a short antenna.

The microprocessor ATUs that are now on the market have made the remotely fed long wire a much more practical reality.

The T-Network Antenna Tuner

The classic pi-network, or LC/CL two-component matching networks, can be used as the basis of an ATU. These are theoretically capable of matching any transmitter to any antenna impedance (resistive or reactive). However, in practice the matching range is dependent on the component values. For the widest step-up and step-down transformations, the high-voltage variable capacitors need to have low minimum and very large maximum capacitance values - a significant disadvantage these days. The Pi-network possesses the advantage that it not only transforms impedance but also forms a low-pass filter; and so provide additional harmonic and higher frequency spurii attenuation.

Modern solid-state transceivers include built-in low-pass filtering tailored to the individual bands, with the result that there is far less requirement for the harmonic attenuation previously provided by the ATU. This has opened the way for much greater use of the T-network which can provide an acceptably wide range of impedance transformations without a requirement for large-value variable capacitors (**Fig 15.26**). The fact that they form a high-pass rather than a low-pass filter is no longer regarded as a real disadvantage.

While the T match has enjoyed considerable popularity, it does suffer losses at some transformation ratios on the higher frequencies. These losses can be mimimised by a

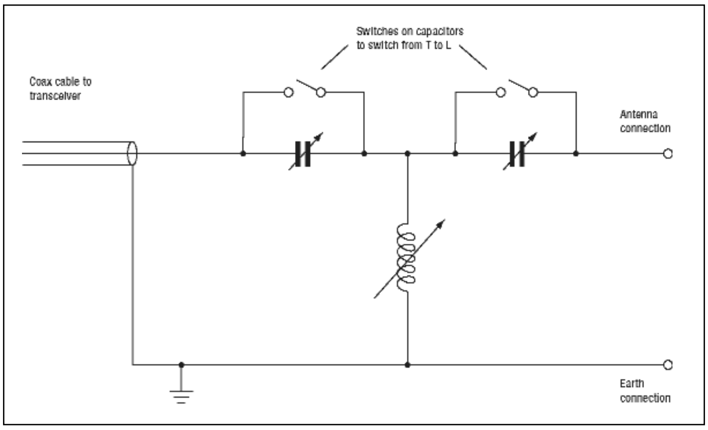


Fig 15.26: The series capacitor T network, which forms the basis of most modern ATUs. The shorting switches across the capacitors allow the unit to be switched to an L network to reduce losses

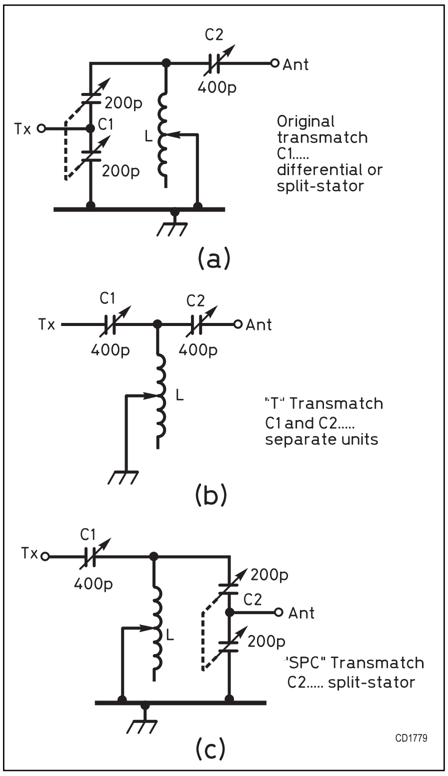


Fig 15.27: Variations of the 'Ultimate transmatch' (a) Original transmatch: Cl differential or spilt stator. (b) T-transmatch: C1, 2 separate units. (c) SPC transmatch: C2 split stator

simple modification which uses a cam switch on the ends of the capacitors, and is described in [8].

The G3TSO Transmatch

The following is a description and a short history of the development of the Transmatch, plus construction details, by M J Grierson, G3TSO [9].

The original design of Transmatch, Fig 15.27(a), used either a differential or a split stator input capacitor. The differential capacitor is less common than the split stator and has one section at a maximum capacitance while the other section is at minimum capacitance. This has the effect of providing a synthetic sliding tap on the inductor L, whereas the split stator capacitor tunes the inductor L, but maintains the tap centrally.

The use of a dual-type input capacitor for harmonic suppression lost all credence some years ago and the circuit was amended to the simpler T-match of Fig 15.27(b). This circuit is that of a high-pass filter and provides no suppression of harmonics. More recently the 'SPC' (series-parallel capacitance) transmatch Fig 15.27(c) has emerged with a dual-output capacitor to providing a degree of harmonic suppression. In any event all three designs perform the task of matching a range of impedances quite successfully. As stated earlier, the advent of SSB and linear amplifiers and, more recently solid state transmitters with built-in low-pass filters, harmonic suppression is not the problem it was when using Class-C AM power amplifiers.

G3TSO decided, in the interest of simplicity, to adopt the T-match variant, shown in Fig 15.27(b), of the transmatch in his general-purpose antenna tuning unit (Fig 15.28) This is the route taken by most ATU manufacturers at the time of writing - more of this later.

The tuning unit to be described provides operation on all bands from 1.8 to 28MHz. Other features have been added to permit the selection of different antennas as well as the facility to ground all inputs when the station is not in use. This unit also includes an SWR meter, and a balun to allow the unit to feed balanced lines.

Component selection

New components suitable for use in antenna tuners are either not readily available or very expensive, so the use of surplus components is the most economical answer. Fortunately the values of capacitors required are not too critical, and almost any high-quality wide-spaced variable capacitor can be put to use. Ideally a value of between 200pF and 400pF is suitable, and a number of surplus Johnson and Eddystone 390pF units have been seen over recent years. These units have ceramic end plates and are tested to 2,000V DC working. If in doubt, aim at a plate spacing of at least 1 .5mm between the stator and rotor plates; this is necessary to cope with the high voltages which can be developed when matching high-impedance long-wire antennas.

Inductors can be either fixed, with a number of taps selected by a rotary switch, or variable such as the roller coaster, which allows maximum flexibility in matching. Roller coasters come in a variety of different shapes and sizes, but in general are not available in other than small numbers and one-offs.

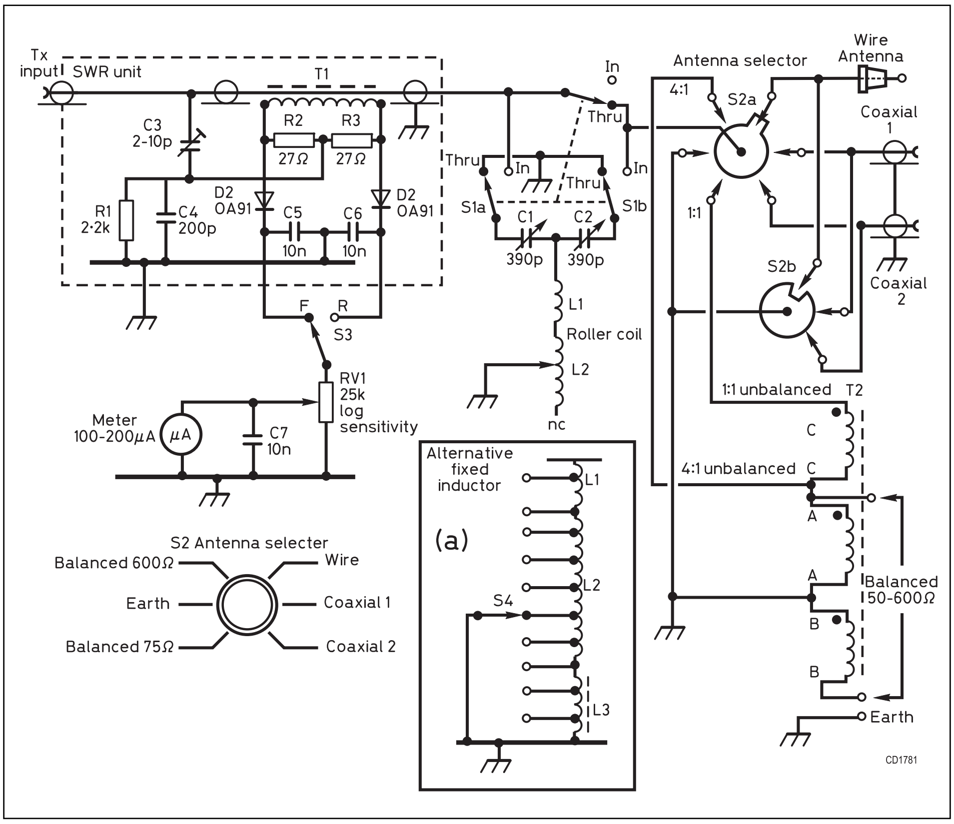


Fig 15.28: Circuit diagram of the G3TSO ATU

All switches used are of the 'Yaxley' type and use ceramic wafers; large numbers of this type of switch can often be found in junk boxes at rallies, and several switches can be broken down and reassembled to achieve the desired configuration. Paxolin wafers can be used, though they are not as good as the ceramic type.

The antenna selector switch uses a double-spaced switch unit giving six stops per revolution rather than the usual 12. The switch wafers are modified by removing alternate contacts, thus reducing the likelihood of arcing between them.

Balanced feeders

As the T-match is an unbalanced antenna tuner, some type of balun transformer must be incorporated if it is to be used successfully with balanced feeders. While a balun transformer provides a very simple solution for coupling a balanced feeder to an unbalanced tuning unit, it is not likely to be as efficient as a properly balanced ATU. Many published designs use a 4:1 balun to provide a balanced input for impedances in the range 150 to 600 ohms. However, if a low impedance feeder from either a G5RV or W3DZZ type of antenna is connected to a 4:1 balun, significant losses may occur. For this reason it was decided to use a 1:1 balun which, if fitted inside the tuning circuit, can easily be switched to 4:1 by use of the antenna selector switch. This now provides a range of balanced inputs from about 45 to 600 ohms without introducing too many losses into the system.

Balun construction

The balun transformer is wound on a single Amidon T200-2 powdered-iron core, colour coded red. For sustained high-power operation, 400W plus, two such cores can be taped together by using plumbers' PTFE tape, which can also be used to provide an added layer of insulation between the core and the windings.

Balun construction is simple, but a little cumbersome; some 14 turns of 16SWG enamelled-copper wire have to be wound trifilar fashion onto the toroidal core. That is to say, three identical windings are wound on together. Care must be taken to ensure that the windings do not overlap or cross one another and that neither the core nor enamel covering is badly scratched during construction.

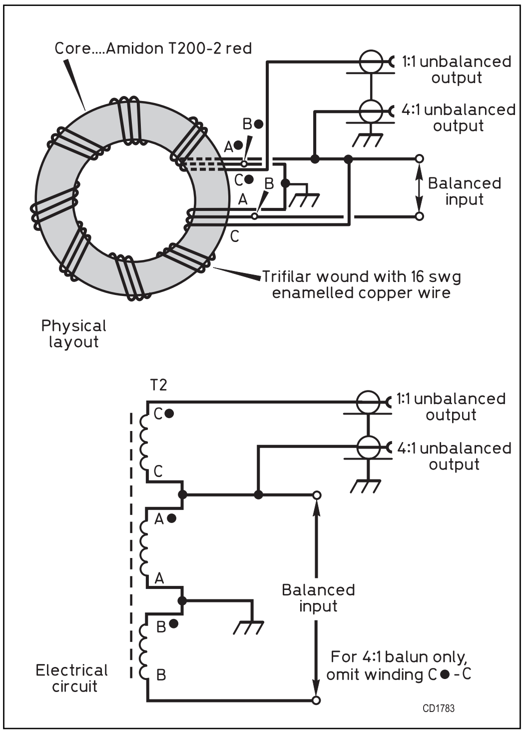


Fig 15.29: 1:1 and 4:1 balun transformer

Fourteen turns will require approximately 97cm (38in) of 16SWG (1.6mm) wire, so cut three equal lengths of 16SWG wire slightly longer than required and pass all three wires through the core until they have reached about halfway.

This now becomes the centre of the winding. It is easier to wind from the centre to either end rather than from one end to the other which involves passing long lengths of wire through the toroid. The T200 size core will accommodate 14 turns trifilar without any overlapping of the start and finish of the winding. Close spacing will occur at the inside of the core, and a regular spacing interval should be set up on the outside. A small gap should be left where the two ends of the winding come close together.

Connection of the balun requires care. It is necessary to identify opposite ends of the same windings, which can be done with a continuity meter, with some form of tagging or colour coding being worthwhile. On the circuit diagram a dot is used to signify the same end for separate windings. It is essential that the various windings are correctly connected if the balun is to work properly.

Details of how the balun transformer is wound and connected are shown in **Fig 15.29**. In this tuning unit, the balun is supported directly by soldering to the balanced input terminals, which are spring-loaded connectors.

A sheet of 8mm (5/16in) Perspex is then used to insulate the balun from the aluminium case. Construction of a four to one balun only is slightly simpler and only requires two (bifilar) windings.

ATU	
C1, C2	390pF 2,000VDC wkg, ceramic end-plates, eg Eddystone or Jacksons
L1	3t 10SWG, 25mm (1in) ID, 25mm (1in) long
L2	Roller coaster 36 turns, 38mm (1.5in) dia, 16SWG
T2	Amidon T200-2 (red); 14 turns trifilar 16SWG enamel
S1	Three-pole two-way ceramic Yaxley
S2	One-pole six-way double-spaced ceramic Yaxley; one-pole six-way shorting water (one pole open)
Alternative ATU circuit	
L1	2.5t 14SWG 25mm (1in) ID tapped at 1 .5t
L2	14t 16SWG 1.25in ID tapped at 1, 2, 6, 9 and 14t
L3	Amidon T1 57-2; 31t I8SWG enam tapped at 6 and 27t
84	One-pole 11-way ceramic (three wafers to include S1 function)
SWR bridge	
R1	2.2kohm
C3	2-I0pF trimmer
C4	200pF mica
C5, C6, C7	10nF disc ceramic
R2, R3	27ohm
RV1	25kohm log
D1, D2	Matched OA91 etc (germanium diodes)
T1	18t 22SWG 13mm (0.5in) OD ferrite ring (Amidon FT50-43, Fairite 26-43006301). Primary: 38mm (1.5in) coaxial cable, braid earthed one end only to form electrostatic shield.
Meter	100-200µA
S3	SPCO miniature toggle

Table 15.2: Components list for the G3TSO Transmatch

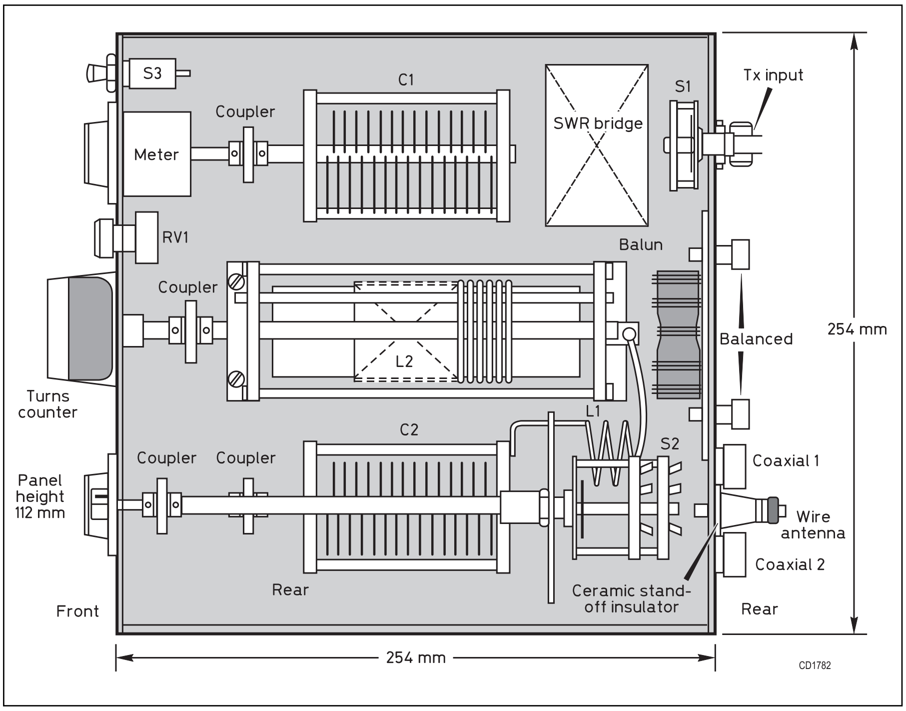


Fig 15.31: Component layout of the G3TSO ATU

A short length of coaxial cable is passed through the ferrite core to form the primary after the 18 turn secondary has been wound on. The braid of the cable can be earthed at one end to form an electrostatic screen, but on no account should both ends of the braid be earthed or it will form a shorted turn.

D1 and D2 should be a matched pair of germanium diodes, which can be selected from a number of similar-type diodes by comparing their forward and reverse resistances. Whilst this is best done with a high frequency signal, adequate matching can be achieved by using a simple multimeter.

Fig 15.30 (in Appendix B) gives a suggested layout and PCB track. The size is not at all critical, but a symmetrical layout should always be attempted.

The completed SWR bridge should be tested away from the antenna tuner by placing it in line between a suitable transmitter and a 50 ohm dummy load. The trimmer capacitor is adjusted to produce a zero-reflected reading with the forward reading at full scale. By connecting the bridge the reverse way around, some check of the diode balance can be judged by comparing the meter deflections in both directions. The forward and reverse switch selection will be reversed if the signal direction through the bridge is reversed. It is advisable to check that the bridge balances on a number of different bands, as C3 may be more sensitive at the higher frequency end of the operating range.

The sensitivity of the bridge is very dependent upon the resistance of the meter used. Comparison with a calibrated SWR bridge will enable a simple calibration of 1.5:1, 2:1 and 3:1 to be made, and in most cases a mental note of where these occur is the only calibration required, unless you wish to dismantle the meter in order to recalibrate the scale.

SWR measurement

It is often convenient to be able to connect the antenna tuner directly to the transmitter without the need for extra cables and external SWR bridges, so a built-in SWR bridge has been included in the design. The circuit, shown in Fig 15.28, is fairly conventional and is a current-sampling bridge which, unlike the voltage sampling stripline bridge, is not frequency conscious.

The current transformer T1 uses a small ferrite ring of about 12mm (0.5in) diameter, and while the size is not critical, the grade of ferrite is. Ferrite having an AL value of at least 125 should be used; the Amidon FTSO-43 ferrite core is ideally suited to this application.

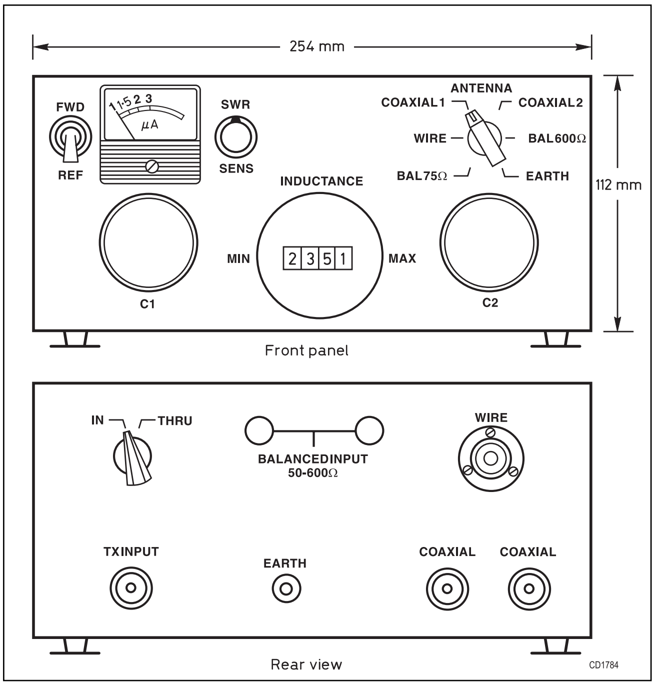


Fig 15.32: Front and rear panels of the G3TSO ATU

Construction of the antenna tuner

The complete tuner layout is illustrated in Figs 15.31 and 15.32 and the Components List is in Table 15.2. It is advisable to collect all the components and lay them out on a sheet of paper before committing yourself to a particular size. Layout is not over-critical, but a sensible approach is needed to minimise lead lengths and unnecessary stray capacitance, which could render 28MHz operation impossible.

Cases can be purchased, or prefabricated using 16 or 18SWG aluminium sheet bent into two interlocking 'U' shapes. Half-inch (12mm) aluminium angle provides stiffening as well as a means of joining the sections together. Roller coaster connections should be arranged so that minimum inductance is located at the end closest to the connections, ideally the rear of the unit. A small heavy-duty coil, L1, is included for ease of 28MHz operation and is more efficient than half a turn on the roller coil.

An alternative arrangement to the roller coaster is shown in Fig 15.28(a). Here a switched inductor is used. The switch should be ceramic with substantial contacts. A third toroidal inductor is included to permit operation on 1.8MHz. It is recommended that the bottom end of this could be shorted to ground to prevent the build-up of high voltages which could arc over.

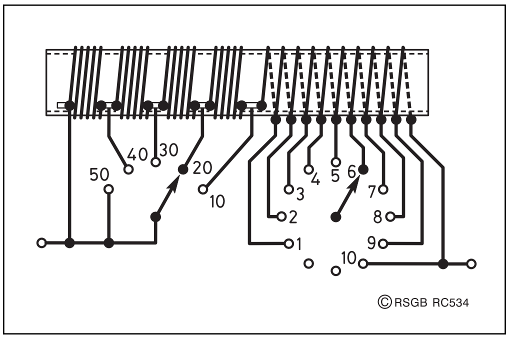


Fig 15.33: A variable inductance ATU coil described by Hector Cole, G3OHK. This arrangement uses two switches and just 14 taps to permit selection of from one to 50 turns of a 50-turn coil and which can be quickly reset to any number of turns previously found suitable without the turns counters required for roller coaster coils

A further switched inductor was described by G3OHK, and this is shown in Fig 15.33.

The capacitors C1 and C2 are electrically above ground and must be mounted on insulators, a problem greatly reduced if the capacitors are constructed using ceramic end-plates. Ceramic pillars or even Perspex may be considered for mounting capacitors with metal end-plates. Additionally the shafts of the capacitors must be insulated; the use of Eddystone spindle couplers is recommended. To ease the rather sharp tuning characteristics that can be encountered on 21 and 28MHz, slow-motion drives were tried but they made tuning on the lower frequencies rather laborious and their use is not advisable. A turns counter on the roller coaster makes for much simpler operation, and may be as simple as a slot in the cabinet with a Perspex window for monitoring the position of the jockey wheel or a more sophisticated geared or direct-drive counter.

Antenna switching can introduce excessive lead lengths as well as stray capacitance, and for this reason the antenna selector switch is located on an extension shaft at the rear of the unit adjacent to the antenna inputs and the balun transformer. The wiring of the antenna switch is done strictly to achieve minimum lead lengths rather than to provide front-panel selections in any logical order. A separate IN/THROUGH switch enables the tuner to be bypassed and the antennas routed directly to the transmitter. It is located on the rear panel adjacent to the input socket to minimise lead length, and is intended only for occasional use. It is necessary to ground the tuning components in the THROUGH position to minimise capacitance effects.

Wiring of the tuner should commence after the mounting of all components, and fairly heavy wiring such as l6SWG tinned wire, coaxial cable braid or copper strip should be used. It has not been found necessary to screen the SWR bridge, but it should be located directly adjacent to the transmitter input socket and all meter leads kept away from tuning components.

The antenna selector switch has two ceramic wafers and is arranged so that every other contact is removed to give double spacing. The second wafer is used for shorting and provides a ground for all unbalanced antennas not in use. This is largely to prevent capacitive coupling to other antennas. The balanced input is grounded to DC through the balun. Balun switching is simply achieved by either taking the input from one side of the balanced input, giving a 4:1 ratio, or by selecting the third winding, giving a 1:1 ratio. An earth position enables the transceiver input to be grounded to prevent static discharge into the receiver.

Operation of the antenna tuning unit

If the SWR bridge is included in the design, it should be checked and balanced independently of the ATU, using a dummy load. Ideally it should be compared with, and calibrated against, an SWR measuring device of known accuracy.

To use the antenna tuner, select the required antenna and ensure that the THROUGH/IN switch is in the IN position. Set both C1 and C2 to halfway positions, adjust the inductance for maximum signal on receive, and one at a time adjust C1 and C2 for maximum received signal. Using low CW transmitter power, further adjust C1, C2 and the inductance to eliminate any reflected reading on the SWR meter. All tuning controls are interdependent, and settings may need to be adjusted several times before minimum SWR is achieved. In addition, more than one setting may give a matched condition, in which case the settings requiring the highest value of C1 should be used. Once the transmitter is matched on low power, increase the operating power for any final adjustments. Never attempt to tune the ATU initially on full power or with a valve power amplifier that has not been tuned up.

Generally, the higher the frequency the lower the value of inductance required, but exceptionally high impedances may require more inductance than expected. Capacitance values may vary considerably, and it is not uncommon on the higher frequencies for one capacitor to be very sharp and require a minimum value while the other is flat and unresponsive. Using the components recommended it is possible to match a wide range of impedances from 1.8 to 28MHz, but operation on 1.8MHz may become impossible if lower values of capacitance are used; however, fixed silver mica capacitors may be switched across C1 and C2 to compensate. Higher values of capacitor will almost certainly prevent operation on 28 and maybe 14MHz.

Conclusion

The antenna tuner described is not new or revolutionary in design, but probably represents the ultimate in flexibility. Performance is good and it is not inhibited by a lack of balanced input or restricted to a very narrow range of low impedances. The power handling capability of the tuner will to a large extent depend upon the impedances encountered and the spacings of the capacitors. As a rule, very high impedances should be avoided, as arcing can occur in the switches and the efficiency of the unit may well suffer. Adjustment of antenna or feeder length can remove any exceptionally high impedances that may be encountered.

G3TSO used this tuner with a 60m (180ft) doublet fed with an unknown length of 300 ohm slotted ribbon feeder, where it could be tuned to give a 1:1 SWR on all amateur bands from 1.8 to 28MHz. Using Eddystone capacitors of the type recommended, the tuning unit should be capable of handling 100W into a fairly wide range of impedances up to several thousand ohms, and the full 400W into impedances up to 600 ohms.

Two versions of the tuner have been built using the same basic circuit, one for base station operation using a roller coaster coil, and a smaller portable version using a range of switched inductors. The portable version has a slightly different layout, largely as a result of trying several other designs, and combining the IN/THROUGH facility on the inductor switch has necessitated several wafers. The balun used in this version is also the simpler 4:1 type and is connected with a flying lead.

For those who wish to adopt the 'SPC' circuit, the value of C2 should be made approximately 200pF, and an additional similar value capacitor should be ganged to C2 and connected between the antenna side of C2 and ground. Both capacitor rotors should be connected together and the stator of the new capacitor should be grounded.

The construction of the described antenna tuning unit should be well within the capabilities of most newly-licensed amateurs,

Fig 15.34: A commercial tuning unit using the T-match principle - the MFJ VersaTuner V

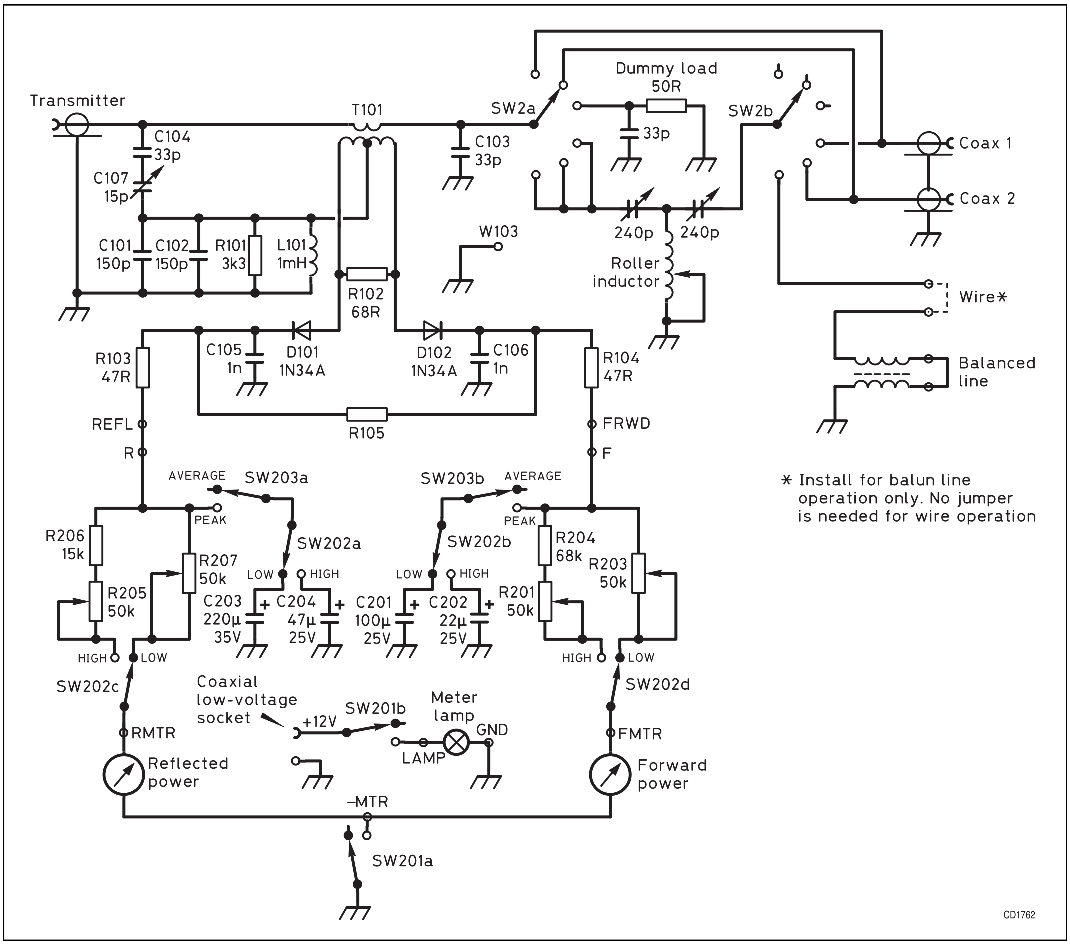
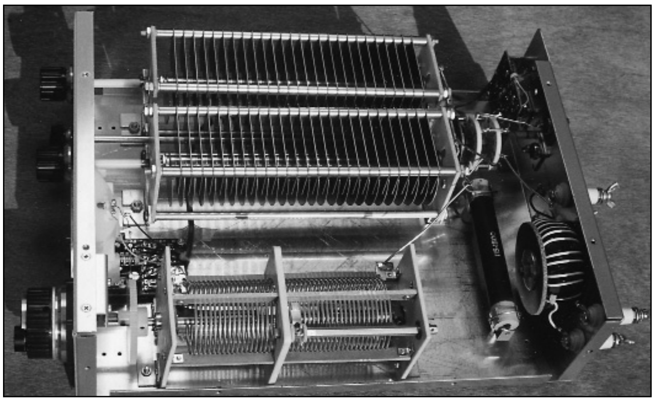


Fig 15.35: Layout of the MFJ VersaTuner V



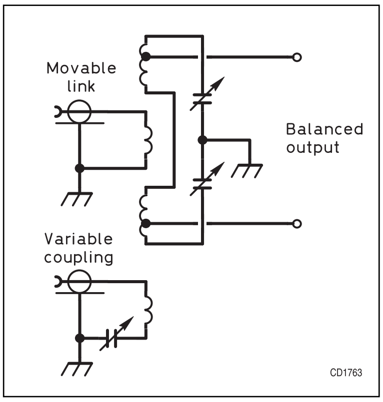


Fig 15.36: Typical link-coupled antenna tuner circuit

and it can represent a considerable financial saving when compared to the commercial alternative.

The MFJ VersaTuner V

This commercial ATU uses the popular T-match tuning arrangement very similar to the G3TSO tuner described above. It also uses similar antenna switching and has a cross-needle power and SWR meter that is particularly convenient to use. The ability to switch in a dummy load is also a useful feature. In fact this is more than an ATU - it is an antenna management system. The circuit is shown in **Fig 15.34** and the layout in **Fig 15.35**

The toroid balun is fixed at 4:1, with its limitations as already described.

Balanced ATUs

Many of the antennas so far described require a balanced feed. The following is material by W4RNL, who describes methods [10] to adapt unbalanced antenna tuners (ATUs or transmatches) to service with balanced lines. Among the schemes used the following are the most common ones:

1. Float the tuner from ground and install a balun at the input end.
2. Install a balun, usually 4:1, at the antenna side of the tuner, to convert the balanced line to an unbalanced line.

Either system is subject to limitations. Floating the tuner does not guarantee freedom from common-mode currents that defeat balance. A 4:1 balun often reduces the already low impedance at the antenna terminals to a still lower one although a 1;1 balun can be used as described earlier by G3TSO.

The more classic alternative is the link-coupled or inductively coupled ATU; the basic circuitry is shown in **Fig 15.36**. The unbalanced input is inductively coupled to the main inductor. Since the mutual inductance between the coils is critical for

Resistors

R1, R2	150 ohm 2 watt metal film
RV1, 2	47k linear potentiometers with plastic shafts, Maplin FW04E

Capacitors

VC1, 3	13-250pF, 7.8kV, type TC250. Nevada
VC2	14-400pF, 1.25kV, Jackson type LAT. Cirkit
C4, C5	10nF 50V ceramic disc

Semiconductors

D1, D2	1N914

Misc

M1, M2	100µA, Maplin RX 33L
S1	4-pole 3- way rotary switch, Maplin FF76H*
Small vernier Dials	(3 off) Maplin 141 RX39N
Pointer Knob	Maplin RW75S
Spindle couplers (3 off)	
Knobs (2 off)	Maplin FK40T
GP1	Grounding Post, Maplin JL99H
TP5, 6.	Terminal Posts, Maplin HF02C
SKT1-13	4mm sockets, Maplin KC49D
SKT14	UHF chassis socket
4mm banana plugs	(54 off) Maplin JB24B (sufficient for 9 coils)
3mm panel head steel bolts (8 off). 16mm long, with nuts and washers	
Self adhesive rubber feet (4off)	
Spacer 1, 2	Terminal block (one 12-way strip, cut to suit), Maplin FE78K
TP1-4	Terminal Posts, Maplin HF02C
MDF	6mm thick, 35cm x 1.2m approx
Perspex	4mm thick, 100 x 300mm approx
Plastic tube	68mm OD, 1.25 metres
Plastic tube	36mm OD, 0.5 metres
Enamelled copper wire (159g)	1.25mm (18SWG)
Tinned copper wire (450g)	1.25mm (18SWG)
Tinned copper wire (150g)	1l.6mm (16SWG)

** Two poles are spare. Use spare tags as junctions for D1, C4, VR1, and D2, CS, VR2.*

Table 15.3: Components for the G0LMJ Balanced ATU

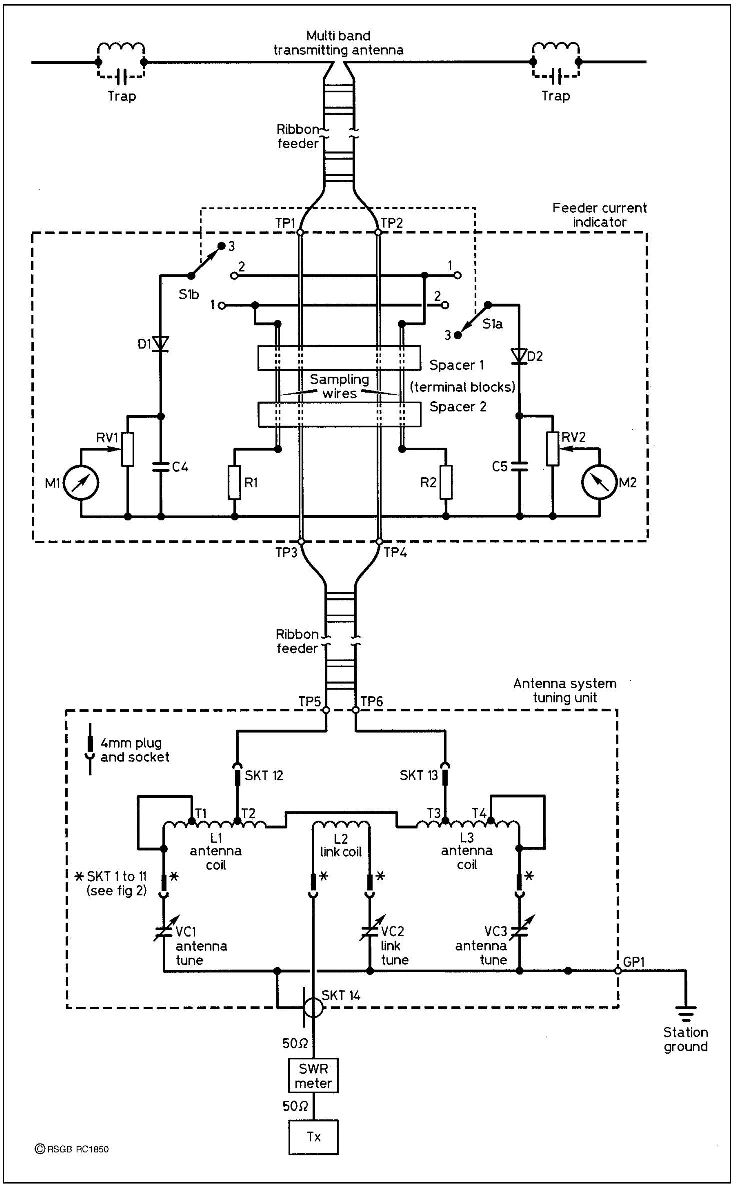


Fig 15.37: The G0LMJ balanced line ATU circuit diagram. The ATU is shown in the lower dotted box, and the feeder current indicator in the upper dotted box

maximum efficiency, the coupling is varied either by a movable link or by a series input capacitor.

Likewise, a single coil and link for all HF bands does not provide the best coupling ratios for all possible conditions. Without provision for coil tapping and series connections, the most efficient operating mode may be inaccessible, despite a 1:1 match.

For an operator who likes to change bands frequently, these inconveniences may be worse than the losses inherent in current systems pressed into balanced-line duty. However, for operators seeking the most efficient transfer of power to balanced lines, nothing beats a properly designed and constructed link-coupled ATU.

Balanced Tuner With Plug-In Coils

A properly designed and constructed link-coupled ATU is one of the most efficient methods of transferring power to balanced lines. The description of the ATU that follows is by Ted Garrott, G0LMJ [11]. It uses plug-in coils rather than switching. Each HF band has its own coil, so nine coils are needed to cover all bands, 1.8 - 28MHz.

The ATU uses a conventional circuit, see **Fig 15.37**, except that L1 and L3 are not tuned by a split stator capacitor. Instead, two separate capacitors VCl and VC3 are used. This arrangement provides the facility of adjusting the ATU to give equal current into the two halves of the antenna. The relative values of RF current in the two feeder wires is monitored using with two meters M1 and M2.

As can be seen from **Fig 15.37**, the unit is built in two parts; the tuner and the feeder current balance indicators. An SWR meter is used between the transmitter and the ATU.

Materials and Components

Medium Density Fibreboard (MDF) is used for the chassis, and plastic drainage piping for the coil construction. All the materials and components (**Table 15.3**) have been chosen because they are relatively easy to obtain.

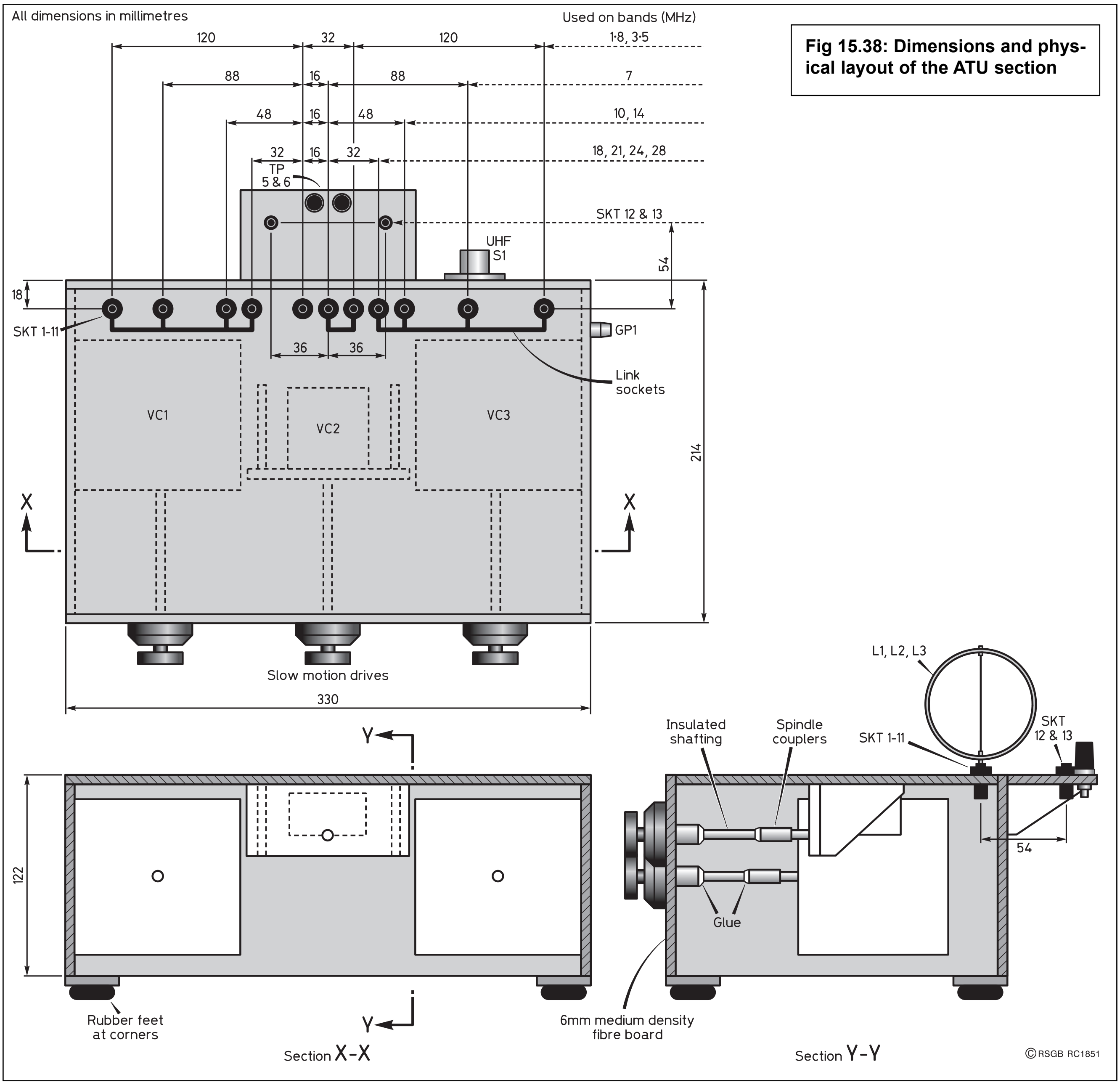


Fig 15.38: Dimensions and physical layout of the ATU section

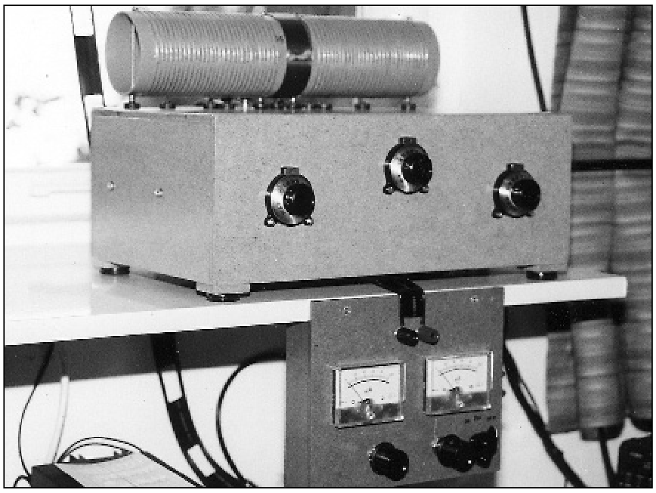


Fig 15.39: General view of G0LMJ's Balanced Line Antenna Tuning Unit

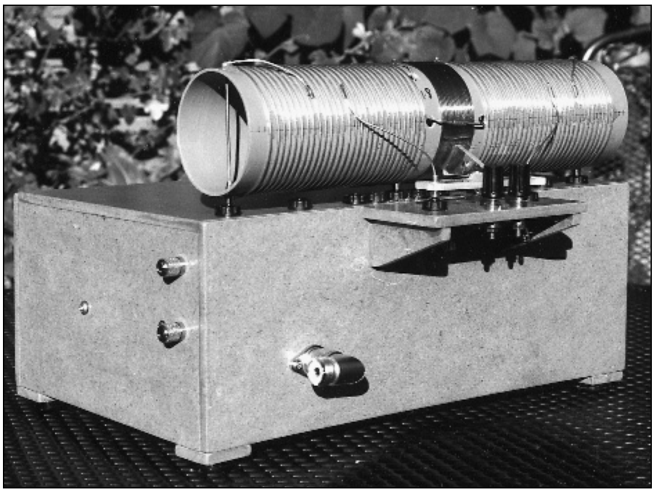


Fig 15.40: Rear view of the ATU. Note the bracket which carries coil sockets Skt 12 and 13, and the output terminals TP 5 and 6

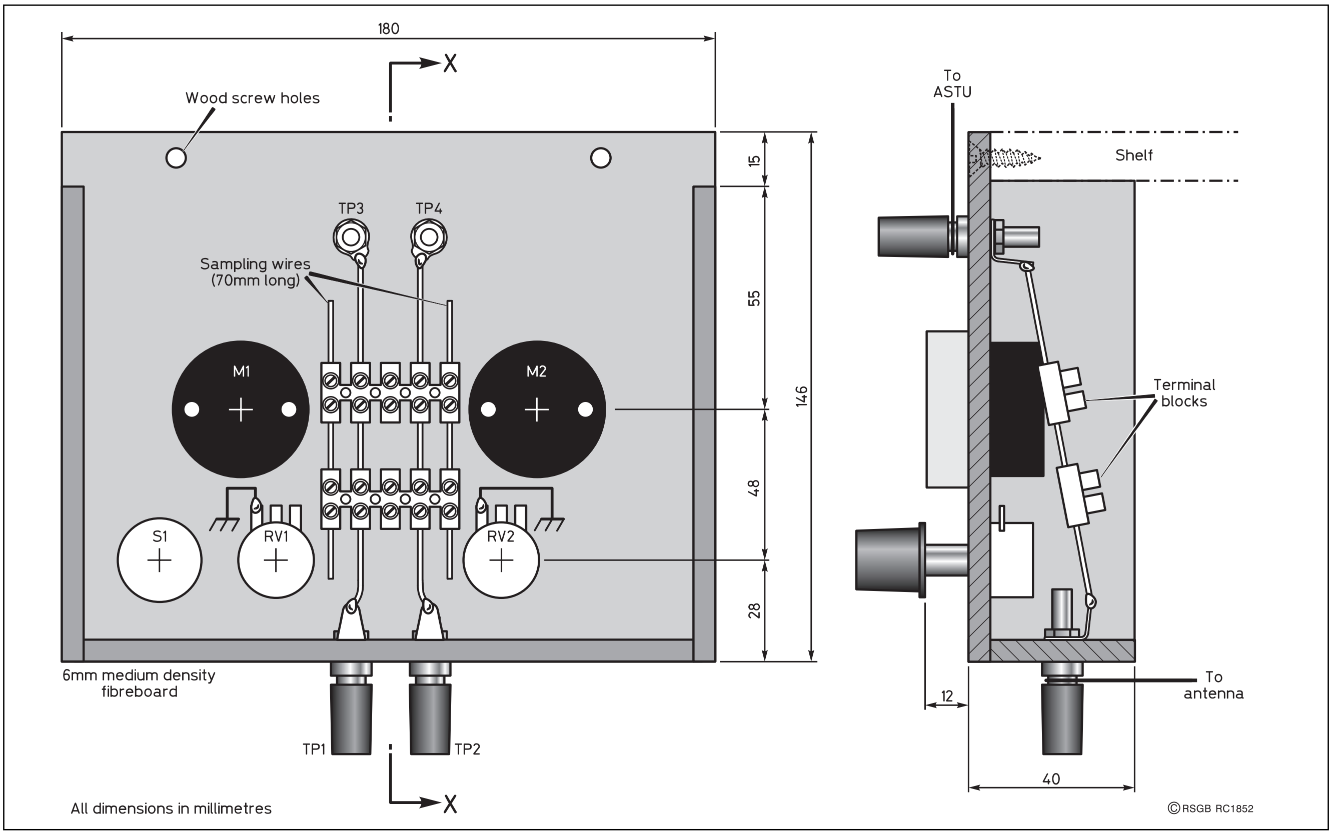


Fig 15.41: Dimensions & physical layout of feeder current indicator

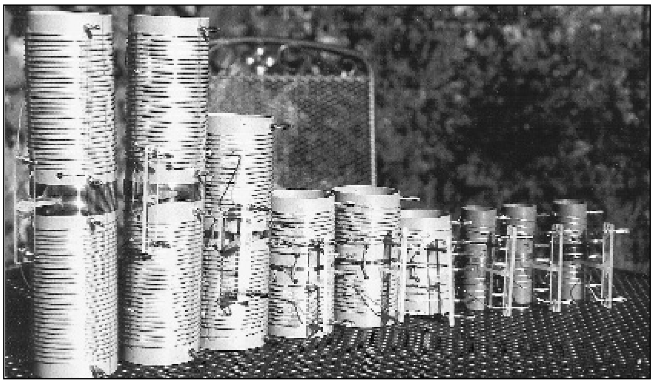


Fig 15.42: The nine coils required to cover all the HF bands

Band (MHz)	L1 (turns)	L2 (turns)	L3 (turns)	D (mm)	A (mm)	B (mm)	C (mm)
1.8	28	18	28	68	120	32	120
3.5	28	11	28	68	120	32	120
7.0	19	5	19	68	88	16	88
10.1	10	3	10	68	48	16	48
14.0	9	3	9	68	48	16	48
18.068	3	2	3	68	32	16	32
21.0	4	4	4	36	32	16	32
24.89	4	4	4	36	32	16	32
28.0	4	4	4	36	32	16	32

Table 15.4: G3LMJ tuner coil turns and dimensions. L1, L3 1.25mm tinned copper wire, L2 1.25mm enamelled copper wire, L1, L3 to fill available space and wound in same direction, L2 close wound. The coils for 21, 24 and 28MHz are identical, but the tapping points are likely to be different (see set-up procedure)

Construction

The general layout and dimensions are shown in **Fig 15.38**. The chassis is made from 6mm MDF, and the joins are fixed with wood adhesive. The outside of the chassis is smoothed with sandpaper and wiped with a damp cloth to remove the dust, and then treated with four coats of varnish. A general view of the ATU is shown in **Fig 15.39**.

VC1 and VC3 are mounted below the chassis and bolted to the side walls. VC2 is also mounted below the chassis, on its own fabricated brackets. The output terminal posts TP5 and 6, together with two 4mm coil sockets, Skt12 and 13, are mounted on a bracket glued to the rear of the chassis, as shown in **Fig 15.40**.

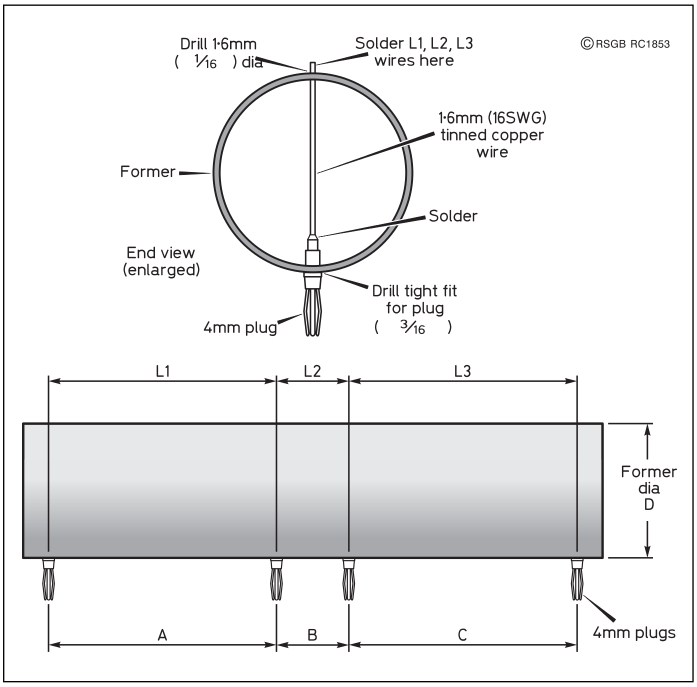
The coil and VCs 1, 2 and 3 are mounted to the rear of the chassis, in order to avoid hand capacity effects when tuning. VCs 1, 2 and 3 are driven by calibrated slow motion drives via lengths of insulated rod. To reduce backlash this rod is both screwed and glued to the coupler and slow motion drive.

The 4mm coil sockets, Skt 1 to 11, are arranged along the rear of the chassis to accommodate the plug-in coils. The seemingly odd spacing of these sockets is to accommodate the various lengths of coil formers and plug spacings. Note that some of the 4mm sockets are connected together, see Fig 15.38, under the chassis. Some of the sockets are too close together to use the fixing nuts, so these are glued into their holes. The sockets must be accurately set out on the chassis.

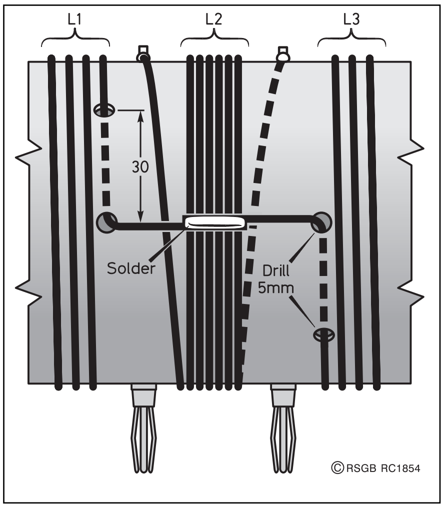
Self adhesive rubber feet are attached via pieces of 25 x 25mm MDF, glued to the corners of the chassis

The general layout of the feeder current indicator section is shown in **Fig 15.41**. This is fixed into a convenient place so that it can be seen when adjusting the ATU. In Fig 15.39 and Fig 15.40 the unit is shown fixed to a shelf.

Note the use of 5-way mains terminal blocks for spacing the sampling wires; 1.25mm wire is used for all wires through the terminal blocks.



(left) Fig 15.43: Basic construction and dimensions of the plug-in coils



(right) Fig 15.44: L1 to L3 junction on the 68mm formers

Coils

The nine plug-in coils are shown in **Fig 15.42**. The formers are plastic pipes, as used for drainage. Winding details for coils to cover all nine HF bands are given in **Table 15.4**. The turns are held in place with beads of epoxy resin, four beads for 68mm and three beads for 36mm formers. The link coils L2 all resonate within the band they are wound for, using the 400pF capacitor VC2.

The method of fixing the 4mm plugs to the formers is shown in **Fig 15.43**.

5mm (3/16in) diameter holes are fine for the Maplin 4mm plugs, and they will self tap into the plastic. If any other type of plug is used, the hole size should be determined by testing on scrap material first. The plugs must be accurately set out on the former. A 45-watt large-tipped soldering iron can be used to solder the 1.6mm wire into the plugs.

The method of terminating the ends of L1 and L3, and joining them over the top of L2, is shown in **Fig 15.44**.

This method only works well for 68mm formers. For 36mm formers the ends of L1 and L3 can be terminated using solder tags, held down to the former with self tapping screws. The coil ends are then joined with a jumper wire over the top of L2.

The construction for fixing the 4mm plugs to the coil former at Skt 12 and 13 is shown in **Fig 15.45**. The two plugs are glued to a bracket, made from 4mm perspex, which is glued to the coil former.

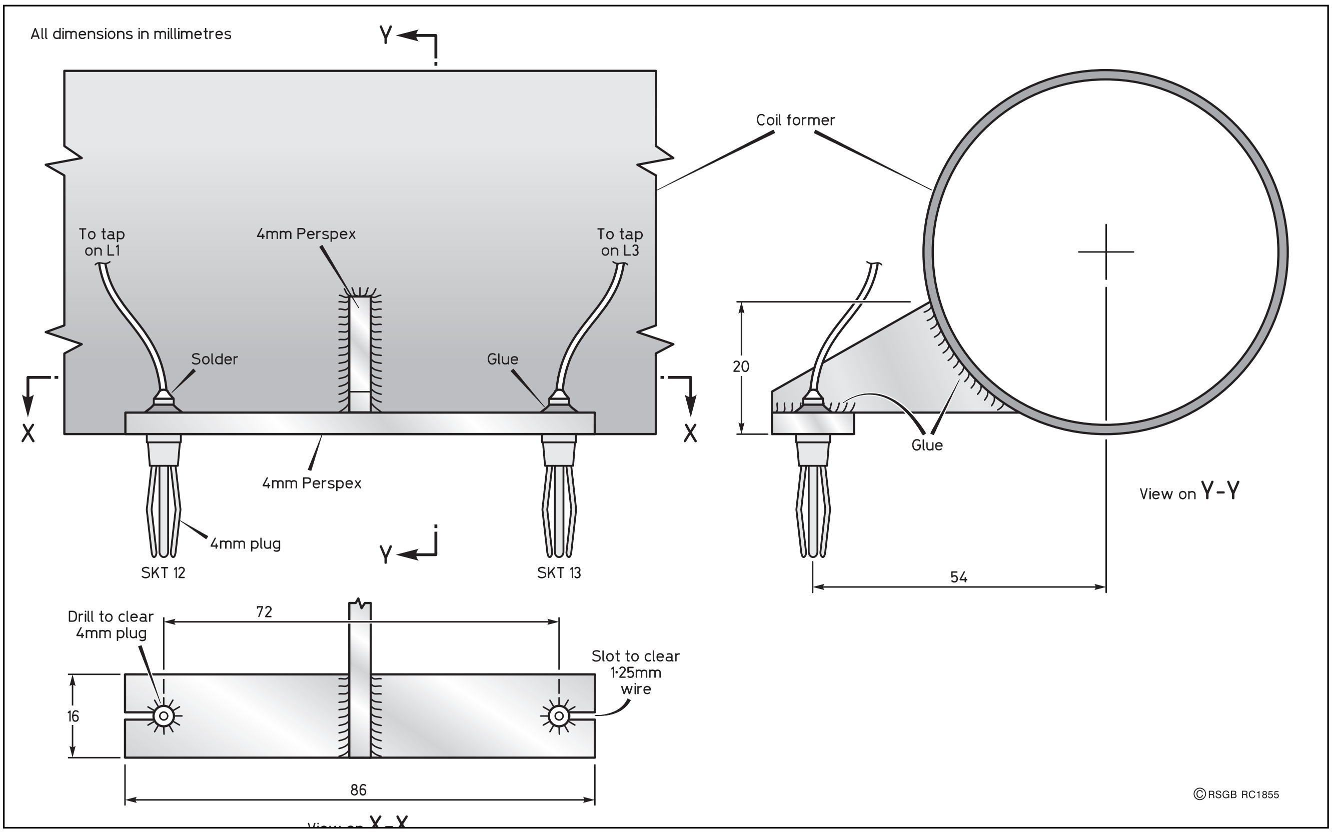


Fig 15.45: Coil connections to the 4mm plugs which connect with Skt 13 and 14

Table 15.5: Example of dial settings for the G3LMJ antenna tuner

MHz	VC1	VC2	VC3
1.81	70	50	72
2.0	32	47	38
3.5	56	55	56
3.8	39	40	37
7.0	86	50	87
7.1	79	47	79
10.1	17	34	19
10.15	16	34	20
14.0	24	27	30
14.35	22	24	28
18.068	52	60	68
18.168	51	53	66
21.0	38	27	55
21.45	37	30	48
24.89	37	15	18
24.93	37	15	18
28.0	25	26	11.0
29.7	15	43	16.5

Wire is soldered to the plugs before assembling the plugs to the perspex. Before applying glue, all components, including the coil are put into place on the chassis. The glue is then applied and allowed to set thoroughly. The result is a perfect fit of the coil plugs to the chassis sockets. In order to facilitate good bonding, the perspex is thoroughly roughened to provide a key for the epoxy resin. The bracket arms are glued to L2 on top of the 1.8, 3.5 and 7MHz coils, and direct to the former for all other coils. Coil taps T1 - T4 are determined by testing, using flexible wire and crocodile clips for attaching to the coil and sockets Skt 12 and 13. All taps are made symmetrically about the coil centre. When the correct tap positions are found, the final, permanent wiring can be made. An SWR of 1.0 is aimed for, and when achieved VCs 1, 2 and 3 should be comfortably within their working range (ie not at maximum or minimum). VC 1 and 3 should be set at about the same dial readings.

Set-up procedure

To determine the correct positions for taps T1 - T4, the following procedure is recommended:

1. Set T1 and T4 one turn from each end of the coil.
2. Transmit low power at the low frequency end of the band.
3. Try various positions for T2 and T3, tuning VCs 1, 2 and 3 for minimum SWR.
4. If an SWR of 1.0 is not achieved, carry out step No.3 again, but with T1 and T4 set nearer the centre of the coil.
5. When an SWR of 1.0 is achieved, connect the permanent taps T1, 2, 3 and 4.

Having established the correct tap positions, the settings for VCs 1, 2 and 3 must be determined for various frequencies in the band. This is done by trying various settings, until one is found that gives an SWR of 1.0. VC 1 and VC3 should be kept at about the same settings.

Current Sharing

The next stage is to ensure that the two halves of the dipole are taking the same current.

Meters M1 and M2 must be adjusted to the same sensitivity before this can be done. The adjustment is carried out as follows:

1. Set RV1 and RV2 fully anti-clockwise.
2. Transmit at low power.
3. Set S1 to position No.1.
4. Adjust M1 to mid scale, using RV1
5. Set S1 to position 2.
6. Adjust M2 to mid scale, using RV2
7. Reset S1 to position 1.

Both meters now have the same sensitivity and will show the relative currents in each half of the dipole. If these currents are not the same, they may be equalised by further adjustments to VCs 1, 2 and 3. It will be found that there are a number of VC 1,2 and 3 settings that will give an SWR of 1.0, but only one that will also give equal currents in each half of the dipole. When the correct settings are found they should be logged. Use **Table 15.5** as a guide (although these the results were obtained at G3LMJ's location with his multi-band dipole). Remember that the slow motion drives are calibrated 0 to 100. Minimum capacitance is 0, maximum is 100.

If you are using an ATU that feeds into a 450-ohm line using a voltage balun, it may be an interesting exercise to construct the feeder current indicator and check the feeder currents and see what the balance is like on your antenna feed lines.

Safety

There are two safety points which must be stressed:

1. Use a dust mask when working on MDF.
2. In thundery weather, earth both sides of the ribbon feeder to avoid a build up of high voltage on the antenna.

The Z-Match

Another link coupled ATU that has been around a long time is the Z-match. Originally it was designed as a tank circuit of a valve PA [12], the anode of which was connected to the top or 'hot' end of the multiband tuned circuit. It was fed directly from the PA valve, with its internal (source) impedance of several thousand ohms

When the circuit was adopted as an ATU [13] the tank circuit was fed directly from a source which requires a 50-ohm load via a 350pF variable coupling capacitor connected to the top (or 'hot') end of a multiband parallel-tuned LC circuit.

In spite of the great disparity between the required 50-ohm load for the transmitter and the relatively high impedance of the tank circuit the Z-match enjoyed considerable popularity, probably due to its simplicity. Z-match ATUs were produced commercially and they are described here because they are easily available and cheap. An example of such a unit is shown in **Fig 15.46**.

The design of the Z-match was improved and described by Louis Varney, G5RV [14]. All of what follows is from his article.

As you can see in **Fig 15.47(a)**, on the 3.5, 7 and 10MHz bands the main inductance, L1, is connected in parallel with the two sections of C1 which are also paralleled.

The effect of the much smaller inductance, L2, can be considered as a rather long connecting lead between the top of C1a and the top of C1b. Since the inductance of L2 is very much less

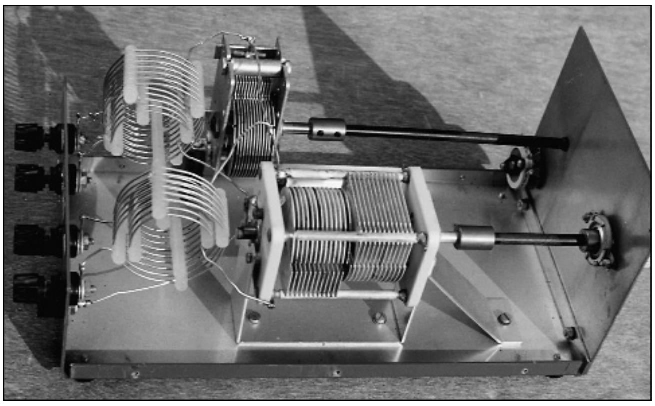


Fig: 14.46: The original KW E-ZEE MATCH, shows the general construction of a Z-match ATU

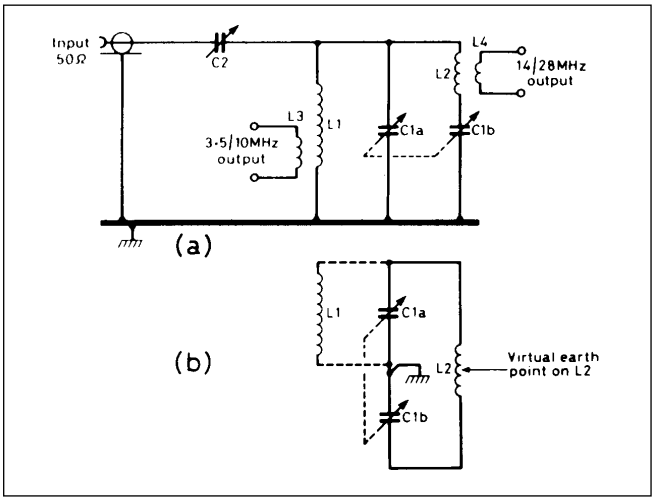


Fig 15.47: (a) The basic Z-match circuit. (b) The 14-28MHz tuned circuit shown in a more conventional form

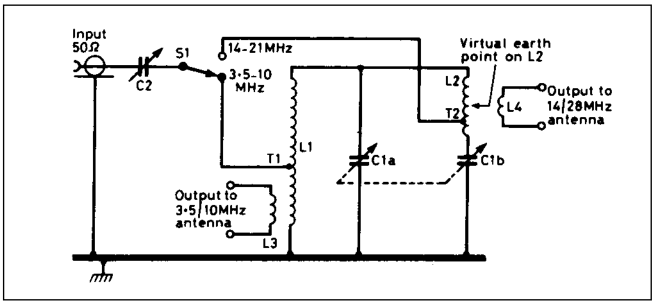


Fig 15.48: The basic Z-match circuit showing the tapped-down feed arrangement

than that of L1, this assumption is valid for the relatively low frequencies of 3.5 and 7MHz. For these bands, therefore, L1, C1a plus C1b may be considered as a simple tuned circuit with one end earthed.

Provided the capacitance range of C1a plus C1b is sufficient, the circuit will also tune to 10MHz. It may be necessary to reduce the inductance of L1 by one or two turns to achieve resonance on that band. However, it should be noted that care must be taken to avoid the occurrence of harmonic resonance between the two circuits comprising the multiband tuned circuit; the values of the inductances. L1 and L2 must be selected with this in mind. On the 14, 18, 21, 24 and 28MHz bands the active tuned circuit consists of the two variable capacitor sections C1a, C1b as a split-stator capacitor, with the moving vanes earthed, and L2 connected between the two sets of stator vanes. Because its inductance is much greater than that of L2, L1 may be considered as an HF choke coil connected in parallel with C1a; and having no noticeable effect on the performance of the split-stator tuned circuit L2, C1a, C1b. This can be proved by first tuning this circuit to any band from 14 to 28MHz, noting the dial-reading of C1a, C1b and then disconnecting the top of L1 and retuning for resonance. It will be found that the effect of L1 is negligible. Fig 15.47(b) shows the effective 14 to 28MHz tuned circuit in a more conventional manner.

The relatively high impedance LC circuits L1, C1a and C1b (paralleled for the 3.5, 7 and 10.1MHz bands) and L2, C1a, C1b (as a split-stator capacitor for the 14 to 28MHz bands) must be detuned slightly off resonance at the frequency in use; so as to present an inductive reactance component. This, in conjunction with the coupling capacitor C2, functions as a series resonant input circuit which, when correctly tuned, presents a 50ohms non-reactive load to the transmitter output.

Modifying the Z-match

Feeding the RF energy from the output of a transmitter requiring a 50Ω resistive load to the top of a parallel-tuned LC circuit cannot be the most efficient method, so G5RV felt that the circuit would benefit from modification. He performed a number of tests, which involved tapping the Coils L1 and L2 to obtain a better match. The circuit of the modified Z-match is shown in Fig 15.48.

The final modified Z-match

The final design is shown in Fig 15.49, and a list of components is in Table 15.6. The circuit incorporates switching for the appropriate coil coupling taps and selects the appropriate output-coupling coil (L3 or L4) to the feeder.

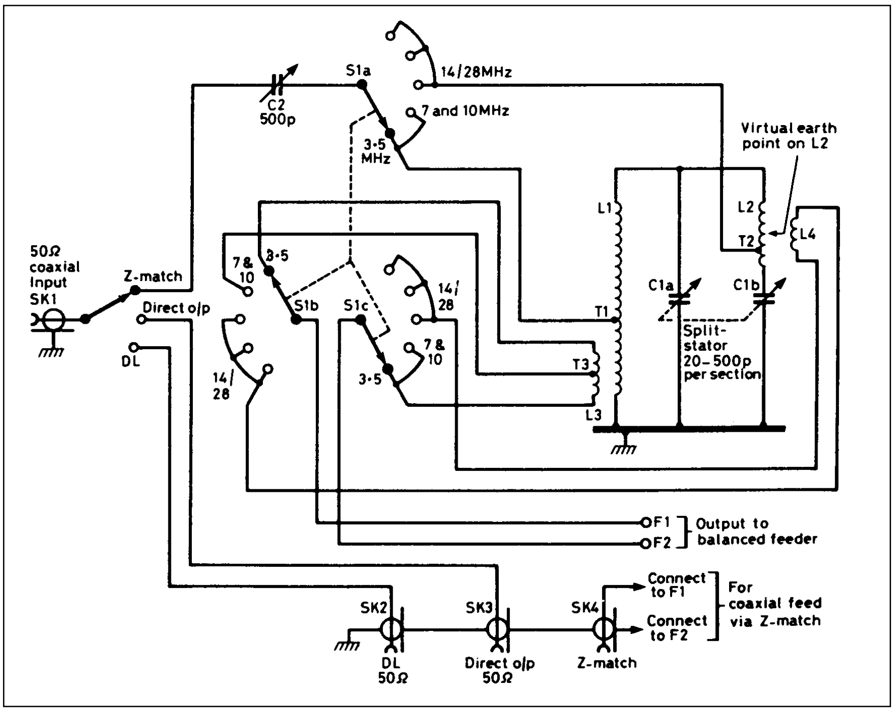


Fig 15.49: The final modified Z-match circuit

C1a-1b	Split-stator variable capacitor 20-500pF per section.
C2	500pF single-section variable capacitor (shaft insulated)
L1	10t 4cm ID C/W 14SWG enam copper wire. Tap T1 4t from earth end
L2	5t 4cm ID turns spaced wire dia 14SWG enam copper wire. T2 1.5t from centre of coil (virtual earth point
L3	8t 5cm ID C/W enam copper wire over L1. T3 at 5t from earth end.
L4	3t 5cm ID C/W over L2. 14SWG enam copper wire.
S1	Ceramic wafer switch. All sections single-pole, five positions
S2	Ceramic wafer switch. Single-pole, three positions.

Notes:

(1) A suitable 250 + 250pF (split-stator or twin-ganged) variable capacitor can be used since the capacitance required to tune L1 to 3.5MHz is approximately 420pF, and for 7.1MHz approximately 90pF. If C1a, C1b (paralleled) have a combined minimum capacitance of not more than 20pF, it should be possible also to tune L1 to 10MHz. Otherwise it may be necessary to reduce L1 to nine turns, leaving T1 at four turns from the 'earthy' end of L1. A lower minimum capacitance of C1a, C1b as a split-stator capacitor would also be an advantage for the 28-29.7MHz band.

(2) Taps on L1 and L2 soldered to inside of coil turn. Tap on L3 soldered to outside of coil turn

Table 15.6: Components list for the Z-match

For maximum output coupling efficiency on the 7MHz and 10MHz bands, a tap on L3 is selected by S1b. Provision is made for coaxial cable antennas to be fed either direct or via the Z-match.

The transmitter output can be direct to a suitable 50-ohm dummy load. The layout is not critical, but it is advisable to mount the coils L1 and L2 with their axes at right angles to prevent undesirable intercoupling. Also, all earth leads should be as short as possible and the metal front panel should, of course, be earthed.

The coupling capacitor, C2, should be mounted on an insulating sub-panel and its shaft fitted with an insulated shaft coupler to isolate it from the front panel, preventing hand-capacitance effects.

The receiving-type variable capacitors used in the experimental model Z-match have adequate plate spacing for CW and SSB (peak) output powers of up to 100W. For higher powers it would be necessary to use a transmitter-type split-stator capacitor (or two ganged single-section capacitors) for C1a, C1b. However, C2 requires only receiver-type vane spacing even for high-power operation.

Tests with additional feedpoint taps on both L1 and L2 in the modified Z-match circuit showed no practical advantage. However, the tap on the output coupling coil L3 was found to be essential on 7MHz, and 10MHz. The very tight coupling between L1/L3 and L2/L4, tends to reduce the operating Q value of the LC circuits. This renders them more 'tolerant' of the complex reactive loads presented at the input end of the feeder(s) to the antenna(s) used.

G5RV noted that the efficiency of a conventional link coupled antenna tuning unit was better than that of either form of Z-match; and that by virtue of its design, the Z-match cannot satisfy all the required circuit conditions for all bands. However, in its original form it does provide the convenience of 3.5 to 28MHz coverage without the necessity for plug-in or switched coils. Nevertheless, the inclusion of the simple switching shown in Fig 15.49 is an undoubted advantage.

LOOPS AND SLOT ANTENNAS FOR HF

Small Loop Antennas, General Comments

If space at your location is very restricted, with no place to put up a wire antenna, a small HF transmitting loop antenna may be an option. A surprising amount of information is available on these types of antennas [15].

Good efficiency can be achieved only by ensuring the loop has a very low RF resistance. Additionally its high-Q characteristic results in a narrow effective bandwidth, requiring accurate retuning for even a small change in frequency. This can be overcome by the use of complex and expensive automatic tuning systems or, more realistically for amateurs, by remote control of the tuning capacitor forming part of the loop. Another disadvantage is that even on low-power, there will be very high RF voltage across the tuning capacitor, resulting in the need for either a high-cost vacuum capacitor or a good-quality, wide-spaced transmitting capacitor.

Against these disadvantages should be set the fact that a well-constructed loop just 0.15m high can have a radiation efficiency close to that of a ground plane antenna, see Fig 15.11. Furthermore, the short loop utilises the near-field magnetic component of the electromagnetic wave, resulting in much less absorption in nearby objects. This means that a short loop can be used successfully indoors or on a balcony. For reception a 'magnetic' antenna is much less susceptible to the electric component of nearby interference sources. The reduction of man-made noise is particularly important on the lower-frequency bands, and is further enhanced by the directional properties of a loop. The loop can work effectively without any ground plane.

The high-Q characteristics of a low-loss loop also means that it forms an excellent filter in front of a receiver, reducing overload and cross-modulation from adjacent strong signals. On transmit, these properties dramatically reduce harmonic radiation and hence some forms of TVI and BCI.

Basics

To achieve good radiation efficiency in a small transmitting loop, it is essential to minimise the ratio of RF ohmic losses to radiation resistance. In a small resonant loop the RF ohmic losses are made up of the resistance of the loop and that of the tuning capacitor (which will have much lower resistive loss than a loading coil). The tendency of HF current to flow only along the surface of a conductor (skin effect) means that large diameter continuous copper tubing (or even silver-plated copper) should be used to achieve a maximum high-conductivity surface area.

Provided that the circumference of a loop is between 0.125 and 0.25 wavelengths, it can be tuned to resonance by series capacitance. If the loop is longer than 0.25λ it will lose its predominant 'magnetic' characteristic and become an 'electric' antenna of the quad or delta type but, unless approaching one wavelength in circumference, will still have relatively low radiation resistance.

The radiation resistance of a small loop is governed by the total area enclosed and is a maximum for circular loop. It is possible to build a transmitting loop antenna with a circumference less than 0.25λ, but in these circumstances the bandwidth becomes so small that it becomes practically impossible to tune the loop accurately enough. It is thus advisable to restrict the operating range of a transmitting loop to a ratio of 1:2, that is to say 3.5 to 7, 7 to 14, or 14 to 28MHz. Extending the tuning range will tend to result in a rapid falling off in efficiency. The most convenient solution for complete HF coverage is to use two loops; one for the higher frequency bands (14, 18, 21, 24 and 28MHz), the other for 3.5 and 7MHz, or 7 and 10.1MHz. For

	14MHz	21MHz	28MHz
Radiation resistance, ohms	0.09	0.46	1.68
Conductor losses, ohms	0.04	0.05	0.05
Efficiency (%)	67.3	89.5	93.3
Loop Inductance, μH	2.4	2.4	2.4
Inductive reactance, ohms	214	321	443
Q factor	789	311	127
Theoretical bandwidth, kHz	17.7	67.5	228
Voltage across tuning capacitor (100W), kV	4.1	3.1	2.3
Tuning capacitance, pF	53	23	12

Table 15.7: Calculated electrical characteristics of a one-metre diameter transmitting loop antenna using 22mm copper tubing

1.8MHz it is advisable to use a loop designed for this band, or for 1.8 and 3.5MHz.

A Small Loop for 14 to 29MHz

This design is by Roberto Craighero, I1ARZ [16]. The main physical characteristics of this antenna are:

- Circular loop: 1m diameter made from copper pipe of 22mm OD, circumference 3.14m.
- Capacitor: Split-stator or 'butterfly' type, about 120pF per section. Minimum capacitance (for 28MHz) 16pF.
- Feed: Inductive coupling with a small loop made from coaxial cable.
- Maximum power: Governed primarily by the spacing of the capacitor vanes. Suggested rating 100W maximum.
- Tuning method: Remote control of capacitor by means of electric DC motor and reduction gear. Rotation speed not faster than one turn per minute.

The electrical characteristics, calculated from the formulae given by W5QJR [17], are set out in **Table 15.7**. The overall design of the loop is shown in **Fig 15.50**.

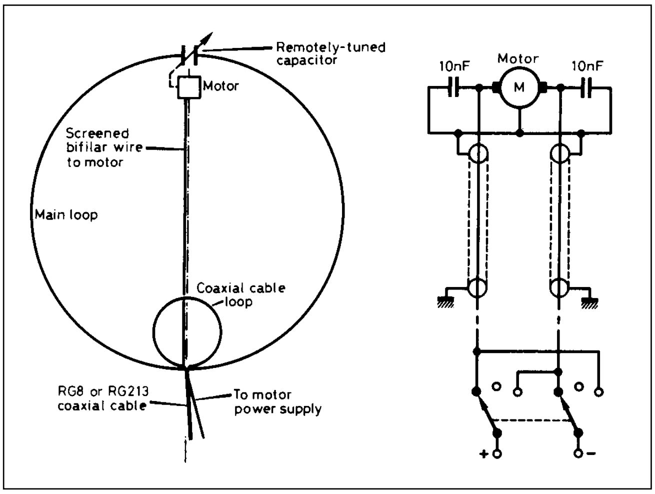


Fig 15.50: Electrical diagram of the I1ARZ loop antenna, plus the tuning motor connections

The loop

Copper pipe of 22mm OD is generally sold in straight lengths of 3m and 6m. The only really practical way of bending 22mm pipe is with a pipe-bending tool. A suitable tool can be hired, or the pipe can be taken to a metal workshop or a plumber - this might be expensive.

Both ends of the loop must be cut longitudinally along the vertical diameter of the pipe for about 5cm, then cutting one half away. The remaining half is flattened to form a strip that can later be inserted through the insulated board used to support the tuning capacitor and connected to the stator plates. In this way only one joint will be necessary for each stator, reducing the soldering losses. At the bottom of the loop, opposite the tuning capacitor, a small copper bracket should be soldered to the loop, see **Fig 15.51**. On this bracket will be fixed the coaxial connector and the connector for the twin lead for powering the tuning motor. The bracket should be soldered to the loop using a flame- torch to ensure good electrical contact.

An external loop supporting mast

A thick PVC pipe of about 40-50mm diameter can be used for this support. Alternatively a glass fibre tube (lighter but more expensive) or a wooden mast waterproofed with plastic compound may be used. The length of this mast should be about 1.5m; with about 200mm used at the top for fixing the plastic board carrying the tuning capacitor; the remaining length is used at the base for fixing the loop to a rotor or another short mast. For obvious reasons, never use a metallic pipe across the loop.

The loop is fixed to the mast, using two U-bolts at the base, see **Fig 15.52** The ends at the top of the loop are held in place by two collar-clamps (these clamps are the cross-joints in cast aluminium, as typically used to connect the boom of television antennas to the mast.). The clamps are connected with stainless steel nuts and bolts to the back of the plastic board supporting the capacitor, see **Fig 15.53.** The bolts should be of sufficient length to act as adjustable spacers in order to have the loop completely upright. The plastic supporting mast is fixed to the back of the board by two semicircular clamps with stainless steel nuts and bolts of sufficient length to reach the front side of the plastic board. The two copper strips of the loop must be bent at 90° and inserted in suitable cuts in the board to reach the stators of the capacitor on the front side of the board (Fig 15.53 and **Fig 15.54**). The cuts should later be waterproofed with silicone compound.

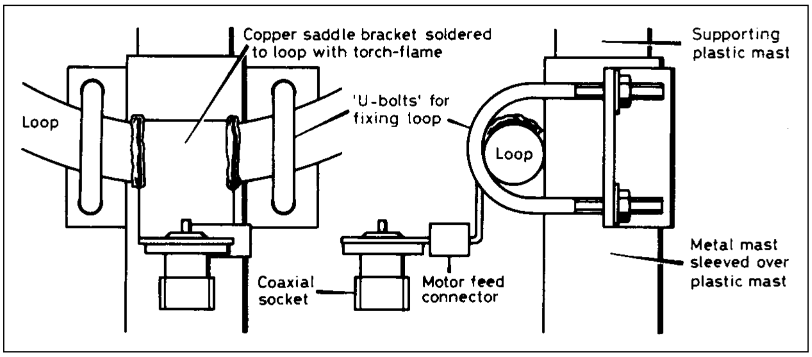


Fig 15.51: Details of the bottom of the loop - front view

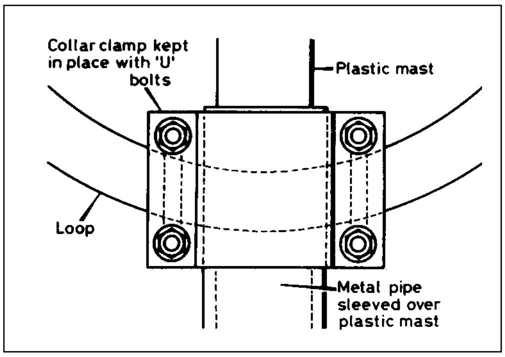


Fig 15.52: Fixing the loop to the support mast

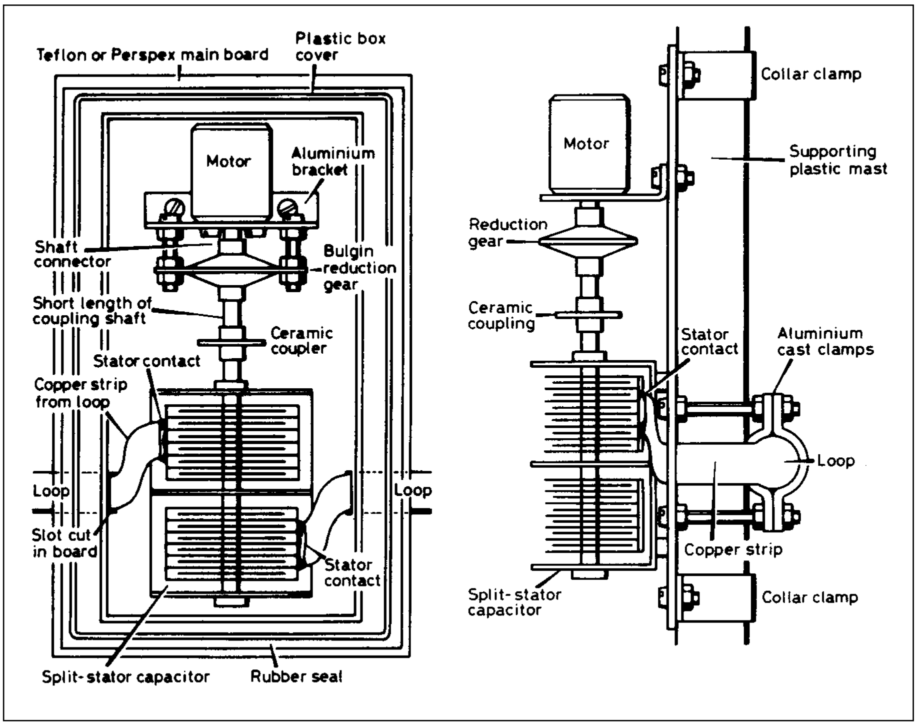


Fig 15.53: The loop tuning board, (a) front view and (b) side view

Tuning board and cover

The size of the tuning board depends upon the dimensions of the variable capacitor and motor. The best material for high-power operation is 10mm thick Teflon; alternatively Plexiglas (Perspex) of the same thickness can be used. When calculating the size of the board, allow space for fixing the clamps of the loop and for a waterproof cover to protect the complete tuning unit. For protection, a plastic watertight box of the type used for storing food in a refrigerator is used. The original cover is cut in the centre with an opening just wide enough to permit the entry of the capacitor and motor. A layer of soft rubber is inserted between the surface of the supporting board and the cover to act as a seal. The cover is then fixed in place with several small stainless nuts and bolts, fastened tightly so that the seal is compressed between the board surface and cover to make it watertight. The plastic box can now be put against its cover, keeping it in place with a tight nylon lashing. Silicone compound should now be applied all round to keep out the moisture. To prevent gradual deterioration of the plastic box it is advisable to use white self-adhesive plastic sheet to protect it against ultraviolet radiation from the sun.

The tuning capacitor

It is most important to use a very good quality transmitting-type variable capacitor; otherwise the efficiency of the antenna will be reduced. Owing to the high Q of this antenna, the RF voltage across the capacitor is very high (directly proportional to the power). With 100W power, this voltage will be 4 - 5kV; with 500W it can be as high as 28kV!

It is most advisable to use a split-stator (or 'butterfly') capacitor of about 120pF per section. The advantage of this arrangement is that the two sections are connected in series thereby eliminating rotor contact losses, which occur in conventional capacitors. Assuming that the loop is intended for use with a transmitter power of not more than 100W, the spacing between the vanes should be at least 1.5-2mm. A home made capacitor is described later.

A vacuum capacitor would seem a good choice. However, the high loop currents tend to heat and thereby distort thin metal in vacuum capacitors and consequently detune the loop [18]. Experiments with a vacuum capacitor tuned low-frequency loop show that with SSB (about 60W PEP) with its low power factor there is no need to retune the antenna. But when used with CW, with its greater power factor, there is a need retune the antenna from time to time.

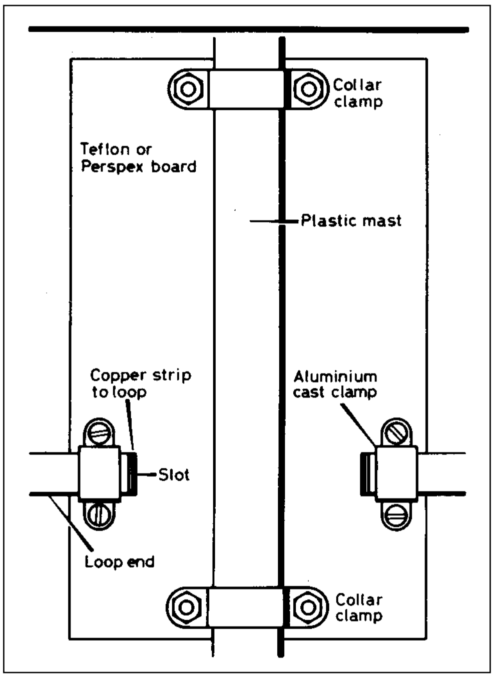


Fig 15.54: Rear view of tuning board showing loop and support mast mountings

The tuning motor

The motor forms an important part of the system; it calls for a DC motor with a reduction gear capable of providing very fine control, with the capacitor shaft rotating at only about one turn per minute or even less. Ideally, a variable speed motor is required to provide slow rotation for accurate tuning but a faster rate for changing bands.

I1ARZ used a motor with that could operate between 3 - 12V, which ran slowly at the lowest voltage and fast at 12 volts. Again, the surplus market may provide such a motor. Should you be unable to find a motor incorporating a suitable reduction gear it is possible to use a receiver-type slow-motion tuning drive; a Bulgin gear with a reduction drive ratio of 25:1 was used on the prototype.

An alternative motor control method by PA0YW is described later.

Construction of the tuning system

When estimating the dimensions of the insulated supporting board, bear in mind the following: The space required for the watertight cover, the aluminium bracket for mounting the motor, and the external reduction gearing, together with the various couplings between the capacitor spindle and the motor.

The first step is to mark the centre line of the board (ie major axis). Bolt the capacitor to the board, taking great care to ensure

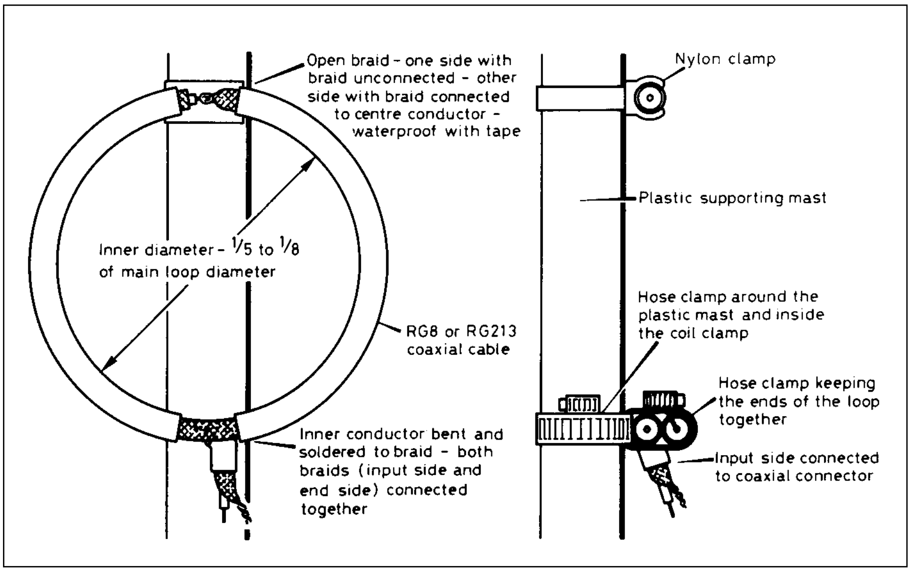


Fig 15.55: Detail of (a) the construction of the coax loop feed and (b) the plastic support mast

that the shaft is aligned with the centre line marked on the board. A split-stator capacitor must be placed with the respective stator contacts symmetrically in the vertical plane so that the copper strips coming from the back of the board on either side of the capacitor have the same length (one being bent upwards, the other downwards). With a butterfly or conventional capacitor, the copper strips must be bent horizontally as both contacts are the same height.

Once the capacitor has been bolted to the board, measure, with callipers or dividers, the exact distance of the board from the centre of the capacitor shaft. Transfer this dimension to the centre line of the vertical side of the L-shaped aluminium bracket to be used for supporting the motor and any external reduction gear.

Drill a small pilot hole just large enough to take the motor shaft. It is important that this operation is carried out carefully since it is vital to the accurate alignment of the system.

Once it has been determined that motor and capacitor shafts are in accurate alignment, the motor may be fixed permanently to the bracket, enlarging the pilot hole and drilling holes for the motor-fixing bolts. Do not fix the bracket to the board yet .

The next step is to adapt the motor shaft to a shaft extension (as normally used for lengthening potentiometer shafts) taking care not to introduce any eccentricity. If your motor does not require external reduction-gear, you can insert the motor shaft into a ceramic coupler (circular shape with ceramic ring and flexible central bush); again making sure there is no eccentricity. The lower flange of the aluminium bracket can now be fixed to the board by means of two nuts and bolts.

If you use the Bulgin drive external reduction gear, drill two 4mm holes in the bracket; one in each side of the motor at the same distance as the mechanical connections of the gear and at the same level as the centre of the motor shaft. If the size of the motor is wider, it is necessary to join two short strips of brass or aluminium to the Bulgin gear so as to obtain an extension of the fixing points of the drive. Two long, 4mm diameter brass bolts should be inserted in the holes to hold the gear in place with the nuts. The Bulgin gear can now be fixed to the motor shaft, with the other side of the gear connected to the ceramic coupler by means of a very short piece of potentiometer-type shaft. Make a provisional check of the tuning system by temporarily connecting the power supply to ensure that everything is working smoothly. The copper strips of the loop can now be soldered to the stator capacitor vanes. This requires the use of a large wattage soldering iron, taking care that the best possible electrical contact is achieved.

Motor feedline

The feed line can be made from twin screened cable, as normally used with hi-fi audio amplifiers etc. The braid should be connected through a soldering lug to the aluminium bracket or to the motor casing. The motor must be bypassed for RF, using two 10nF ceramic capacitors connected to the braid. The cable is kept in place by means of nylon clamps along the supporting plastic mast. At the base of the loop solder a connector on the small copper bracket, with the braid soldered to the bracket. From this point to the operating position, normal electrical twin cable can be used. Some constructors have suggested inserting the feed line inside the loop pipe but this reduces the efficiency of the antenna. A small box containing the DC power supply and switch for reversing polarity of the supply is operated from the shack.

Coupling loop and matching procedure

A variety of methods for feeding the loop are shown later. I1ARZ found the most satisfactory method of coupling was a small single-turn (Faraday) coupling loop formed from a length of coaxial cable (RG8 or RG213) with a diameter one-eighth of the main loop. In practice, the optimum diameter of the coupling loop will vary slightly from this figure and it may prove worthwhile to experiment with slightly different size loops. This is done by aiming for the lowest SWR over a wide frequency range and is best achieved by constructing several coupling coils.

With the I1ARZ antenna the optimum diameter proved to be 18cm rather than the theoretical 12.5cm. The coil should have the braid open at top-centre; at this point one side is connected to the inner conductor of the coaxial cable. At the base of the loop, inner conductor and braid are connected together and jointed to the braid on the input side of the coil as shown in **Fig 15.55(a)**.

The ends and braid of the coupling loop are held together using a stainless hose clamp. This, in turn, is fixed to the mast at 90° to another hose clamp on the plastic mast, see **Fig 15.55(b)**. This provides a very simple method of adjustment by sliding the small loop up or down the mast to find the best SWR position.

The upper opening should be protected with tape and, to avoid any subsequent movement of the coil, then fixed to the mast by means of nylon clamps mounted in the same way as for the hose clamps at the base. Final matching of the antenna has to be carried out after determining the final position of the installation. An SWR bridge is connected at the base of the loop close to the input coax connector. If your transmitter covers 18MHz, make your adjustments on this band; otherwise use 21 MHz. Apply minimum power, just sufficient to deflect the SWR meter. After finding loop resonance, move the coupling coil up and down, or deform it slightly to check how the SWR varies. The coupling coil must be maintained in the same plane as the loop. After finding the lowest SWR, tighten the hose clamps and nylon clamps to keep the coil in position. The coax line and tuning motor power line must be kept vertical for about 1 m or more from their connectors at the base of the loop to avoid undesir-

Fig 15.56: Some experimental loops used by GW3JPT

able coupling with the loop itself and subsequent difficulty to achieve a proper matching. The minimum SWR should be better than 1:1.5 on all bands.

Installing and using the loop

The loop can conveniently be installed on a terrace or concrete floor or roof. One method is to use as a base or pedestal the type of plastic supports that can be filled with water or sand and often used for large sun umbrellas. Light nylon guys can be used to minimise the risk of the loop falling over in high winds. Remember that a transmitting loop operates effectively at heights of 1 to 1.5m above ground, and little will be gained by raising it any higher than say 2 or 3m at most. I1ARZ tested his loop using a telescopic mast at heights up to 9m above ground but with very little difference in performance; and that normally it was used with the mast fully retracted to about 3m high.

With a garden, the loop could be fixed directly to a short metallic mast driven into the ground. A small TV rotator could be used but this is not essential; maximum radiation is in the plane of the loop, minimum off the sides of the loop. Large metallic masses like fences; steel plates, pipes etc reduce the efficiency of the antenna if close and in the direction of the plane of the loop. The radiation is vertically polarised at all vertical angles making the loop suitable for DX, medium and short range contacts.

There is nothing particularly complicated about operating with a small loop antenna other than the need to tune it to resonate it at the operating frequency. Tune initially for maximum signals and noise in the 'receiving' mode; this will bring the loop close to the tuning point for transmission. Using the SWR meter, tune carefully with the aid of the polarity-reversing switch to the precise point where minimum reflected power is achieved. The 'receiving-mode' procedure should always be used when changing bands.

Conclusion and final comments

I1ARZ began experimenting with small diameter transmitting loops in 1985 and he is now convinced that the loop is a thoroughly practical antenna that should not be written off as either a compromise or emergency antenna. Its performance, provided the RF ohmic losses are kept very low, is very good.

Wire Loop Antenna for the Lower HF Bands

As already mentioned, it is necessary to ensure that the resistance of the loop is as low as possible.

However, larger loops for the HF bands may be impractical due to the weight. C R Reynolds, GW3JPT, constructed many magnetic loop antennas, all of which were made from 22mm copper tubing or strip aluminium. Some of the experimental loop antennas used are shown in **Fig 15.56**.

He wanted to operate on the lower HF bands and although he found that it was possible to tune a small loop to 160m using a very large 1000pF capacitor there were two problems. On 160 metres the efficiency is rather low and on 40 metres tuning is rather critical because it only takes a few picofarads of tuning capacitor variation to tune the whole of the 40m band. This represents a very small percentage of 1000pF, requiring only a fraction of capacitor rotation to cover the band.

In an article [19] GW3JPT described a different design of a practical loop antenna for the 160, 80 and 40 metre bands. This uses a much larger square loop of a size shown in **Fig 15.57**. If this were to be made from copper tube it would be very heavy so he used a 19.5m (64ft) length of plastic covered wire. This antenna requires a 250-300pF tuning capacitor.

The Faraday coupling loop is shown in **Fig 15.58**. It is close coupled for about 0.77m (30in) each side of the centre of the tri-

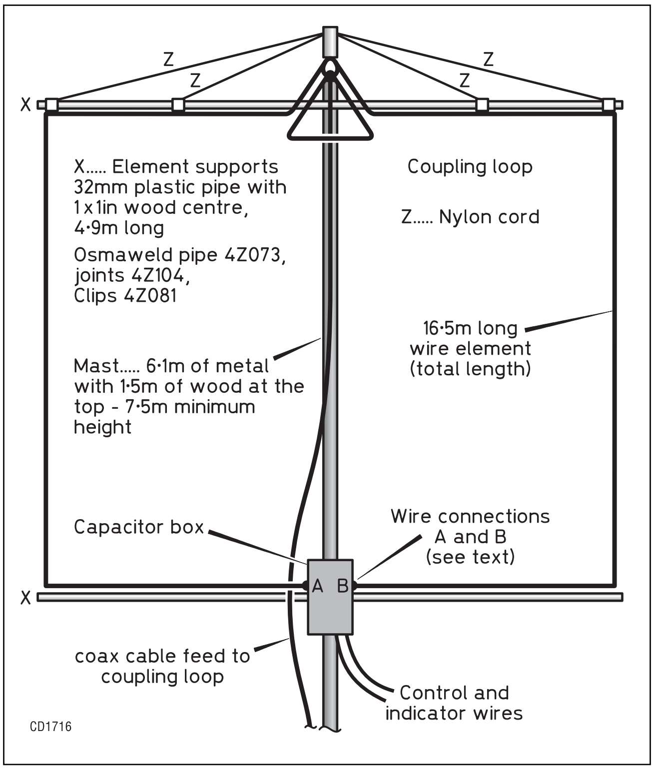


Fig 15.57: Overall view of the LF band magnetic loop

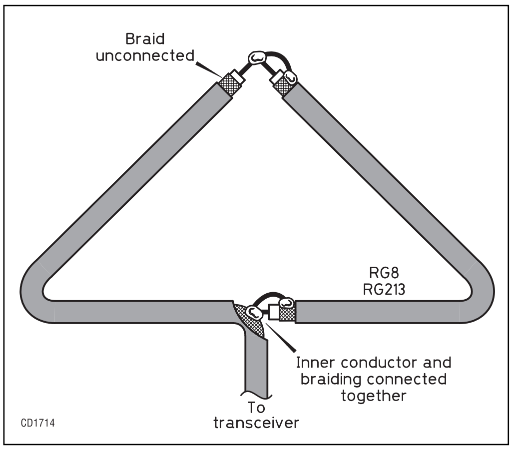
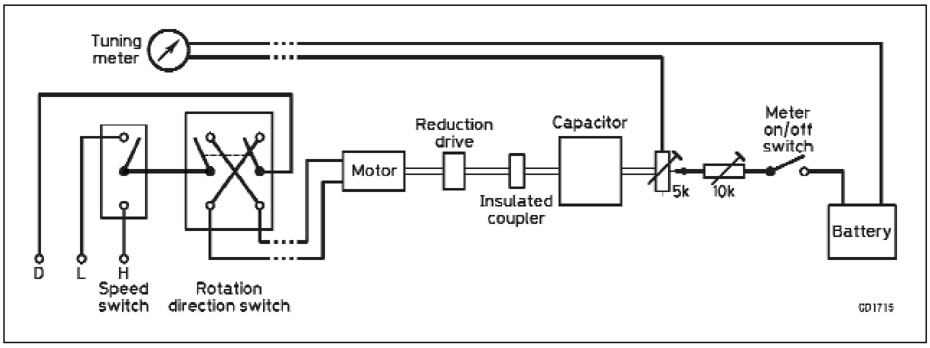


Fig 15.58: Faraday coupling loop

Fig 15.59: Control and indicator system for the magnetic loop antenna



angle section of the element. This wire loop will also work on 40m. This is achieved by using a relay or a switch to disconnect the capacitor at points A and B, (Fig 15.57). The loop is then tuned by the stray capacitance of the switch or the relay. Because this stray capacity cannot be varied, the antenna element length is adjusted for correct matching using an SWR meter.

The antenna and mast can be fitted to a good ground post. It does not need any guy wire support and can be raised or lowered easily. For portable use it can be erected in a few minutes using three or four guy wires.

Capacitor drive motor

There is a reasonable range of motors available suitable for rotating the loop capacitor. The cheapest and one of the best available is a barbecue spit motor. Although this is already geared down it does require extra reduction using a 6:1 or 10:1 epicyclic drive for more precise tuning.

The motor will rotate slowly if energised by a 1.5V battery. With 3V applied the motor will run much faster. By switching from 1.5 to 3 volts a fast or slow tuning speed can be selected (**Fig 15.59**). The positive lead of the 3V battery is connected to H and the positive lead of the 1.5V battery is connected to L. The negative leads of both batteries are connected to D.

The direction of rotation is achieved using a two-pole, three-way switch. When the switch is set to the centre position the motor is disconnected from the battery (OFF position). The battery polarity to the motor is selected by the two other positions of the switch and should be labelled DOWN or UP.

The drive mechanism must be electrically isolated from the high RF voltages present at the capacitor. An insulated coupler can be made from plastic petrol pipe. This pipe size should be chosen so that it is a push fit on to the drive mechanism and capacitor shafts. The pipe can then be fixed to the shafts by wrapping single strand copper wire around the ends of the pipe and tightening with a pair of pliers.

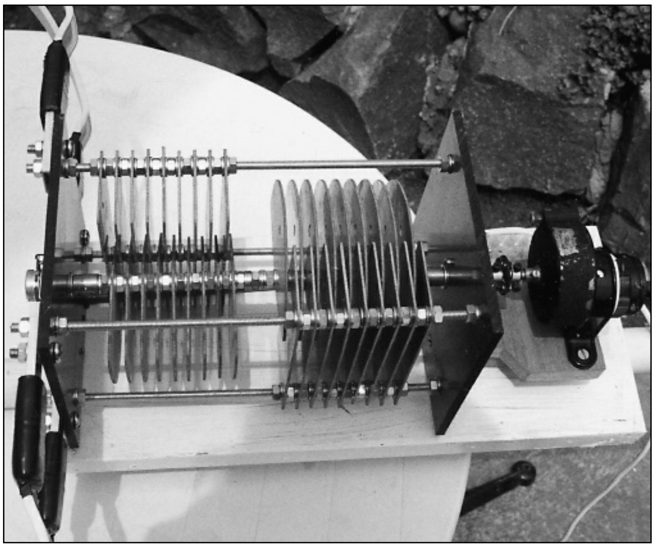


Fig 15.60: An example of one of GW3JPT home made capacitors

All the capacitors made by GW3JPT have the spindle extending both sides of the capacitor. One spindle is used to couple the capacitor to the drive mechanism; the other is used to connect the capacitor to a position indicator. This indicator circuitry must be electrically isolated from the capacitor as described above.

The control unit is housed in a plastic box with the fast/slow and rotation direction switches fixed to the front, together with the capacitor position meter.

Capacitor unit housing

One of the main problems of constructing any electrical circuits associated with antennas is protecting them from wind and rain. One option is to try and find some sort of suitable plastic housing and then organising the components to fit, but GW3JPT prefers to make the tuning housing from exterior plywood. The bottom and sides of the box are fixed together using 25mm square strips of timber. Glue and screws are used to make the joints waterproof. The top must, of course, be made so that it can be removed fairly easily. Paint or varnish the box as required.

Construction of capacitors

The capacitors for tuning loop antennas are very difficult to come by so GW3JPT makes his own. An example of one of his home made capacitors in shown in **Fig 15.60**.

GW3JPT used aluminium and double-sided circuit board for the vanes, and nuts and washers were used for the spacers. Various types of insulation material were used for the end plates. The centre spindle and spacing rods were constructed from 6mm-threaded plated steel rod.

Make the 76mm x 76mm (3 x 3in) end plates first, see **Fig 15.61**. These can be taped together, back-to-back, for marking and drilling. The same can be done with the vanes. Masking tape is used so the surface is not scratched around drill holes, which are drilled to clear 6mm with the centre hole acting as a bearing.

The number of vanes required dictates the length of the 6mm spindle. For double-sided board, washer/nut/washer spacers can be used so that there is no need to bond the copper sides. The resulting spacing is about 6mm (0.25in).

The first capacitors made by GW3JPT used the conventional shape for the moving vanes, but this is very difficult to cut out and fragile to use. The shape illustrated in Fig 15.61 (a) is much easier.

The fixed vane is a simple rectangle, which can be modified to reduce the minimum capacity. (Dotted line Fig 15.61 (c)). For the size shown, six pairs of vanes with 6mm (0.25in) spacing work out to about 150pf. Units using both printed circuit board and

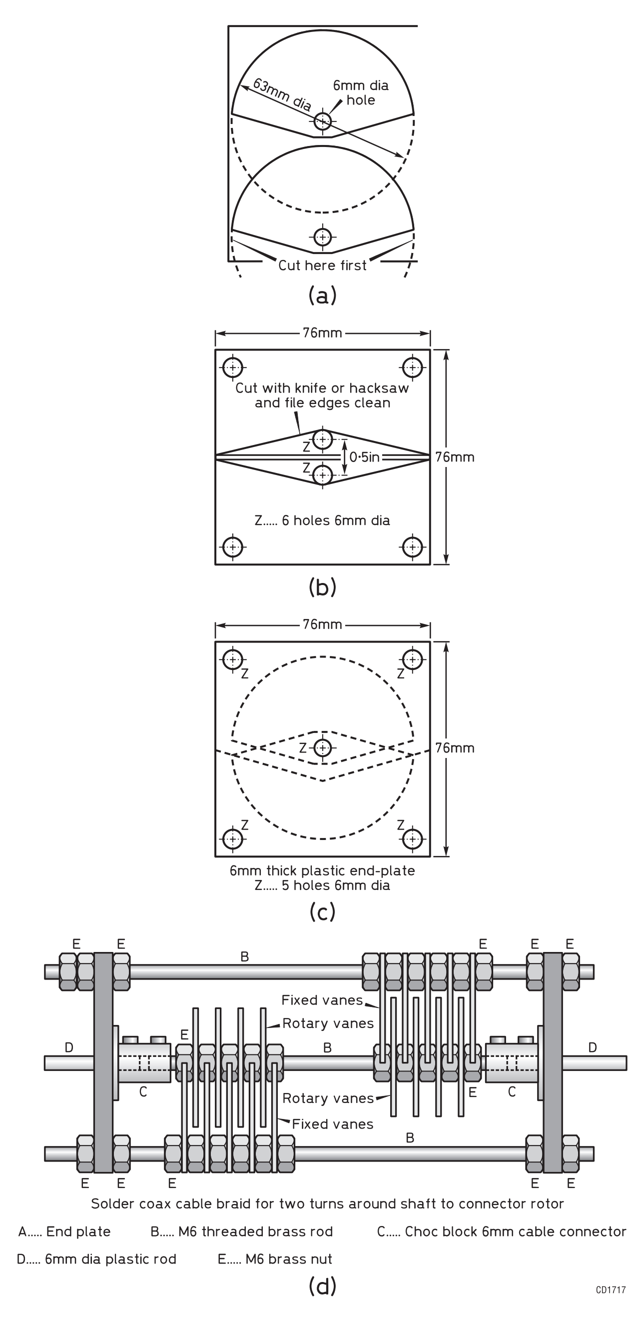


Table 15.8: Calculated data for the PA2JBC 80m, 2m diameter loop antenna made from 22mm tubing, using a 100W transmitter at 3.74MHz

L	5.8µH
Loaded Q	1273
Resistance	7.4mOhms
Loss resistance	46mOhms
Efficiency	14%
Bandwidth -3dB	2.94kHz
C at resonance	314pF
Capacitor Volts	8.3kV
Loop current	43.3A RMS

Fig 15.61: Details of homemade capacitor; (a) moving vanes; (b) fixed vanes; (c) fixed and moving vanes geometry showing minimum capacitance; (d) capacitor assembly

aluminium vanes had been in use for over two years and both were still in good working condition at the time of writing.

Operation

Loop tuning needs to be adjusted precisely for minimum SWR, which should coincide with maximum power out. This tuning is critical; a few kilohertz off tune and the SWR will rise dramatically. The best way of finding the correct position of the tuning capacitor is to listen for maximum noise, or signals, whilst tuning the loop, then fine-tune using an SWR meter.

The performance of this antenna on 80m was at least as good as a G5RV. It tuned all of 160m and gave quite good results as compared with local signals on the club nets.

A 2-Metre Diameter Loop for 80m

This loop antenna is very compact and although designed for mobile use it would be suitable for 80m operation from a very restricted location. It was designed by PA2JBC [20] to have a diameter of 2m and, for transportation purposes, be capable of being dismantled into two pieces. This feature would make it easy to get through a small loft access hatch. It also has a most interesting tuning arrangement. However, bearing in mind what has already been said about loops, an antenna this small does not have the efficiency of the larger models. The specification of the PA2JBC loop is given in **Table 15.8**.

The electrical characteristics were calculated for 22mm copper tubing. For practical reasons this antenna was built as an octagon. Measurements on the final antenna correlated closely with the calculations and PA2JBC has concluded that soft-soldered (rather than brazed or silver soldered) 45 degree elbows and compression couplers do not spoil the Q. This is a slightly at odds with the description of I1ARZ's loop, above. The structure of the antenna is shown in **Fig 15.62**.

The eight 820mm lengths of copper tubing are prepared by thoroughly cleaning the ends with fine emery paper and coating with flux. The pipe must be cut with a pipe cutter so that the ends fit snugly into the connector.

Two of the pipes to be joined are fitted into the 45° connecting elbows. The joint is heated with a blowtorch while at the same time applying multi-cored solder at the point where the pipe joins the connector. When the solder flows freely the joint is complete. Repeat for all the other joints, making sure the alignment of the loop is flat and make sure you fit the current transformer on to one of the sections of tubing (see later) before completing the loop. The completed loop is then cut in two sections as shown in Fig 15.62 and compression joints fitted at point A. If the antenna has to be frequently dismantled and reassembled, an 'olive' should be soldered to the tubing to reduce wear.

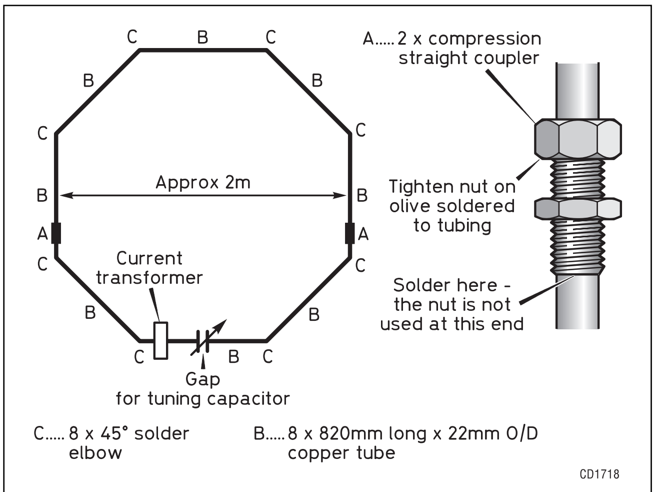


Fig 15.62: The PA2JBC 80m compact loop antenna

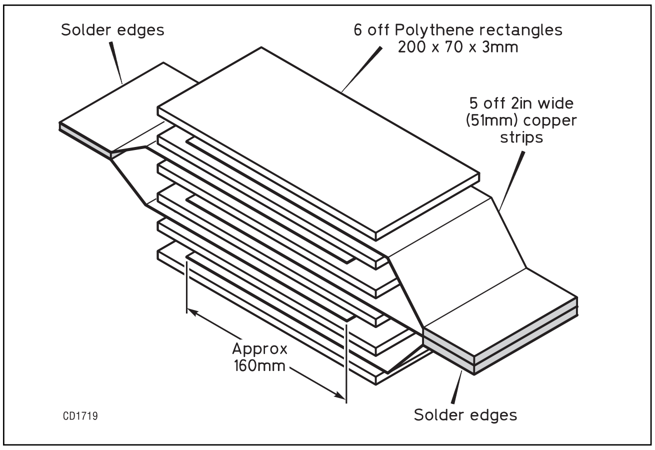


Fig 15.63: This fixed 260pF home made capacitor is good for 8kV @ 40A

The required capacity variation to cover 3.5 - 3.8MHz is 300pF to 360pF. This capacitance is made up from a 260pF fixed capacitor and a 100pF maximum variable in parallel. Using a small variable capacitor reduces the cost and improves the band-spread tuning.

The 100pF variable must be able to handle up to 9kV peak and 13A RMS when used with a 100W transmitter. A wiper connection to the rotor is unsuitable at 13A so a 2 x 200pF split-stator capacitor is used. Even then, the current path between all rotor plates must be low resistance, preferably soldered or brazed; the same goes for the stator plates and their connections to the loop tubing. At 9kV, conservative design requires 9mm spacing between the plates, or 4.5mm in a split-stator (each half takes 50% of the voltage).

The fixed capacitor is made from 51 x 0.3mm copper strips interleaved with slabs of dielectric as shown in **Fig 15.63**. Polyethylene works well as a dielectric and is inexpensive. Genuine polyethylene will not get hot! The capacity is set by adjusting the meshing of the two sets of copper 'plates' but the dielectric must extend beyond the copper by at least 6mm. After adjustment, the capacitor can be wrapped with glass-fibre-reinforced tape. Four parallel 3mm copper wires connect the fixed capacitor to the loop tubing. The 3mm-thick polyethylene is just adequate for 100W. On test the power was increased to 180W before it broke down.

With a loop of this design, PA2JBC could not get a gamma-match to work. A coupling loop also proved unsatisfactory as its shape had to be adjusted when changing frequency. The final solution was a current transformer. This transformer must match the 53 milliohm loop to a 50 ohm coax, an impedance ratio of 940:1 - a turns ratio of $\sqrt{940} \approx 30:1$. With this transformer the '1' is the loop tubing fixed in the centre of a toroid.

With the loop at resonance the feeder 'sees' inductance. By increasing the transformer winding to 36 turns and adding a series capacitor a 1:1 SWR can be obtained anywhere in the band. This capacitor is a receiver-type air-dielectric 250pF variable. A 1:1 balun keeps the outside of the coax 'cold'. An electrical diagram of the transformer and balun is shown in **Fig 15.64**.

Construction of the current transformer is shown in **Fig 15.65**. 6 x 6 turns of 1 mm PTFE-insulated copper wire gave the best results. Ferrite (Philips 4C6, violet) and iron powder (Amidon, red) both worked well. The transformer can be placed anywhere on the tubing, eg next to the capacitors where they and the coupler can housed be in a weatherproof box.

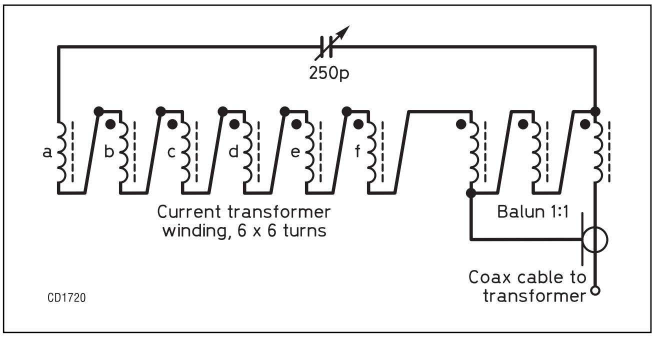


Fig 15.64: An electrical diagram of the matching transformer and balun

PA2JBC installed the antenna in his loft 3 metres above ground level and above all the electrical wiring. It should be fixed using good insulating material such as plastic pipe, as used in the I1ARZ loop.

The antenna's location close to wooden rafters and clay roofing tiles did not noticeably affect the Q of the loop, even when the roof was wet. If the loop is rotated with a TV rotator then it can be used to null out sources of interference.

With 100W PEP, only 14W is radiated from this indoor antenna, which is probably as good as the best mobile antenna for the band.

Certainly there is no problem with normal 80 metre country-wide contacts in the daytime and occasional DX at night. The high-Q characteristics of the antenna give a marked improvement in the signal to noise ratio in the presence of general electrical interference and QRN. This antenna could be used as a 'receive only' antenna in conjunction with a larger antenna for DX.

Tubing of 28mm would raise the Q and efficiency but it would also reduce the bandwidth; fine for CW, but too narrow for 80m SSB! As it is, the loop must be re-tuned for every change of frequency.

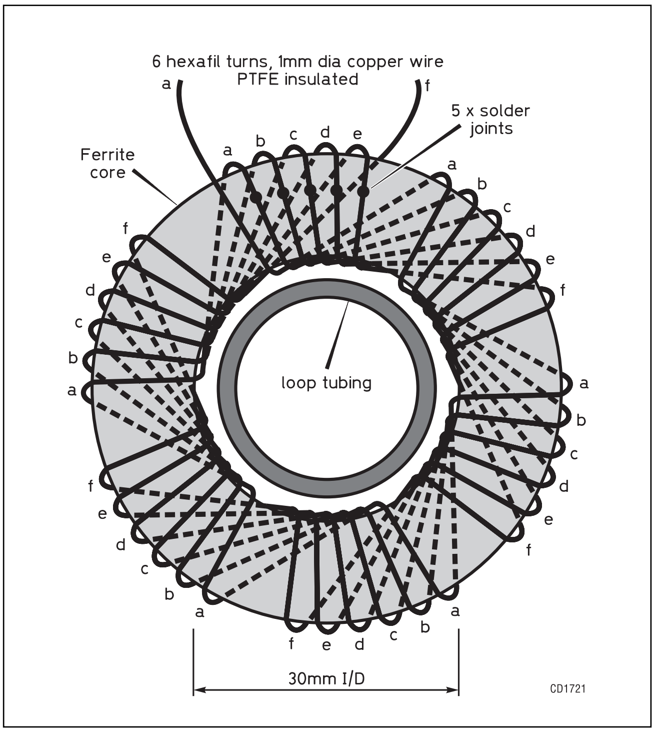


Fig 15.65: Construction of the current transformer

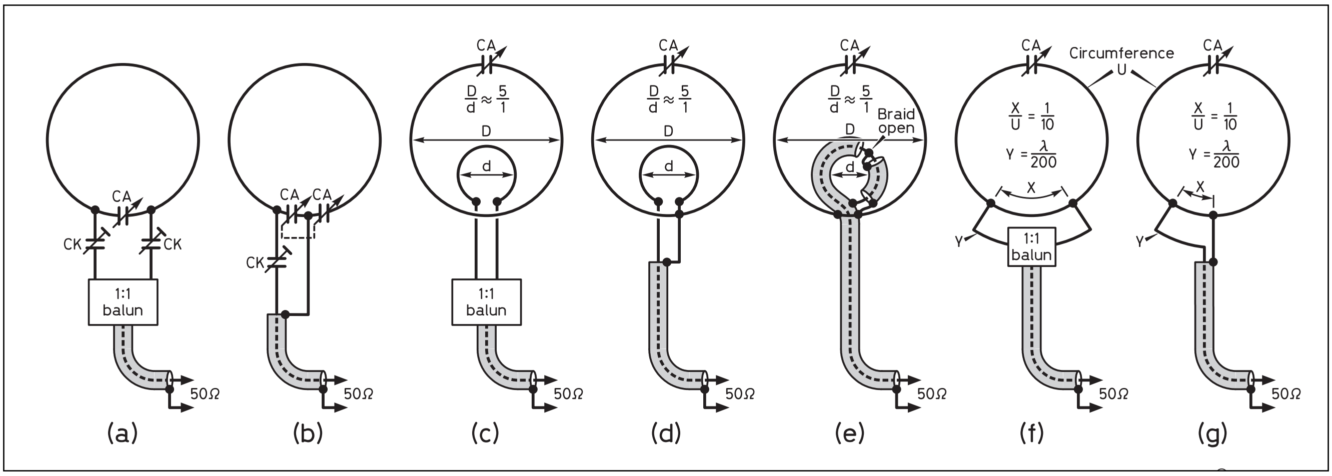


Fig 15.66: Matching a transmitting or receiving antenna to 50 ohm coaxial cable as described in 1983 by D12FA and reported in *RadCom*, October 1996. The Faraday loop method (e) is favoured, but see text

For outdoor use, the loop should be de-greased and painted.

Comments on Small Loop Antennas

The compact loop is a viable solution for these not able to erect a wire antenna. The compact loop by I1ARZ is, in the worst case, about 4 or 5 dB down on a dipole half a wavelength high. This is less than one S-point. It is obvious that, under conditions of normal HF fading, difficulties might be experienced when making meaningful comparisons.

The compact wire loop by GW3JPT is about 60% efficient on 160m. Making comparisons on this band is even more difficult - getting a 160m comparison dipole up half a wavelength high is a challenge.

There are numerous ways of coupling a low-impedance loop to coaxial cable and most of these are shown in **Fig 15.66**. The favoured method is the Faraday loop, shown in Fig 15.66(e). There has been some comment that the Faraday loop connections, found in most descriptions of loops (including the I1ARZ and GW3PJT designs above) are incorrect. The coax inner and braid at the top or apex of the loop in Fig 15.58, for example, is shown joined, which would make a Faraday half loop. The inner to braid connection should be removed but the gap in the braid halfway round the loop should remain.

The matching methods in Fig 15.66 (a) and (b) have been used with loops of 10m or more diameter for 136kHz, for both transmit and receive. The PA2JBC compact loop for 80m, with its transformer and balun, is worthy of further development for more conventional sized loops.

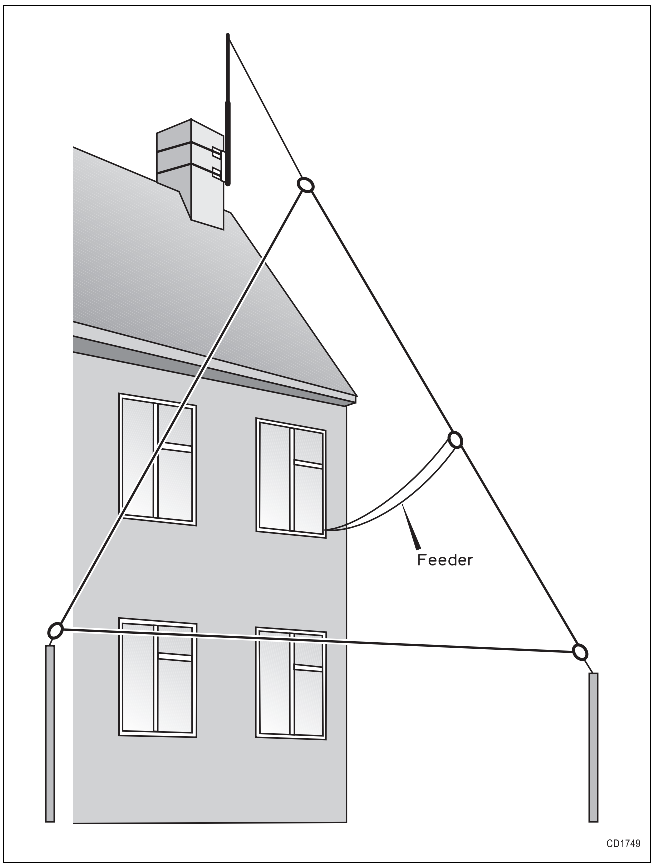


Fig 15.67: Loop antenna one wavelength circumference on 7MHz

Multi-Band Delta Loop Antenna

If you have the space, a larger loop is well worthwhile. If the loop is larger than 0.25λ it will lose its predominant 'magnetic' characteristic and become an 'electric' antenna of the quad or delta type. From the previous descriptions of loop antennas it can be seen that the efficiency improves with an increase in size and the resistive losses of a loop with a full wavelength circumference are very small.

A full wave loop on 7MHz can be fed with coax and will also operate on the 14, and 21MHz bands and without an ATU, provided that a transformer and balun are connected between the coax and the antenna. The shape of the loop is not too important.

If a loop antenna in the form of an equilateral triangle is used then only one support is required. If this support were a mast fixed to the chimney, it can probably circumvent planning restrictions.

The antenna is shown in **Fig 15.67**. As you can see, part of this antenna is close to the ground. This means there is a possible danger of someone receiving an RF burn if the antenna is touched when the transmitter is on. For this reason, insulated wire for the lower half of the antenna is recommended. A loop antenna of this type is not a high-Q device so very high voltages, such as those found at the tips of a dipole, do not occur.

The top half of the antenna can be constructed with bare copper wire. You could use insulated wire for all the loop, however lightweight wire for the upper half of the loop, and a lightweight support, has a low visual impact. Using lightweight thin wire does not affect the antenna performance because the radiation resistance of the loop is fairly high.

The first experiments were carried out with the coax connected directly to the loop, but the SWR was over 3:1. However, most literature puts the feed impedance of a loop greater than 100 ohms. A 4:1 balun was fitted, enabling the antenna to be fed directly with 50-ohm coax with little mismatch.

The best results occurred when the antenna was fed about one third up from the bottom on the most vertical of the triangle sides. This antenna will give good results even when the lowest leg of the triangle is only 0.6m from the ground. Fig 15.67 shows the corner insulators fixed to the ground with tent peg type fixtures. It can be run along a fence with shrubs and small trees being used for fixtures for the lower corner insulators.

The apex support in the experimental model was a 2.5 metre length of scaffolding pole fixed to the chimney with a double TV lashing kit. The top of the chimney was about 9m above the ground. The pole gives the antenna enough height and a reasonable clearance above the roof.

The loop proved to be a good DX transmitting antenna on 7MHz. It did tend to pick up electrical noise from the house on receive. It could be used with a smaller loop on receive if electrical noise or QRM is a problem.

Skeleton Slot Antenna

The Skeleton Slot is is a loop antenna with a difference. With the dimensions given it will operate on the 14, 18, 21, 24 and 28MHz bands using a balanced ATU.

It is very easy to construct and is a simple design with no traps or critical adjustments. This antenna has a turning radius of only 1.5m (5ft) although it is 14m (47ft) tall. However its construction means that it has a much lower visual impact than a conventional multi-band beam. The antenna is bi-directional and has a calculated gain, over average ground, of 8dBi on 14MHz and 11dBi on 28MHz. The Skeleton Slot antenna was first documented in an article by B Sykes, G2HCG, in 1953 [21].

Non-Resonant Slot Antenna for 14 - 29MHz

The main exponent of the HF Skeleton Slot, other than G2HCG, is Bill Capstick, G3JYP, whose version of this antenna was described in [22].

The G3LDO version of the slot uses wire for the vertical elements, resulting in a more simplified and rugged construction. It was first thought that this method of construction would not work because [21] and [22] gave minimum tube diameters for the elements. However, computer modelling with EZNEC4 was reassuring.

The antenna essentially comprises three aluminium tube elements fixed to the mast at 4.6m (15ft) intervals, with the lowest element only 4.6m from the ground. The mast is an integral part of the antenna, as a boom is to a Yagi. The general construction is shown in **Fig 15.68**.

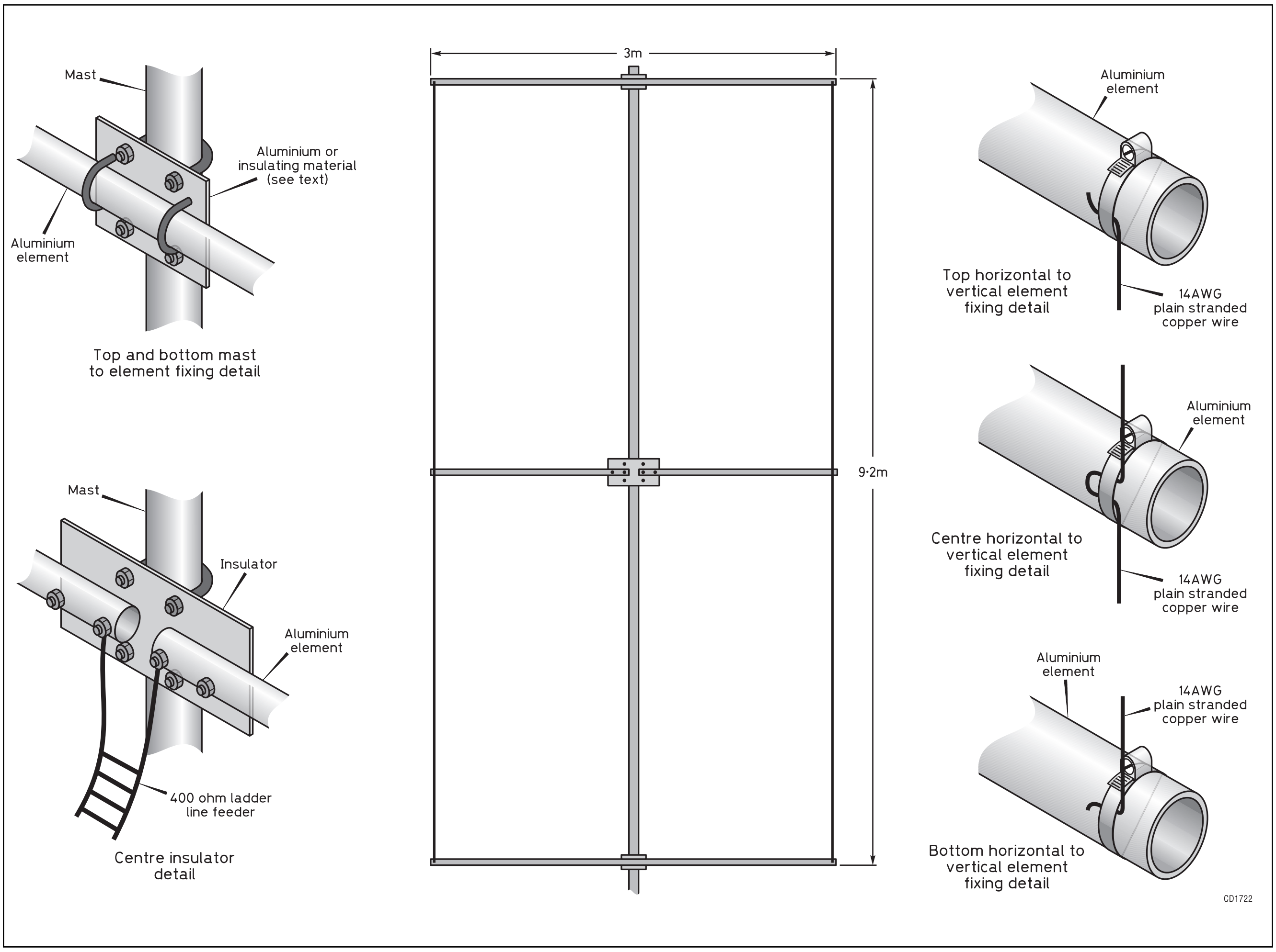


Fig 15.68: The G3LDO multiband Skeleton Slot antenna for 14 to 28MHz. The elements are fixed to the mast and the whole mast is rotated. The wire elements are fixed to the horizontal elements with hose clips. The centre insulator, as shown, is home made but a commercial one would be suitable

The centre element is fed in the centre with balanced feeder, and the upper and lower elements are fed at the ends by copper wire from the driven dipole

The aluminium tubing and copper wire are fixed using hose clips. These dissimilar metal connections have in the author's experience presented no corrosion problems, even in a location close to the sea, provided they are well coated with grease.

The centres of the upper and lower elements can be fixed directly to a metal earthed mast using an aluminium plate and U-bolts as shown in Fig 15.68. Performance on the normal HF bands is unaffected by grounding or insulating the upper and lower elements.

The diameter and length of the aluminium tube and wire are not critical.

The antenna requires a balanced feed and is fed with 450-ohm slotted line feeder, although the impedance is not critical. The feeder should be fixed on stand-off insulators about 150mm (6in) from the mast until clear of the lower element to prevent them blowing about in the wind and affecting the impedance, although this was not done in the antenna shown in **Fig 15.69**.

An ATU with a balanced output is required. A conventional Z-match was found to be adequate with the two sets of balanced outputs, one ostensibly for the higher HF frequencies and the other for the lower ones. In practice the lower frequency output worked best for all frequencies. The antenna can be fed with any of the ATUs described in earlier.

G3LDO built his skeleton slot to the size specified by Bill Capstick, and these dimensions seem nearly optimum for the five higher HF frequency bands. While the DX performance of the Skeleton Slot is good up to 30MHz, it deteriorates at frequencies higher than this.

On the 21, 24 and 28MHz bands the antenna performed very well, particularly in marginal conditions.

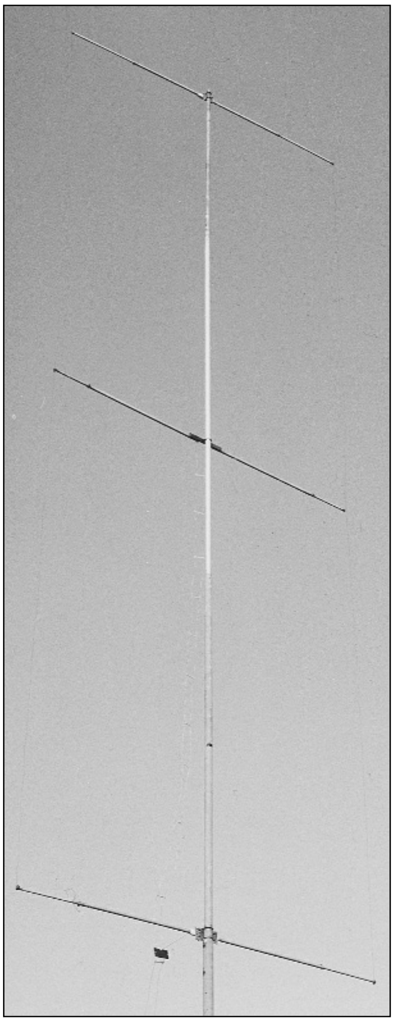


Fig 15.69: The G3LDO multiiband Skeleton slot antenna for 14 to 28MHz

ROTARY BEAM ANTENNAS

The rotary beam antenna has become standard equipment for the upper HF amateur bands, and the best known icon of amateur radio is the three-element Yagi. It offers power gain, reduction in interference from undesired directions, compactness and the ability to change the azimuth direction quickly and easily. All this has many advantages for a restricted site. All the beam antennas described in this chapter are parasitic beam antennas.

Optimum dimensioning of spacing and element lengths can only be obtained over a very narrow frequency range, and the parasitic beam will work only over a relatively restricted band of frequencies. In most cases, the bandwidth of such an array is compatible with the width of an HF amateur band.

The compactness of a parasitic beam antenna more than outweighs the disadvantage of the critical performance and no other antenna exists that can compare, size for size, with the power gain and directional characteristics of the parasitic array.

Two-Element Yagi

A two-element Yagi is shown in **Fig 15.70**. The parasitic element (Ep in the diagram) is energised by radiation from the driven element, which then re-radiates. The phase relationship between the radiated signal from the driven element and the re-radiated signal from the parasitic element causes the signal from the antenna to be 'beamed' either in the direction of Ep or away from it.

This phase relationship is effected by the length of the parasitic element. When the parasitic element is longer than the driven element it operates as a reflector and causes the power gain in a direction away from Ep. When the parasitic element is shorter it operates as a director causing the power gain in a direction towards Ep.

When the parasitic element is to be used as a director, optimum spacing between it and the driven element is around 0.1 wavelength. Optimum spacing when using the parasitic element as a reflector case is approximately 0.13 wavelength

The effect of these options can be seen in the computer simulation in **Fig 15.71**. There is very little difference in performance of a two-element beam when the parasitic element is used either as a director or reflector, with perhaps just a marginal improvement in the front-to-back ratio when the parasitic element is a director.

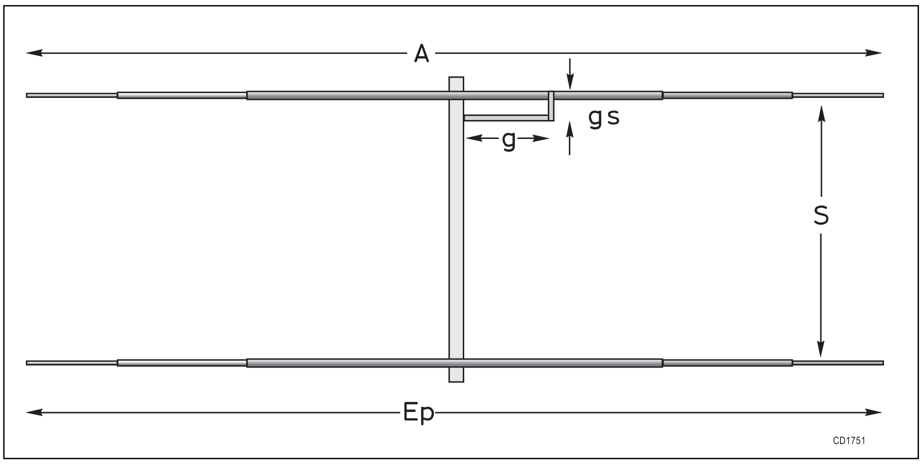


Fig: 15.70: Construction of a two-element Yagi beam with dimension references for the 20, 18, 15, 12 and 10m bands

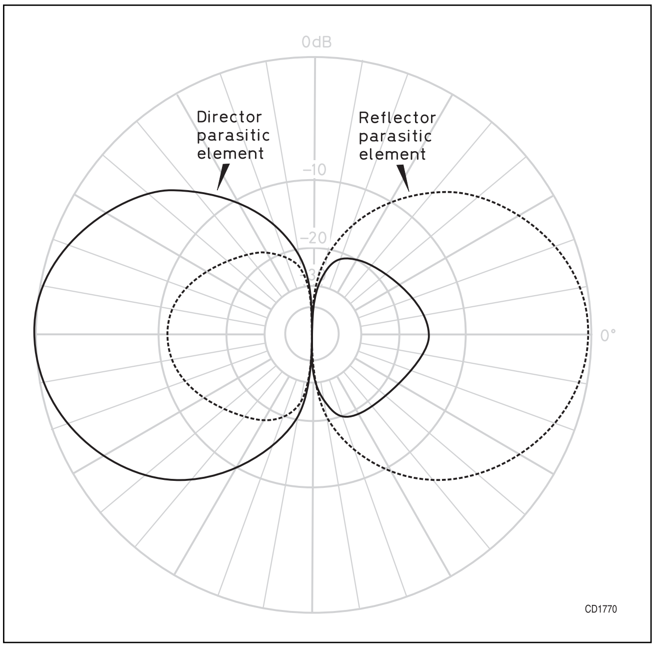


Fig: 15.71: Computer analysis of a two-element beam with the parasitic element as (a) a reflector and (b) as a director

Frequency MHz	14.1	18.1	21.2	24.9	28.5
(S) Element Spacing (m)	2.11	1.66	1.41	1.20	1.05
(Ep) Director length (m)	9.66	7.58	6.47	5.50	4.81
(A) Driven Elt (m)	10.30	8.08	6.90	5.88.	5.13
(S) Element Spacing (in)	83	65	56	47	41
(Ep) Director length (in)	380	298	255	217	189
(A) Driven Elt (in)	406	318	272	231	202

Table 15.9: Dimensions for a two-element beam. Refer to Fig 15.70 for dimensions S, Ep and A. These dimensions have been calculated using EZNEC for a non-critical design to give a free-space gain better than 6dBi and a front-to-back ratio greater

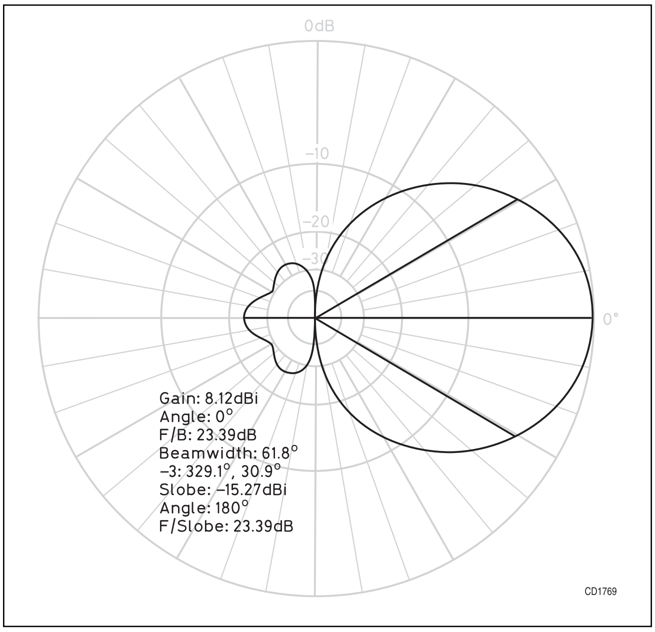


Fig 15.73: Polar diagram of a three-element beam designed using EZNEC for a high F/B ratio at the expense of gain

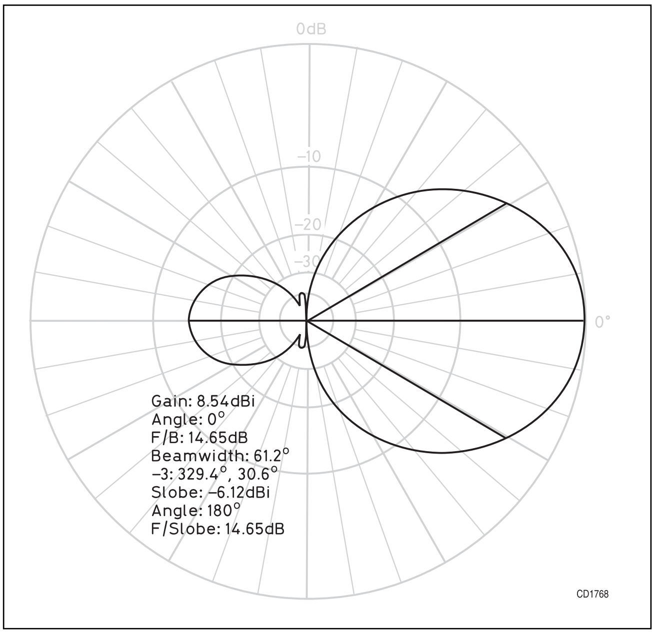


Fig 15.72: A three-element beam from the W6SAI *Beam Antenna Book* [23] shows high gain and a F/B ratio of nearly 15dB

Additionally, a two-element beam with a parasitic director will be the slightly smaller and lighter of the two options.

Practical dimensions for this option are shown in **Table 15.9**. These dimensions have been calculated using EZNEC for a non-critical design to give a free-space gain better than 6dBi and a front-to-back ratio greater than 14dB, as shown in the director parasitic element polar diagram shown in Fig 15.71. These calculations assume an average tube diameter of 20mm (0.75in) on 21MHz, which is scaled to an average of 30mm on 14MHz and 15mm on 28MHz. In practice the diameter of the tube is not critical and the diameter should be such that the antenna is mechanically stable. The elements should be made of, say, five sections that telescope into each other (Fig 15.70). Aluminium scaffolding pole 50mm (2in) in diameter is useful material for the boom for any of the bands. The construction of the elements and methods of fixing the boom to the mast are described in the antenna construction and masts section of this book.

As with all parasitic beams, the dimensions of the parasitic elements determine their performance. The length of the driven element is less critical and its length only determines the feed impedance.

The feedpoint impedance of this antenna is approximately 30 ohms. To feed it with 50-ohm coaxial cable a matching arrangement is necessary.

The Three-Element Yagi

By adding a reflector and a director to a driven element to form a three-element parasitic beam, the free-space gain is increased to over 8dBi and a front-to-back (F/B) ratio greater than 20dB, although this depends if the antenna is tuned for maximum gain or maximum front-to-back ratio. Most antenna constructors tend to tune beam antennas for maximum F/B ratio. The reason for this approach is that adjustments to the F/B ratio make a marked difference that is easy to measure. For example the polar diagram of the W3SAI antenna [24] shown in **Fig 15.72** has a gain of 8.54dBi and the front-to-back is only 14.65dB.

On the other hand, the polar diagram of an antenna selected for a good front-to-back ratio (23.4dB), such as the one shown in **Fig 15.73**, is only 0.4dB down in forward gain on the W3SAI

Frequency MHz	14.1	18.1	21.2	24.9	28.5
(S) Element Spacing (m)	2.96	2.32	1.98	1.67	1.47
(D) Director length (m)	9.66	7.60	6.47	5.52	4.83
(A) Driven Element (m)	10.30	7.92	6.76	5.76.	5.03
(R) Reflector length (m)	9.66	8.24	6.49	5.99	5.23
(S) Element Spacing (in)	116	91	77	66	58
(D) Director length (in)	382	229	254	216	190
(A) Driven Element (in)	402	314	268	229	200
(R) Reflector length (in)	414	324	276	236	206

Table 15.10: Dimensions for a three-element beam. Refer to Fig 15.74 for dimensions S, D, R and A. The dimensions are shown in metres and inches and have been calculated using EZNEC for a non-critical design to give a free-space gain better than 8dBi and a front-to-back ratio greater than 20dB

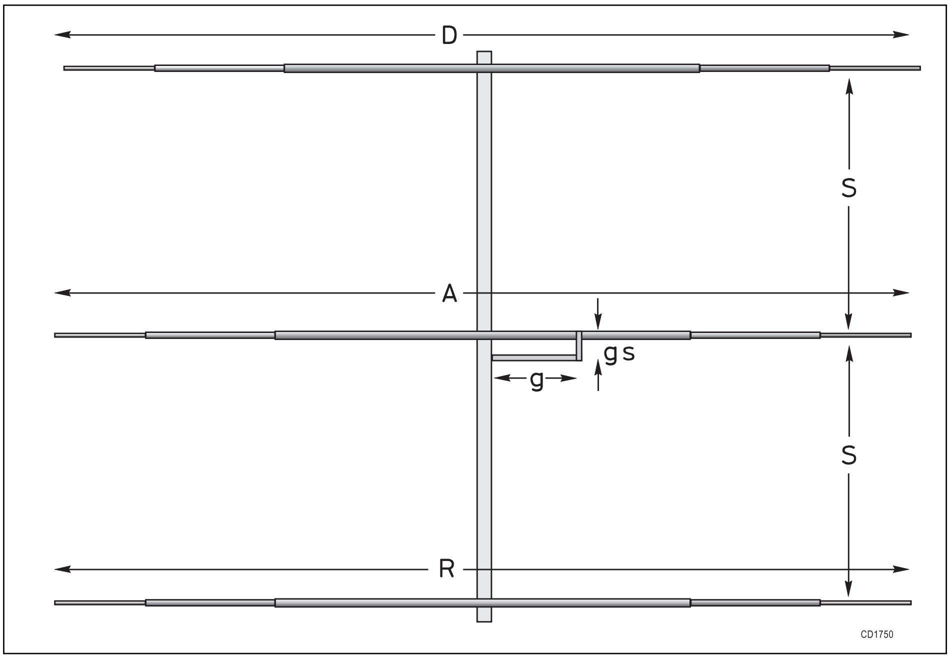


Fig 15.74: Construction of a three-element beam with dimension references for the 20, 18. 15, 12 and 10m bands

antenna. As 6dB is 1 S-point, the improvement of 1.5 'S' units on F/B is noticeable. The gain difference of 0.42dB is not going to be noticed on any 'S' meter.

The construction is similar to that described for the two-element beam. The dimensions for this antenna are given in **Table 15.10** and are read in conjunction with **Fig 15.74.**

The feedpoint impedance of this antenna is around 25 ohms. To feed it with 50-ohm coaxial cable a matching arrangement is necessary. The Gamma Match is described in the Transmission Lines chapter.

The Cubical Quad

The Cubical Quad beam is a parasitic array whose elements consist of closed loops having a circumference of one-wavelength at the design frequency. The quad construction is shown in **Fig 15.75** and the dimensions are given in **Table 15.11**.

The parasitic element is normally tuned as a reflector. It can be tuned as a director but the gain and front to back ratio is inferior. Additionally, the optimum settings are more critical.

The reflector can be constructed using the same dimensions as L, the driven element; a tuneable stub

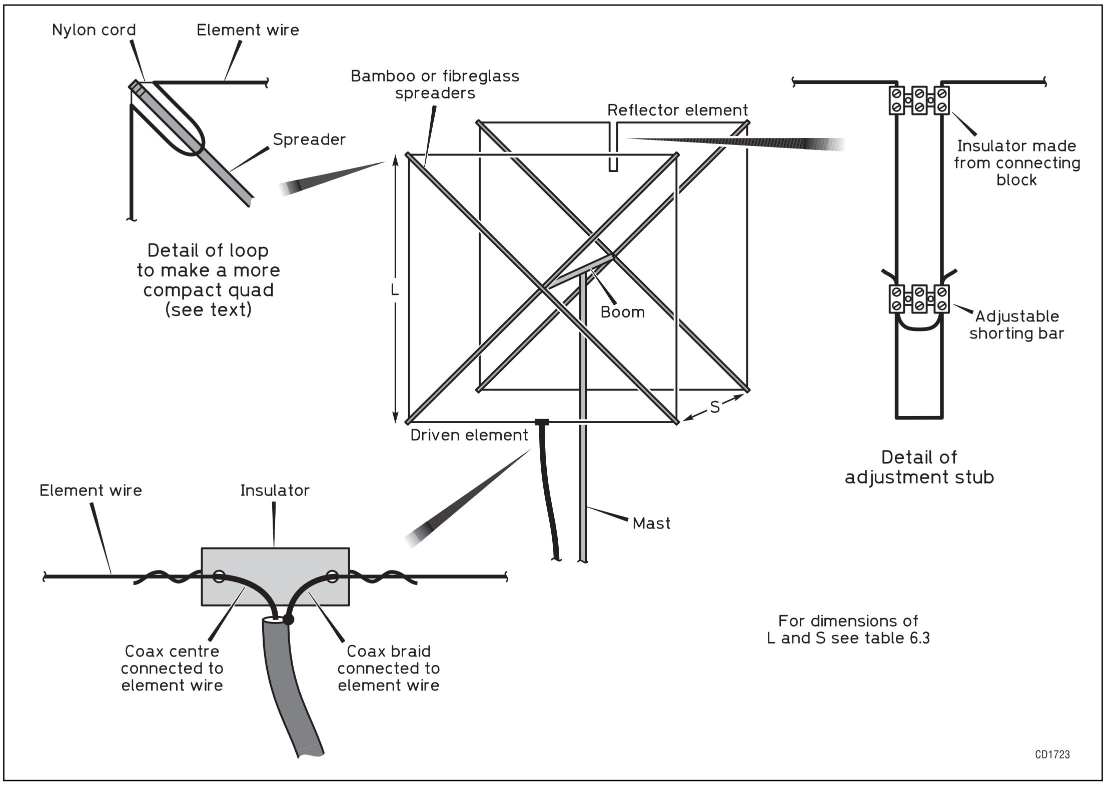


Fig 15.75: Construction of a two-element wire quad, with dimension references in Table 15.11. The reflector can be constructed using the same dimensions as L, the driven element; a tuneable stub (see detail on right) is then used to lower the frequency of the reflector. This stub can be used to tune the reflector for the greatest front-to-back ratio of the beam. The stubs on the element corner supports (detail left) are discussed in the text. A sealant should be used to prevent water ingress at the end of the coax cable

Frequency MHz	14.1	18.1	21.2	24.9	28.5
(S) Element Spacing (m)	2.98	2.34	1.99	1.70	1.49
(R) Reflector length (m)*	5.56	4.38	3.73	3.17	2.77
(ER) Element support length (m)	3.93	3.1	2.64	2.24	1.96
(A) Driven Elt (m)*	5.33	4.18	3.57	3.04.	2.65
(S) Element Spacing (in)	117	92	79	67	59
(R) Reflector length (in)*	219	172	147	125	109
(ED) Element support length (in)	155	122	104	89	77
(A) Driven Elt (in)*	210	164	140	120	105

*Note: These dimension are for one side of the quad. The total length

Table 15.11: Dimensions for a two-element quad beam. These dimensions have been calculated using EZNEC for a non-critical design to give a free-space gain around 7.5Bi and a front-to-back ratio greater than 15dB

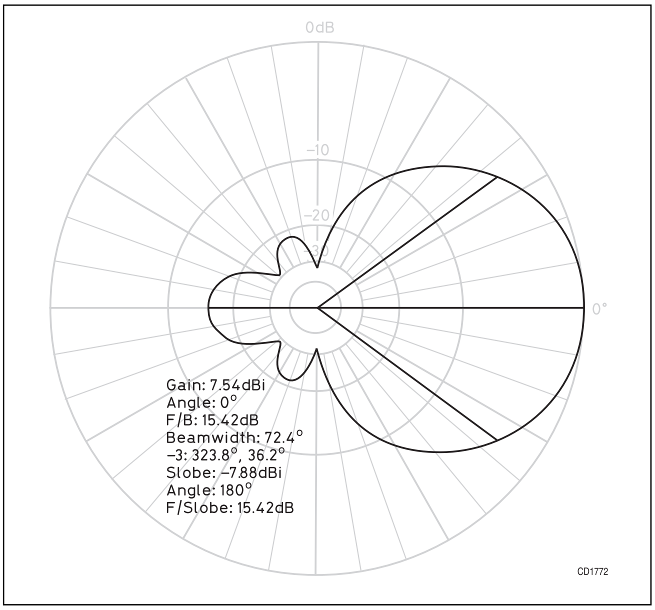


Fig 15.76: Computer analysis of a two-element wire element quad with 0.14 wavelength element spacing

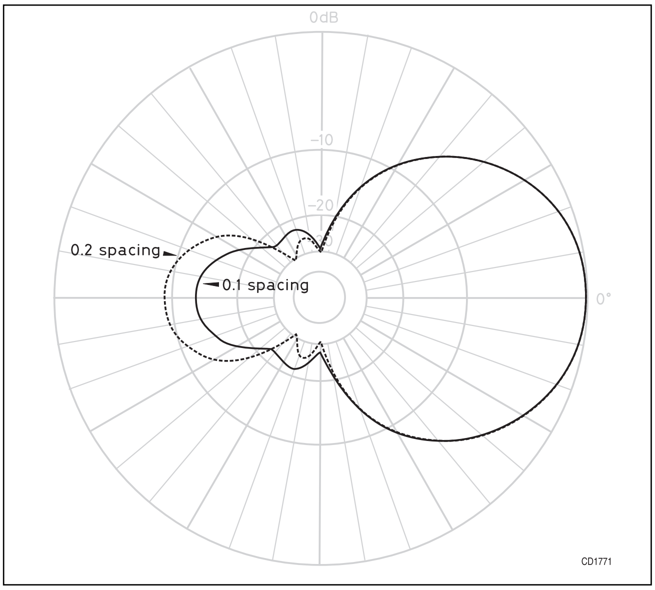


Fig 15.77: Computer analysis of a two-element wire element quad, (a) using 0.2 wavelength spacing; (b) using 0.1 wavelength spacing

is then used to lower the frequency of the reflector. This stub can be used to tune the reflector for the greatest front-to-back ratio of the beam. The stubs on the element corner supports can also be used reduce the overall size of the element and can be used with the driven element and the reflector. However the lengths will have to be determined by experiment. The easiest way to construct these stubs is to use plastic insulated wire elements and then to tape the stub along the element support, as shown in the right-hand detail of **Fig 15.75**.

The dimensions given in Table 15.11 are for a quad using an element spacing of 0.14 wavelength; the computed free-space performance is shown in **Fig 15.76**.

The lengths of the element supports could be longer than given. The length dimension is the point where the element is connected to the support.

Using the dimensions in Table 15.11, the feed impedance of the quad is around 65 ohms so the driven element can normally be connected directly to 50-ohm feedline with only minimal mismatch. The 0.14 wavelength spacing (S) was chosen because it is the most prevalent in antenna literature. However, the spacing for a two-element quad can be reduced to 0.1 wavelengths without any noticeable deterioration in performance, see **Fig 15.77**. Reduced spacing lowers the feedpoint impedance and can give an improved match to 50-ohm coaxial cable.

The quad can be made into a multi-band antenna by interlacing quad loops for the different bands on to a common support structure. In this case the element support length (ER) and (ED) should be the length for the lowest frequency band. The disadvantage of this arrangement is that the wavelength spacing (S) between the driven element and the parasitic element is different on each band. This problem can be overcome by using an element support structure with a modified geometry as shown in **Fig 15.78**

A multiband quad using this type of geometry is often referred to as a 'boomless' quad for obvious reasons. The structure, which hold the element supports in place at the correct angles

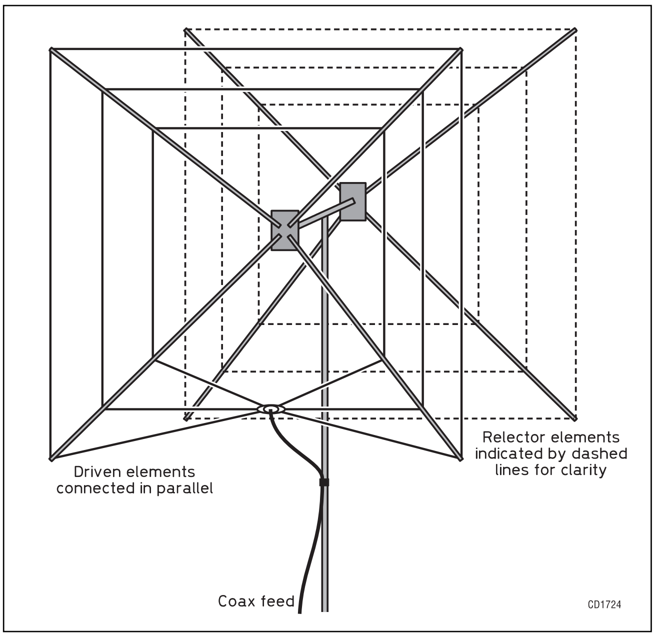


Fig 15.78: General view of a multiband variant of the quad using optimum driven element/reflector spacing for each band

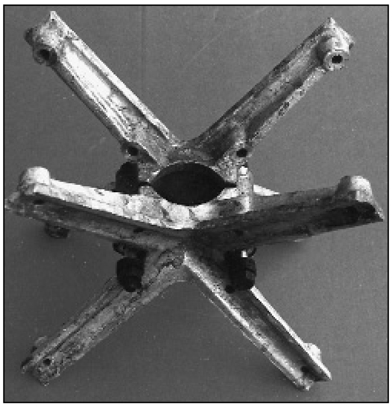


Fig 15.79: Construction of a commercial 'spider' for a multiband quad to allow optimum spacing on all bands

is often referred to as a 'spider'. An example of this type of structure is shown in **Fig 15.79**.

Dimensions (ER) and (ED) will have to be increased by around 5% with the boomless quad. All the driven elements can be fed in parallel, as shown in Fig 15.78, without any compromise in performance.

Methods of fixing cane or fibreglass element supports to booms are given in the Antenna construction chapter

COMPACT BEAMS WITH BENT ELEMENTS

The 10 metre 'wingspan' of a conventional Yagi for 20m can be a problem for many locations. So, can the elements be bent, as is done with a dipole when trying to fit it into a smaller space, and still retain the beam characteristics?

With antennas there is very little that is actually new. A configuration where the elements of a two-element beam were bent to halve the 'wingspan' was first suggested by John Reinartz, W1QP, in October 1937. Burton Simson, W8CPC, constructed such an antenna [24], the elements of which were supported on a wooden frame. This allowed the element ends to be folded towards each other. The 14MHz antenna was constructed from 6mm (1/4in) copper tubing with brass tuning rods that fitted snugly into the ends of the elements.

A wire edition of the W1QP/W8CPC two-element antenna was described, in 1973, by VK2ABQ [25]. In this configuration, the tips of the parasitic and driven elements support each other in the horizontal plane. The insulators are constructed so that the tips of the elements are 6mm (1/4in) apart. The gap between the tips of the elements is described as 'not critical'.

The computer model of the W1QP/W8CPC/VK2ABQ arrangement suggests that the driven element/parasitic element coupling is the same as for a wide-spaced two-element Yagi. Its performance is shown in **Fig 15.80**.

Multiband versions of this antenna were constructed without any known difficulty by nesting one antenna within the other and using a common feed for the driven element.

The G6XN antenna and the Moxon Rectangle

Les Moxon, G6XN [26], changed the structure from a square to a rectangle ,thereby reducing the centre section spacing of the elements from 0.25λ to 0.17λ, which resulted in improved gain and directivity. G6XN used loops in the elements at the element support points. This makes for a more compact antenna but increases the mechanical complexity.

C B Cebik, W4RNL [27], reduced the element spacing further to 0.14λ and obtained yet more gain and improved directivity. This antenna he called the Moxon Rectangle. The downside of this higher performance is the difficulty of making a multi-band structure due to interaction.

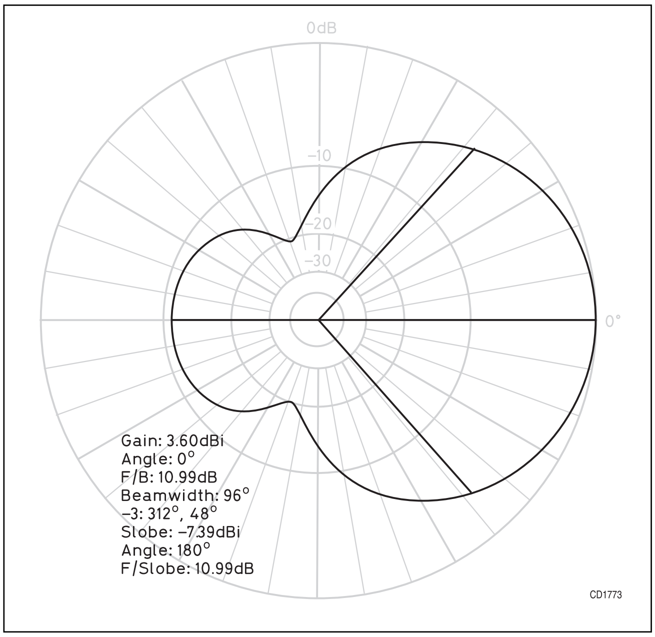


Fig 15.80: EZNEC analysis of the W1QP/W8CPC/VK2ABQ configuration

Tony Box, G0HAD, built a G6XN antenna whose overall size was 6.1m x 3.8m (20ft x 12ft 6in) as recommended by G6XN; this antenna out-performed his previous commercial mini beam. A computer model (EZNEC 4) was used to check these dimensions, and produced the antenna dimensions 6.92m x 3.8m (22ft 10in x 12ft 6in).

A comparison of the geometries of these antennas is shown in **Fig 15.81**. The VK2ABQ and the G6XN geometries can be multibanded.

Below are formulas to calculate dimensions for the G6XN antenna (without loops at the element support points).

Reflector 155/f = length (m)
Driven element 149.4/f = length (m)

Reflector 508/f = length (ft)
Driven element 490/f = length (ft)

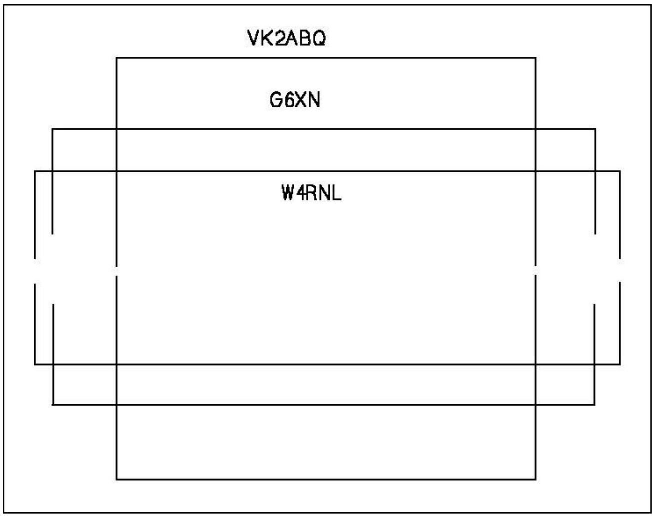
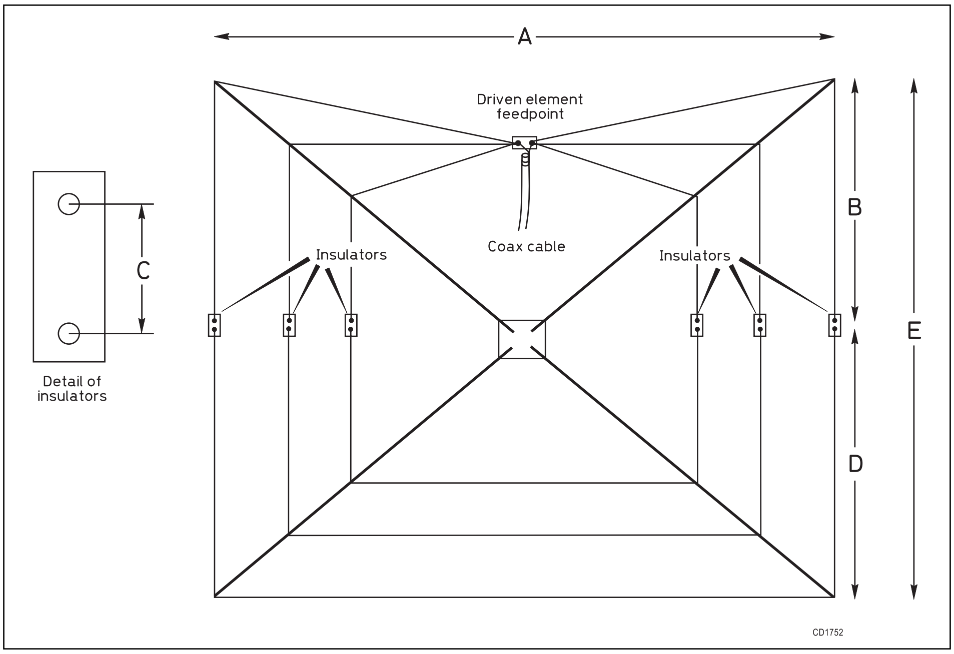


Fig 15.81: The original VK2ABQ antenna structure compared with the G6XN and the W4RNL. The G6XN has a centre section spacing of the elements of around 0.17 wavelength spacing, while the W4RNL has element spacing further to 0.14 wavelength

Fig 15.82: The G6XN multiband antenna. See text for dimensions



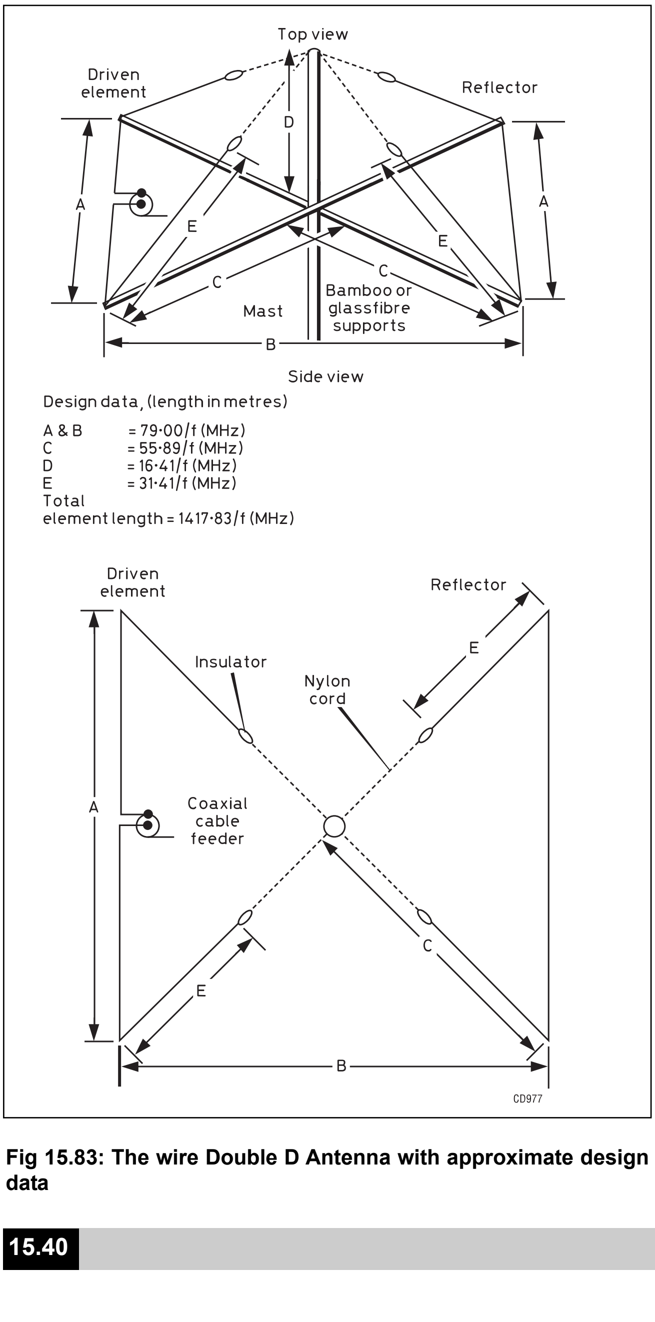


Fig 15.83: The wire Double D Antenna with approximate design data

A suggested multiband G6XN antenna is shown in **Fig 15.82**. The dimensions A and E can be found by:

A = 98.26/f = (m); 322/f = (ft)
E = 53.96/f = (m); 177/f = (ft)

C = 560mm (22in) for 14MHz, 380mm (15in) for 21MHz and 250mm (10in) for 28MHz (from experimental work by G0HAD [28]).

To work out the length of each support (cane or fibreglass rod) structure required the formula is:

56.09/f = length of diagonal in metres
184/f = diagonal length in ft.

The units of feet are indicated as a decimal number. To convert 12.5ft to feet and inches, multiply the part after the decimal by 12, eg 0.5 x 12 = 6; 12ft 6in.

The G3LDO Double D Antenna

If you want to make the bent element Yagi even smaller the ends of the elements can be folded back towards the mast in the vertical plane. This results in a pymamid configuration, and its construction was first described in [29] is shown in **Fig 15.83**. Use plastic tape to fix the wire to the canes.

This antenna will provide 3 - 4dB of gain over a dipole and a front-to-back ratio better than 14dB, which is not as good as the Moxon Rectangle but is a very compact antenna. The ends of the elements, with its 'guy' supports provide a strong lightweight structure.

Use the formula in Fig 15.83 to obtain the approximate wire lengths. In practice it is difficult to optimise the element lengths in a formula because of the geometry of the antenna. It is suggested that the ends of the elements (where they connect to the insulator) are made variable using tie wraps, as in the dipole antenna construction, shown earlier in this chapter.

Then adjust the reflector for maximum F/B and the driven element for minimum standing wave ratio. If you are in the mood to experiment you should be able to increase the gain and improve the SWR by reducing dimension B. This is achieved by altering the angles of the fixing supports relative to the mast.

The Double-D is also amenable to multibanding. A number of these antennas, for different bands, can be mounted on the same support. The simplest method of feeding turned out to be the best; paralleling the driven elements and feeding them with the one coax line as shown in Fig 15.82.

PHASED VERTICAL BEAM ANTENNAS

A phased array is a set of similar (usually identical) vertical antennas arranged in a regular geometric way and fed with a specific set of RF sources having a defined relationship to each other in terms of current magnitude and phase. Phased arrays offer a way of achieving modest gain and good reception directivity from a low profile antenna. Gains of up to 6dB, with front to back ratios of 20dB, can be achieved relative to a single vertical element with a well-designed phased vertical array.

A practical phased array system will consist of the set of radiators, earth systems, feedlines, networks to shift phase and match impedances, and a switch box. This box contains relays that switch the feedlines and allows the beam headings to be changed by changing the current distribution amongst the elements in the array. In some cases phasing and impedance matching is achieved by feeding the antennas via specific lengths of coaxial cable. Other methods use inductors or capacitors in addition to the coax feeds.

Mutual coupling between the elements in an array changes the impedances of the elements from the impedances if the elements were in isolation. These effects can be large and will change current distribution and relative phases. The performance of an array is critically dependent on errors in currents or phase relationships.

For this reason full details of phased verticals are beyond the scope of this chapter so the following are brief descriptions, with references of detailed construction and setting up. A detailed description of the phased vertical antenna was written by G3PJT [30].

One of the simplest arrays is a pair of quarter wavelength verticals, spaced at a quarter wavelength apart and fed with RF currents which are equal but 90 degrees out of phase (**Fig 15.84**). This arrangement has a gain of 3dB over a single vertical and produces a cardiod pattern, having a front-to-back ratio of 20dB with a front-to-side of about 3dB. With element one fed at 0 degrees and element two fed at 90 degrees the lobe is in line with the elements, and the arrow shows the direction of maximum radiation,

More common is the 4-element array shown in **Fig 15.85**. This arrangement uses four quarter-wave radiators, arranged in a quarter-wavelength square, the so called '4-square' array. This has a gain of up to 6dB with a front-to-back ratio of 20dB with a front-to-side of 10-15dB.

The elements are fed with equal currents in the following phase relationship.

Element 1	0 degrees
Element 2	90 degrees
Element 3,	180 degrees
Element 4	-90 degrees

The array fires diagonally across the square in the direction of element three, from element one to three as shown in Fig 15.85.

The disadvantage of the quarter wave 4-square is that it needs quite a bit of space. However there is nothing sacred about the quarter wave spacing. For example, providing that the current phase relationships are changed, satisfactory patterns can be obtained for spacings between 2.5 and 15m, corresponding to spacings of 1/16 to 3/8 wavelengths at 7MHz. The optimum phase difference lying between 160 degrees and 80 degrees respectively (for equal current amplitude).

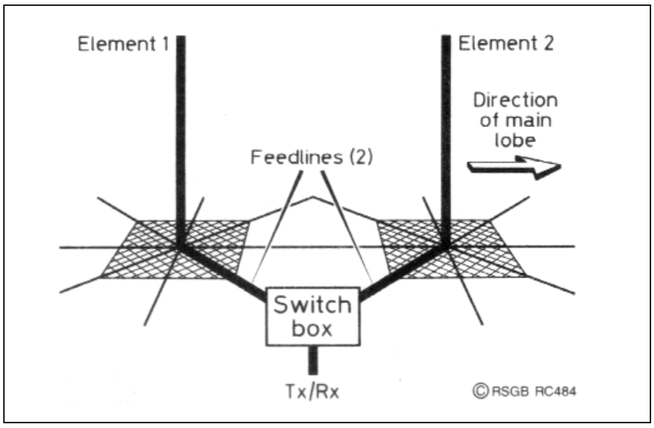


Fig 15.84 : A two-element array using quarter wavelength elements spaced quarter wavelength apart. With element 1 fed at 0 degrees and element 2 fed at 90 degrees the lobe is in line with the elements, and the arrow shows the direction of maximum radiation

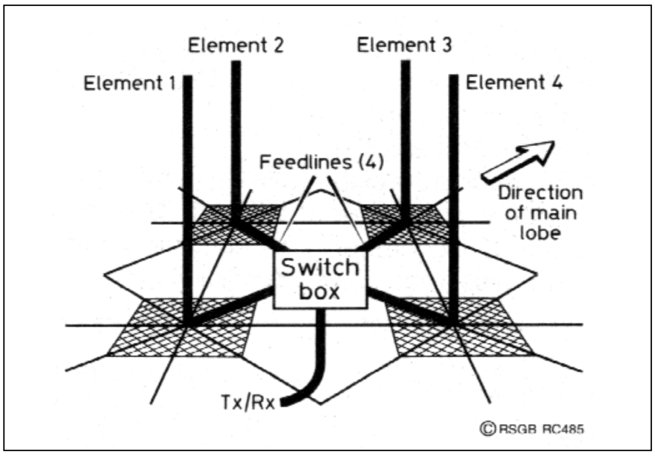


Fig 15.85: the '4-Square' array uses four quarter wave radiators, arranged in a quarter wavelength square. The elements are fed with equal currents in the following phase relationship: Element 1, 0 degrees; Element 2, 90 degrees; Element 3, 180 degrees, Element 4,-90 degrees. The array fires diagonally across the square, indicated by the arrow

G3HCT has developed an array for 7MHz using three elements, spaced only 1/8 wavelength (5.32m) apart [31]. This antenna system is capable of switching the beam in any one of six directions.

The disadvantage of closer spaced arrays is that they are more critical to set up, requiring accurate measurements of impedance. The 4-square can be set up using measurements of RF current and phase made with simple test equipment.

The performance of a phased array can more easily be achieved if all the elements in the array are identical in terms of length of element, earth system and feed impedance. Making a good earth system was described earlier in this chapter.

Further details of the phased vertical design and construction can be found at [32], [33] and [34].

FIXED LONG WIRE BEAM ANTENNAS

Generally, radio amateurs require a beam antenna that can be rotated so that it may be pointed to any position on the great circle map. Occasionally, however, a high gain fixed direction antenna can be useful for certain experimental work. An example of this was when the Narrow Band Television Association transmitted 40-line, mechanical scan, television pictures from

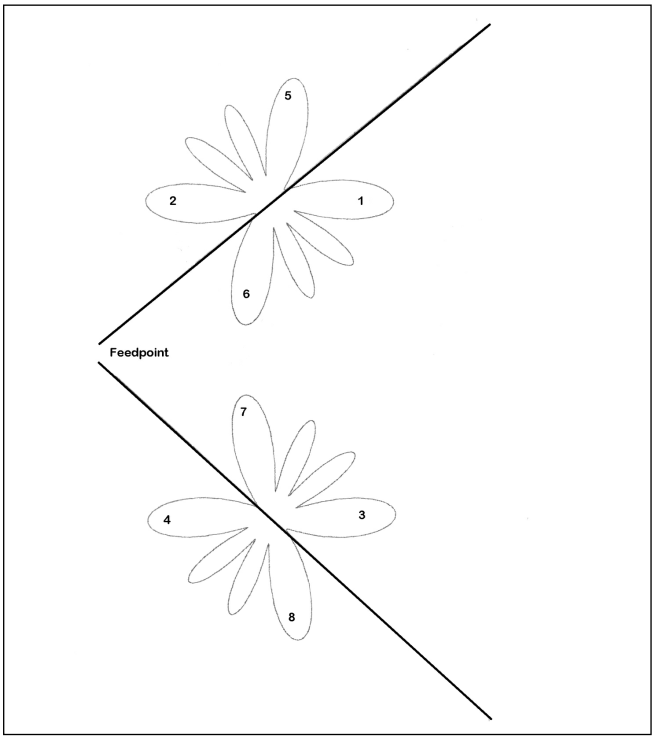


Fig 15.86: The azimuth polar diagrams of two wires, two wavelengths long, arranged in a V-beam configuration. Lobes 1, 2, 3 and 4 add in the direction of the bisector of the apex. All other lobes tend to cancel

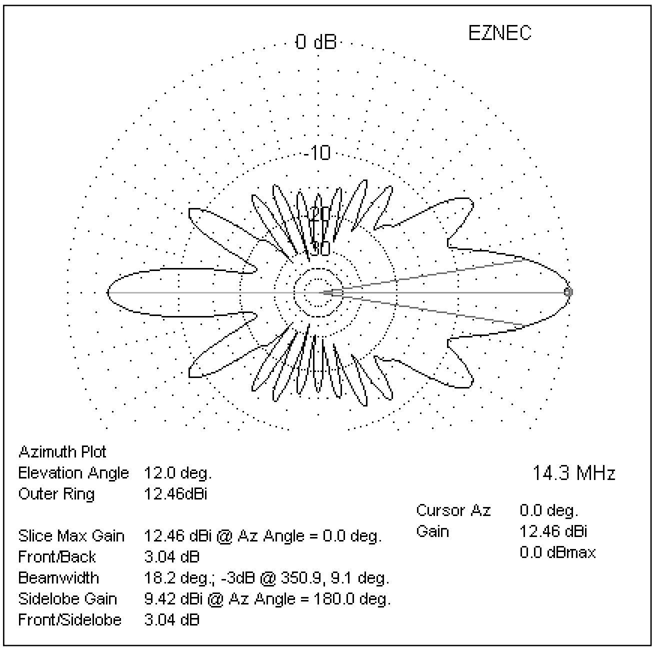


Fig 15.87: Prediction of the performance of the V-beam used by the Narrow Band Television Association (see text) using EZNEC4. The antenna is bi-directional because it is not terminated

Leg length Wavelength	Gain dBd	Apex Angle Degrees
1	3	108
2	4.5	70
3	5.5	57
4	6.5	47
5	7.5	43
6	8.5	37
7	9.3	34
8	10	32

Table 15.12: V-beam gain and apex angles for given lengths of element

Amberley museum in Sussex across the Atlantic to the USA in 2003. This was done to commemorate the Baird transmission on the 8th and 9th February 1928. A fairly high ERP was required to ensure the TV signals would get through so a high gain antenna was required.

The antenna used was a V-beam. This provides a combination of low cost, good gain bandwidth product, electrical and mechanical simplicity and ease of design and construction. The downside is that fixed wire beams need a great deal of space.

V-Beams

The V-beam consists of two wires made in the form of a V and fed at the apex with twin wire feeder, as shown in **Fig 15.86**. A long-wire antenna, two wavelengths long and fed at the end, has four lobes of maximum radiation at an angle of 36 degrees to the wire. If two such antennas are erected horizontally in the form of a V with an included angle of 72 degrees, and if the phasing between them is correct, lobes 1, 2, 3 and 4 add in the direction of the bisector of the apex. All other lobes tend to cancel. The result is a pronounced bi-directional beam as shown in **Fig 15.87**.

The directivity and gain of V-beams depend on the length of the legs and the angle at the apex of the V. This is likely to be the limiting factor in most amateur installations, and this is the first point to be considered in designing a V-beam. The correct angle and the gain to be expected in the most favourable direction is given in **Table 15.12**.

A practical V-beam capable of producing bi-directional high gain on the higher frequency bands (14 to 29MHz) is shown in **Fig 15.88**. V-beams are often constructed so that the apex is placed as high as possible with the ends close to the ground. This arrangement means that only one mast is required for the installation and, if space is available, several V-beams pointing in different directions could use a common support.

The V-beam so far discussed is known as resonant. The input impedance of this antenna may rise to 2000 ohms in a short V, but will be between 800 and 1000 ohms in a longer antenna. Therefore, 400 to 600ohm feed lines can be used, matched to the transceiver with a suitable balanced ATU.

The V-beam can be made unidirectional if it is terminated with resistors inserted approximately a quarter wavelength from the ends of the elements, so that final quarter-wavelengths act as artificial earths. A suitable value of resistor would be 500 ohms for each leg. Termination resistors have the effect of absorbing lobes 2, 4, 6 and 7 in Fig 15.85 and the elements become travelling wave devices.

The Narrow Band Television Association antenna was 33m high at the apex and 3m high at the ends, with the apex being supported by a tree on top of a 33m high cliff.

The Rhombic

The rhombic antenna is a V-beam with a second V added, see **Fig 15.89(a)**. The same lobe addition principle is used but there is an additional complication because the lobes from the front and rear halves must also add in phase at the required elevation angle. This introduces an extra degree of control in the design so that considerable variation of pattern can be obtained by choosing various apex angles and heights above ground.

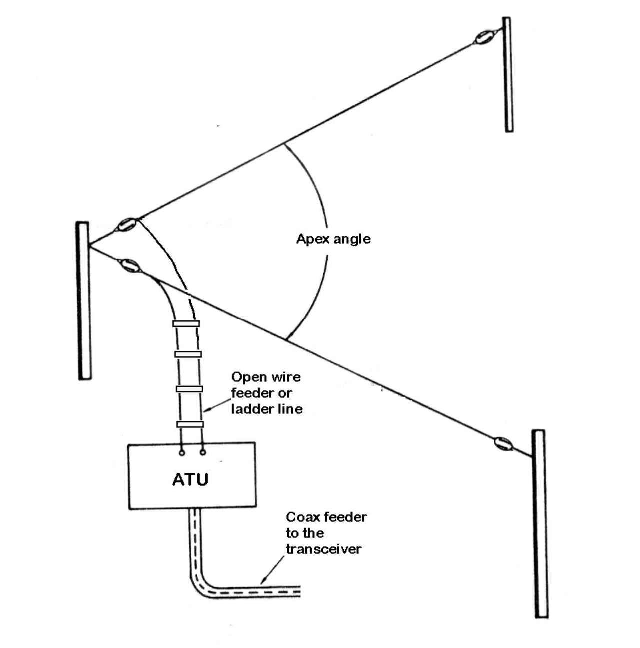


Fig 15.89: A practical resonant V-beam for the HF bands 14 to 29MHz. Ideally a balanced line ATU should be used to ensure an equal current level in each element

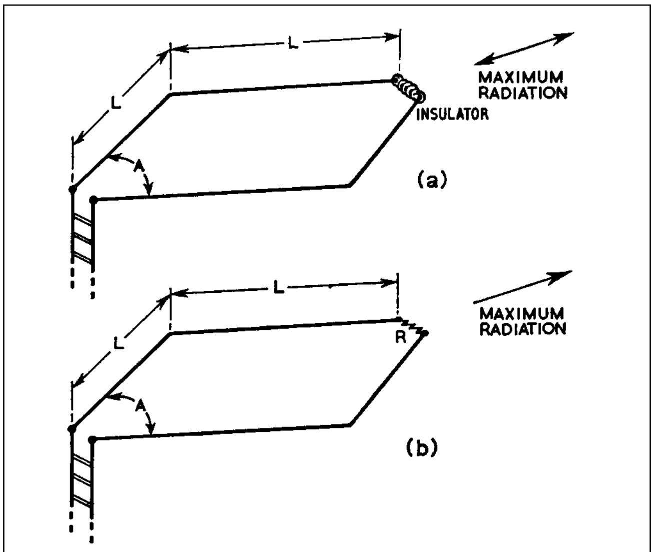


Fig 15.90: The Rhombic antenna. (a) shows the resonant unterminated version, (b) the terminated version

The rhombic gives an increased gain but takes up a lot of room and requires at least one extra support. As with the V-beam, the resonant rhombic has a bidirectional pattern, and the terminated rhombic, shown in **Fig 15.90(b)**, an unidirectional one. The terminating resistance absorbs noise and interference coming from the rear direction as well as transmitter power, which would otherwise be radiated backwards. This means that it improves signal-to-noise ratio by up to 3dB without affecting signals transmitted in the wanted direction.

The use of tuned feeders enables the rhombic, like the V-beam, to be used on several amateur bands. The non-resonant rhombic differs from the resonant type in being terminated at the far end by a non-inductive resistor comparable in value with the characteristic impedance, the optimum value being influenced by energy loss through radiation as the wave travels outwards. An average termination will have a value of approximately 800 ohms. It is essential that the terminating resistor be as near a pure resistance as possible, ie without inductance or capacitance - this rules out the use of wire-wound resistors. The power rating of the terminating resistor should not be less than one-third of the mean power input to the antenna. For medium powers, suitable loads can be assembled from series or parallel combinations of say, 5 ohm carbon resistors. The terminating resistor may be mounted at the extreme ends of the rhombic at the top of the supporting mast. Alternatively the resistor may be located near ground level and connected to the extreme ends of the rhombic via twin wire feeder.

The impedance at the feed point of a terminated rhombic is 700-800 ohms and a suitable feeder to match this can be made up of 16SWG wire spaced 300mm (12in) apart. The design of rhombic antennas can be based on Table 15.12, considering them to be two V-beams joined at the free ends.

The design of V and rhombic antennas is quite flexible and both types will work over a 2:1 frequency range or even more, provided the legs are at least two wavelengths at the lowest frequency. For such wide-band use the angle is chosen to suit the element length at the mid-range frequency.

Generally the beamwidth and wave angle increase at the lower frequency and decrease at the upper frequency, even though the apex angle is not quite optimum over the whole range. In general, leg lengths exceeding 10 wavelengths are impractical because the beam is then too narrow.

Advantages of the rhombic over a V-beam are that it gives about 1-2dB greater gain for the same total wire length and its directional pattern is less dependent on frequency. It also requires less space and is easier to terminate. The disadvantage is that it requires four masts.

MOBILE ANTENNAS

The antenna is the key to successful mobile operation. Because of shape of the vehicle, space limitations and the slipstream caused by the vehicle motion the vertical whip antenna is the most popular mobile antenna, regardless of the band in use. The easiest way to feed such an antenna is to make it a quarter wavelength long at the frequency in use. The resonant quarter-wavelength is a function of frequency and is 1.48m (58.5in) on 50MHz and 2.5m (8ft 2in) on 28.4MHz and progressively shorter on the higher VHF bands. Quarter wave antennas on the 28MHz bands and higher are quite practical, but on the lower HF bands it is a different matter. Even on 21MHz a quarter wavelength is 3.45m (11ft 2in) and on 14MHz is 4.99m (16ft 4in).

It follows that a practical antenna for the HF bands will be shorter than a quarter wave long. For a given antenna length, as the frequency of operation is lowered the feedpoint exhibits a decreasing resistance in series with an increasing capacitive reactance. In order to feed power to such an antenna it must be brought to resonance so that the feed point is resistive. This is achieved by adding some inductance, and is known as inductive loading.

A loading coil for a mobile antenna must be rugged to stand up to weather and the mechanical strain of a fast moving vehicle slip stream. The following represents a suitable solution.

The G3MPO Coil and Antenna

This design uses a single antenna structure with a different coil for each band. This coil was produced using workshop facilities little more than a Workmate, electric drill, and taper taps and dies. According to G3MPO, in several thousand miles of motoring this design has proved completely secure. Full use was made of a local plumber's stockist's supply of ready-made brass, stainless steel and plastic bits and pieces. 15mm plumber's brass compression couplers were selected as both coil terminations and the means of fixing them into the antenna. The construction of the antenna and coils is shown in **Figs 15.90 and 15.91**.

Because the fittings and the antenna material are an integral part of the design these are described as well as the coil. The bottom section of the antenna is made from a length of 15mm stainless steel central heating tubing.

White polypropylene waste pipe proved a good choice for a coil former. The thread of the brass 15mm compression couplers can be screwed (with some difficulty) into the end of the 20mm (0.75in) version of this tubing to make a very strong joint. The ends of the tube can be pre-heated in hot water if necessary. Even better, a 12.5mm (0.5in) BSP taper tap can be used to cut a starting thread in the tubing. A second coupler screwed into the other end gives an excellent coil former with ready-made 15mm connections at each end, which fit and clamp directly onto the 15mm diameter lower mast section.

Varying lengths of former are used for the higher frequency coils, and where a greater diameter is needed for the lower frequencies, the same 20mm (0.75in) former is used as a spine. This runs up the middle of a larger diameter tube to which it is attached by packing the space between them at each end with postage stamp size pieces of car-repair glass mat soaked in resin. The coil assembly can then be waterproofed with a silicone rubber sealant.

The whip above the coil former comprises a short length of small diameter tube, fixed to the top of the coil with a 15mm coil coupler. A length of stainless steel whip is slid inside this tubing. Suitable tubing can be obtained from a car accessories shop in the form of copper brake tubing, which comes in outside diameter sizes from 8mm down. A nice sliding fit to the 2.5mm diameter whip was provided by a 230mm (9in) length of 8mm diameter pipe, with one end plugged by short lengths of the next two sizes down and soldered into position.

Some sort of quick release lock is required to hold the whip in position once its length is set. This is achieved by cutting a thread on the last 12mm of the end piece of tubing with a thread-cutting die and making cross cuts down its length with a mini-hacksaw.

A matching nut with a tapered thread can be made from a short length of brass rod, drilled and taper-tapped so that it would close the tube down on to the end whip as it is screwed on; thus locking it. The whip structure was completed by connecting the telescopic section onto the coil using a 15mm-to-8mm (microbore) brass reducer and a 51mm (2in) length of 15mm tubing, as shown in Fig 15..90.

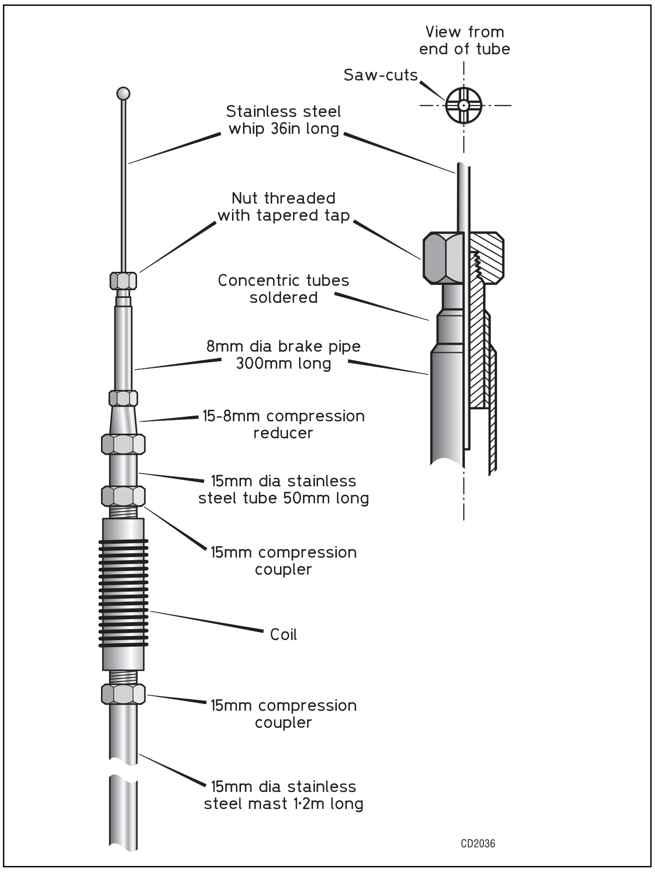


Fig 15.90: (a) Section of the G3MPO mobile antenna. (b) detail of stainless steel whip / 8mm diameter brake pipe clamp

The best method of attaching the wire to the end couplers is to drill two small holes through the polypropylene just beyond where the end of the coil would lie, and pass the wire into the tube and out through the coupler to which it is then connected. It was found best to solder a hairpin of wire onto the inside of the coupler before fitting it into the plastic former. The coil wire was then easily soldered onto this pigtail at the appropriate time.

Two or three lengths of double-sided tape are then stuck to the coil former. A sufficient length of enamelled copper wire is cut for the coil in question. Seven times the number of turns, times the diameter of former (from **Table 15.13**) allows enough

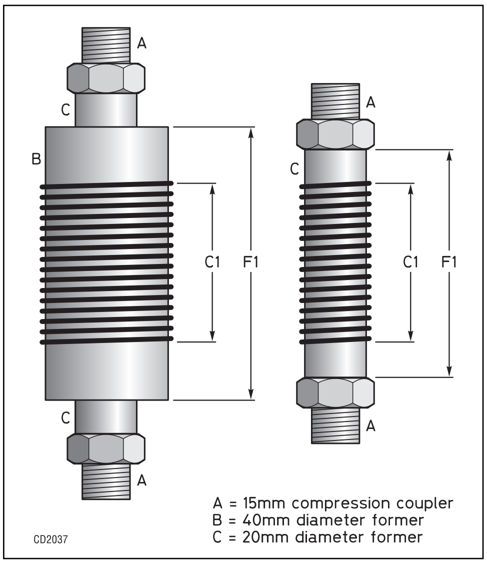


Fig 15.91: Coil former construction and dimensions of G3MPO antenna. F1 is the coil former length and C1 the coil winding length, see Table 15.13

COIL DATA

F MHz	D mm	Fl mm	Wire SWG	N	Cl mm	L µH	Rr ohms	Rf ohms
29.0	20	77	18	9	28	0.9	35	48
24.9	20	90	18	15	44	1.7	29	48
21.2	20	115	18	23	64	3.0	22	47
18.1	20	140	18	34	92	4.5	17	43
14.25	20	146	20	45	96	8.4	11	34
10.13	40	115	20	31	72	19	6	26
7.05	40	165	20	58	117	41	3	20
3.65	40	305	22	130	157	153	0.8	21
1.9	40	280	28	294	236?	558	0.2	37

Table 15.13: Read in conjunction with Fig 15.92. F = frequency (MHz), D = coil former diameter (mm), Fl = Length of coil former tube (mm), N = number of turns, Cl = Length of coil winding (mm), L = coil inductance (microhenries), Rr = Theoretical radiation resistance (ohms)

Fig 15.92: Detail of the tuning section of the 'screwdriver' antenna, which shows the coil and fingers that short the turns as it emerges. This photo, courtesy of Waters and Stanton, is of the WBB-3 derivative, see text

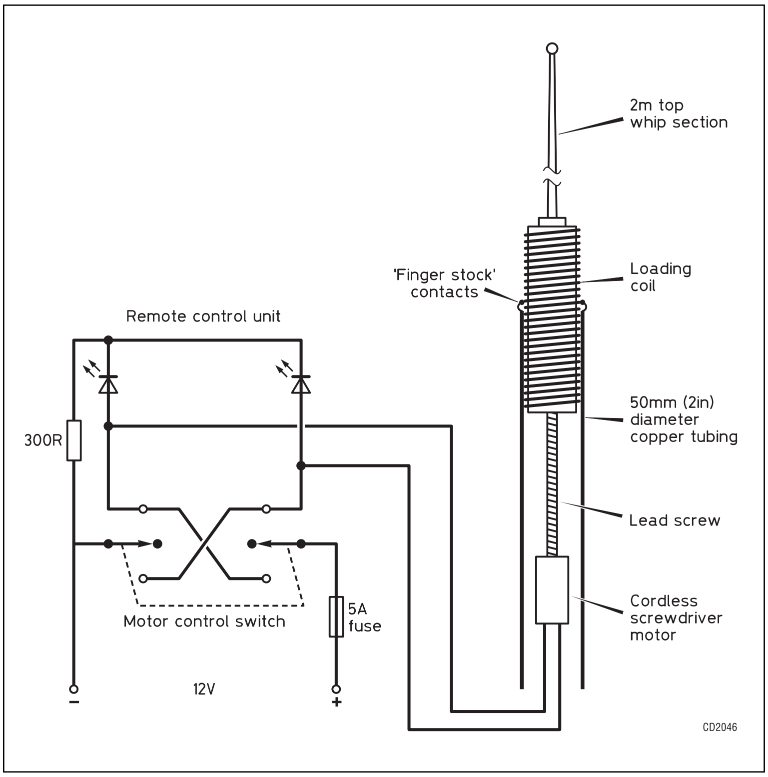


Fig 15.93: W6AAQ's DK3 mobile antenna (not to scale). The control box is located by the driver and power obtained from either the rig supply or the cigar lighter socket. The original had relay switched capacitors, selected from the drivers control box, to match the antenna on the lower frequencies

to wind the coil with some to spare. The wire spacing is achieved by winding two lengths of wire onto the former side by side and subsequently removing one of them. The double-sided tape fixed to the former holds the remaining winding in position. 10 to 12mm of wire is wound beyond the holes through which the wire endings were taken and, after removing the spacing wire, the winding is coated with polyurethane varnish. When dry, the coil is wound back at each end until the required number of turns are obtained; the ends fed through into the former, out through the end couplings and soldered to the coupling hairpins. The two small holes in the former can be sealed with varnish or mastic and the winding bound with a double layer of self-amalgamating tape.

Soldered connections are pushed well down into the coupling, out of the way, and the coil given two coats of polyurethane varnish. The self amalgamating tape can be omitted if you prefer the appearance of varnished copper coils, but it is easy to use and provides additional protection against knocks and bangs.

The W6AAQ Continuous Coverage HF Mobile Antenna

In this design the antenna resonance is adjusted from the drivers/operator's position using a cordless screwdriver electric motor.

This motor rotates a brass leadscrew via a nut fixed to the coil to cause the coil to move up or down inside in 1m (3ft) long 50mm diameter aluminium, brass or copper tube as shown in **Fig 15.92**. As the motor is rotated the coil is raised or lowered so that more or less of the coil is contained within the lower tube section. Finger stock connectors are used to short the coil to the tube to obtain the appropriate resonance. A circuit of the antenna and the control box is shown in **Fig 15.93**.

The antenna is tuned to resonance, first by listening for an increase in receiver noise, then applying transmit power and fine-tuning for the lowest SWR.

Frequency (MHz)	1.8	3.6	7.05	10	14.2	18	21.3	25	28.5
R_{rad}	0.2	0.8	3	6	12	17	21	28	36

Table 15.14: Radiation resistance (R_{rad}) of a typical mobile antenna

Matching a Mobile Antenna to the Feeder

All the antennas so far discussed are fed with 50-ohm coaxial cable; normally the centre is connected to the antenna and the braid to the vehicle body. However the radiation resistance of the antenna will generally be lower than 50 ohms and, for a given antenna size, it depends on frequency. Typical radiation resistance figures for a 2.4m (8ft) antenna are shown in **Table 15.14**:

In practice, the feed impedance will include the RF resistance of the loading coil and the resistance losses. The loss resistance, taken in total, is usually much greater than the radiation resistance, at the lower operating frequencies.

For example, the radiation resistance of an 80m antenna is around one ohm and the loading coil resistance may be around 10 ohms. The ground loss will be between 4 and 12 ohms, depending on the size of the vehicle, so the feed impedance could be in the region of 20 ohms.

This will give an SWR of 2.5:1 at resonance, which gets progressively worse very quickly as the transceiver is tuned off the antenna resonance, clearly beyond the impedance range of a modern solid state transceiver 50 ohm PA (unless it has a built-in ATU).

At the other end of the HF spectrum the radiation resistance is much higher and even though the coil losses are lower, a transceiver can be connected directly to the antenna via a length of 50-ohm coax.

There are several ways of matching the nominal 50-ohm transceiver output to the impedance encountered at the base of a resonant mobile antenna. Of these the most common are:

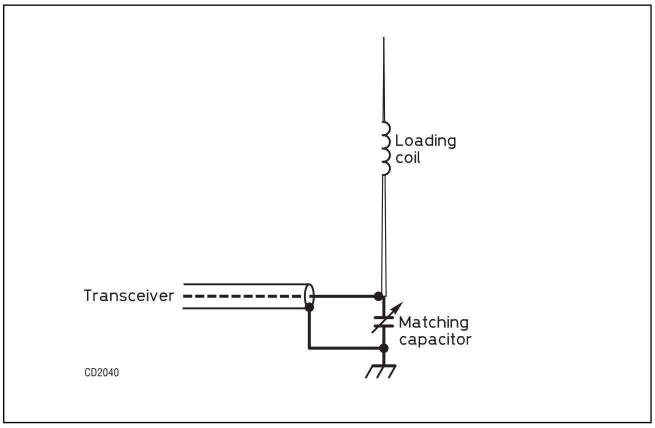


Fig 15.94: Capacitor matching. In practice the variation in capacity is achieved by switching in appropriate values of fixed capacitor

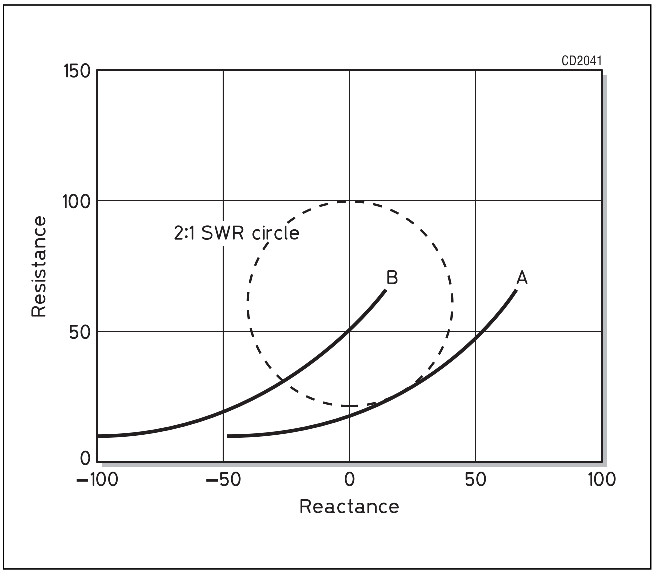


Fig 15.95: Curve A; feed impedance of an 80 metre mobile antenna in the frequency range 3.55 to 3.65MHz. On no part of the curve is the standing wave ratio better that 2:1. An improved match is achieved by increasing the inductance of the loading coil slightly, and compensating with a capacitor across the feedpoint, thereby moving the curve to B

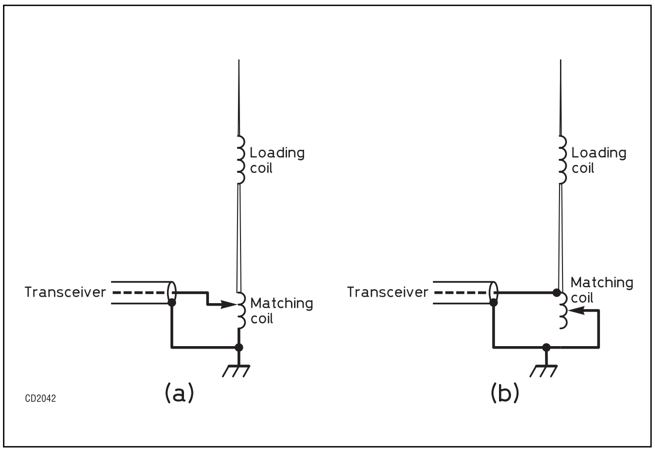


Fig 15.96: Two methods of using a tapped inductance for matching at the base of the antenna

1. Capacitive shunt feeding. This is simply the addition of a shunt capacitor directly across the antenna feedpoint as shown in Fig 15.94. Capacitor values calculated by G3MPO are shown in Table 15.15:

Exact values can be determined experimentally and will need to be switched for multiband operation.

The way that this works can be seen by referring to Fig 15.95. The curve A represents the feed impedance of a Pro Am antenna in the frequency range 3.55 to 3.65MHz, measured using the 3-m impedance box [7]. At the lower frequency the impedance is about R10-50jX, while at the higher frequency it is R70+70jX. On no part of the curve is the SWR better that 2:1. By increasing the inductance of the loading coil slightly and compensating with a capacitor across the feedpoint, the curve can be shifted to B to achieve an improved match

2. Inductive shunt feeding. This is achieved with the addition of a small tapped inductance at the base of the antenna. With the loading coil adjusted to take into account the effect of the base coil the antenna base impedance is raised in proportion to the size of the base inductance. There are two ways that this method of feeding can be implemented.

Selecting an inductor that results in a value greater than 50 ohms at the lowest point of the antenna impedance/frequency curve. The transceiver connection is then tapped down the base inductance to obtain the best match as shown in Fig 15.96(a).

Using a variable inductance across the feedpoint as shown in Fig 15.96(b). The inductance value or tapping point must be changed when the frequency band is changed.

3. Transformer matching. This arrangement uses a conventional RF transformer wound on a toroid core as shown in Fig 15.97. A commercial or home-brew matching transformer can be used. The one described is designed by G3TSO and uses toroid cores such as the Amidon T 157-2. It is wound with 20 bifilar turns using 18SWG (1 2mm) wire. Both windings are connected in series, in phase, and the second winding is tapped every other turn as shown in Fig 15.98. With the loading coil adjusted to take into account the inductance of the transformer windings, antenna impedances from 50 ohms down to 12 ohms can be matched.

The matching arrangements shown can be located part way between the transceiver and the antenna. As stated earlier, the

F, MHz	29	24.9	21.2	18.1	14.25	10.13	7.05	3.65	1.9
pF	18	27	37	74	150	300	544	1000	1000

Table 15.15: Values for capactive shunt feeding of a mobile antenna

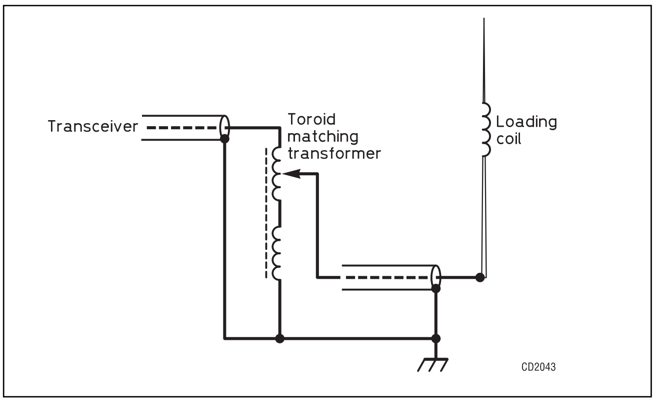


Fig 15.97: Matching arrangement for a mobile antenna using a variable ratio RF transformer

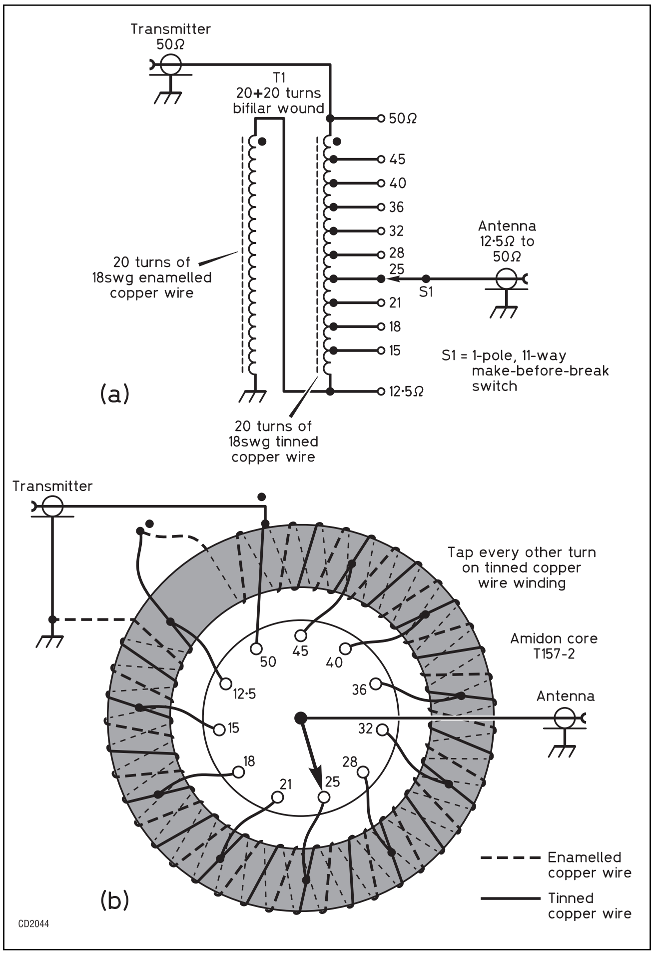


Fig 15.98: Details of the G3TSO RF transformer. (a) The circuit and impedance matching range. (b) Constructional details

feed impedance comprises the radiation resistance, earth resistance and coil resistance in series, which means that, in practice, the transceiver can be connected directly to the antenna without any matching at frequencies 14MHz and above. On the lower frequency bands the coax feeder is so electrically short in a mobile installation that losses caused by a higher SWR are minimal. If the matching arrangement can be adjusted from the driver's seat then this represents a greater degree of operator convenience that if it were located at the base of the antenna.

Further Mobile Antenna Information

Details of mobile antenna construction, mounting and matching can be found in *The Amateur Radio Mobile Handbook*, RSGB [37].

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