17 Practical Microwave Antennas

The big advantage that microwave antennas have over those used for other amateur bands is that they are relatively small. We can let our imagination loose and have antennas with gains that are not achievable elsewhere and mount them at heights, in wavelengths, that users of the lower frequency bands can only dream of.

This chapter has been organised by type of antenna rather than by band usage, the types being:

- **Patch antennas:** These are easily constructed because they are etched onto printed circuit board. They are small and have found lots of applications in commercial electronics such as mobile phones, cordless phones and local area networks. If you need a small antenna, the patch may suit your needs.
- **Slot antennas:** These are omni directional and can be used for repeaters or mobile use.
- **Helical antennas:** The big advantage of the helical antenna is that it is circularly polarised. This has made it widely used for satellite operation.
- **Yagi antennas:** The Yagi is probably the best known antenna. With the reduced element size on the microwave bands some impressive gains can be achieved.
- **Horn antennas:** As the frequency increases, the horn antenna comes into its own at 10GHz and above.

PATCH ANTENNA

Antenna for 5.8GHz

This design was produced by Gunthard Kraus, DG8GB as a practical project to design a patch antenna for 5.8GHz [1].

The techniques described here can be used to design patch antennas for any of the lower amateur microwave bands, ie 23cm to 3cm. The main design work uses PUFF CAD software, this is will run on a wide range of PCs running DOS to Windows XP, the use of the software is described in much more detail in the reference material [1], [2].

The patch antenna was developed for the 5.8GHz ISM (Industrial, Scientific and Medical) band for monitoring video feeds two floors away in the new Tettnanger Electronic Museum in Germany. Since no holes could be bored and no slots could be cut out for cables in the historic museum building, the designers simply used the wall of the house opposite as the reflector for the 5.8GHz signal; the patch antenna was aligned with it. The 5.8GHz ISM band contains 16 channels at 9MHz intervals. between 5732MHz and 5867MHz.

The antenna thus has to display a self-resonant frequency of 5800MHz and a bandwidth of approximately 140MHz (2.4%). The input resistance should be 50 ohms, with a semi-rigid cable having a soldered SMA plug. The circuit board is made from Rogers R04003, which is a very stable material from the mechanical point of view and is easy to machine. It should have the following specification:

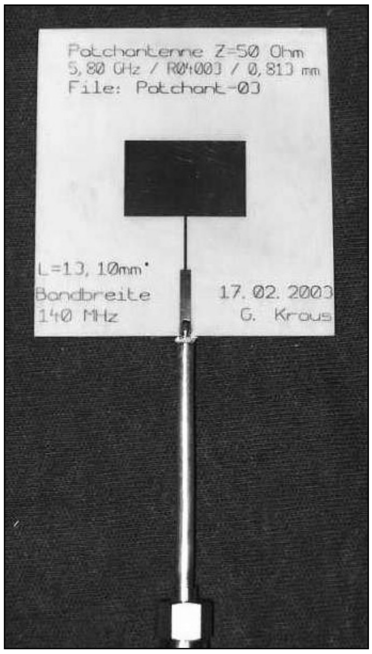

Fig 17.1: The finished patch antenna for 5.8GHz

- ε_r = 3.38
- Printed circuit board thickness = 32mil (0.813mm)
- Dielectric loss factor = 0.001
- Copper coating = 35µm

A $\lambda/4$ line transforms the antenna radiation resistance to the required 50 ohms. The circuit board size should be 50mm x 50mm and a short 50-ohm microstrip is needed from the transformation line to the cable connection on the circuit board. This can be seen clearly in the photograph of the finished product in **Fig 17.1**.

Design Procedure

The basic procedure can be found in an article on the subject from *VHF Communications* [2], [3].

After a little experimenting with the *patch16* program (available from the Internet [4]), an initial design was produced with a

```
These are the design parameters:

 Length (L) =  .5271  inches
 Width (W) =  .8  inches
 Height (H) =  .032  inches
 Dielectric Constant (D) =  3.38
 Loss Tangent (T) =  .001
 Feedpoint Distance (F) =  0  inches

 Do you wish to edit any value? (Y/N):
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Fig 17.2: The input parameters for *Patch 16*

```
The Resonant Frequency is   5.800 GHz
Qo is  26.0

The Edge Radiation Resistance is  142.42 ohms
Zc of Quarter-wave transformer is  84.4 ohms
Approx. width of the Quarter-wave transformer is 0.028 inches
Length of Quarter-wave transformer is 0.321 inches at the Resonant Freq.

Input Resistance at probe location is 142.42 ohms

The 2:1 VSWR Bandwidth is  2.9%
Upper Frequency Limit =  5.883 GHz
Lower Frequency Limit =  5.716 GHz


Press 'ENTER' to continue:
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Fig 17.3: Simulation results for the patch antenna

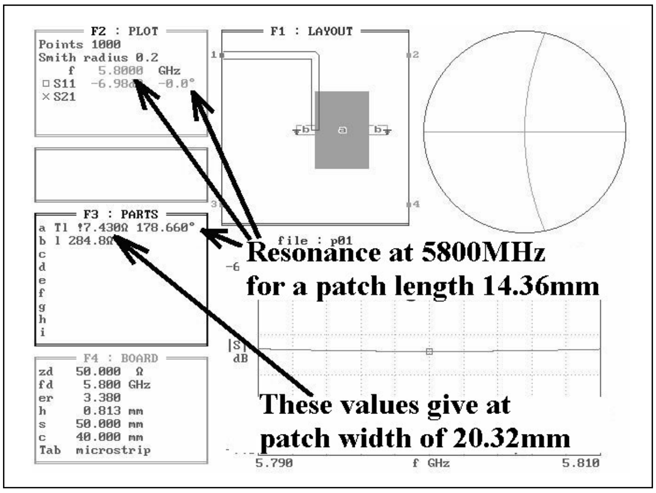


Fig 17.4: Simulation of the patch antenna using *PUFF*

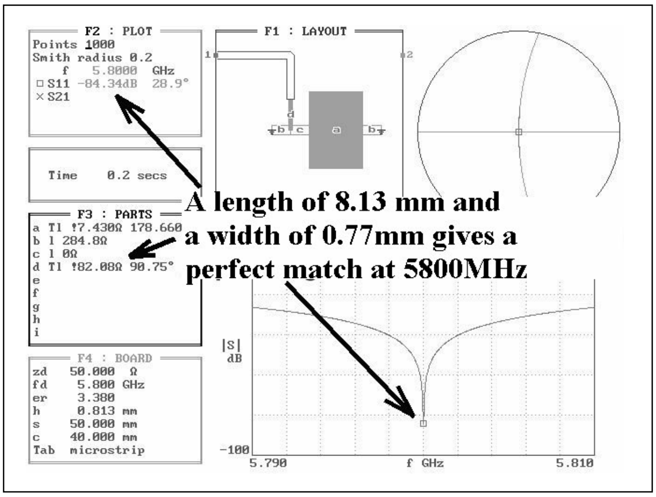


Fig 17.5: Using a quarter-wave transmission line, the input resistance is matched to 50Ω

centre frequency of exactly 5800MHz, while the bandwidth was deliberately increased to 2.9%.

The input and calculated characteristics of the antenna can be seen in **Figs 17.2 and 17.3**. The values required for the subsequent work using *PUFF* [5] must first be converted from inches into millimetres:

- Patch width = 20.32mm
- Patch length = 13.39mm
- Total radiation resistance = 142.4Ω, which gives 284.8Ω on each patch edge.

A text editor is needed to open the setup file of *PUFF21*, and to enter the R04003 material and circuit board data. *PUFF* is started up (work with the protected mode version by loading *puffp.exe*) and the patch is modelled as a large width, lossy transmission line. The two radiation resistances are positioned on the two patch edges and the centre frequency is set at 5.8GHz.

First, delete the exclamation mark after the entry "TL" in field F3, and experiment with the characteristic impedance of the line until (once the equals sign has been entered) a width of w = 20.32mm is set.

Now replace the exclamation mark, and vary the electrical length of the line until the configuration is as near as possible to resonance. This situation can easily be recognised, since then the phase angle of S11 is exactly zero degrees. Remember to select a swept frequency range as small as possible, and also try to obtain the highest possible resolution for the amplitude range for |S11|. The process is clarified in **Fig 17.4**, which immediately supplies the required data. For a patch width of 20.32mm, a microstrip line is needed with a characteristic impedance of 7.43Ω at low frequencies. A mechanical length of 14.36mm has an electrical length of $\lambda/2$ at 5.8GHz.

Note: If you're surprised by the big difference between this length value of 14.36mm and the *patch16* suggestion of L = 13.39mm, the following will clear up the mystery. First the patch has to be shortened by the open-end extension on both sides. More on this subject later, but the result can be given in advance: it is 0.41mm on each side. But this only reduces the length to 14.36mm - 2 x 0.41mm = 13.53mm. The difference is provided by something discovered by chance in the specialist literature: ". . . . the difference between the patch resonance and the electrical length for the corresponding $\lambda/2$ microstrip is about 1 % . . .". Thus 0.99 x 13.53mm = 13.40mm.

Using a $\lambda/4$ transformation line, the input resistance of the configuration must be brought to precisely 50Ω. In **Fig 17.5**, this has already happened, and the required data are:

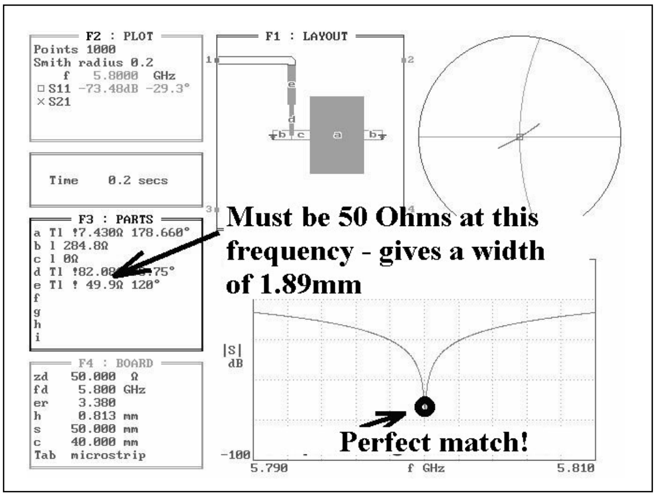


Fig 17.6: Matching patch antenna to 50Ω

- Line length = 8.18mm
- Line width = 0.765mm

Providing the configuration with a 50-ohm feed (required length about 11mm up to the edge of the board), is shown in **Fig 17.6**. From this, the width of the feed can be determined (once again, after removing the exclamation mark after "TL" and pressing the equals sign) at w = 1.89mm. First, the open-end extensions for the microstrip line must be determined. The quickest way is still to use the appropriate diagram from the *PUFF* manual. **Fig 17.7** shows the necessary procedure and also supplies the raw data required:

- For a patch with Z = 7.4Ω use 51% of the board thickness of 0.813mm = 0.42mm
- For the 50Ω feed, use 45% of the board thickness of 0.813mm = 0.37mm

Since the transformation line displays the highest characteristic impedance and thus the smallest width, it must be extended by the following amounts at both ends (the correction formulas can be found on the same page in the *PUFF* manual):

For the patch side, the result is:

$$\Delta L = \left(1 - \frac{w2}{w1}\right) \cdot 0.42 = \left(1 - \frac{0.77}{20.32}\right) \cdot 0.42 = 0.41\text{mm}$$

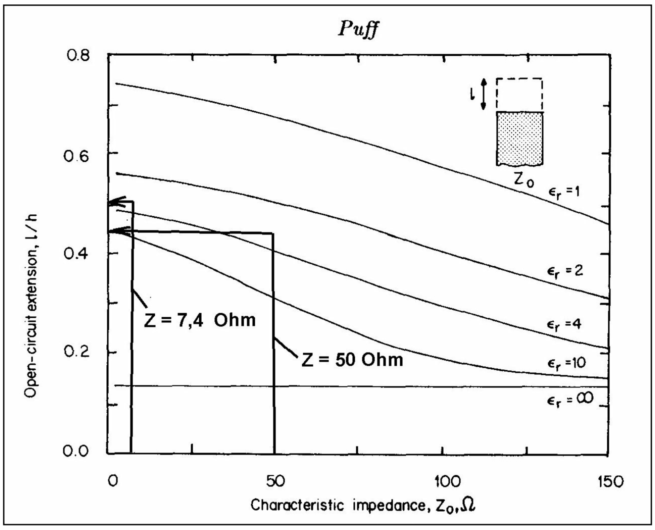


Fig 17.7: Determining the open end extension using the graph published in the *PUFF* manual

For the feed side, the result is:

$$\Delta L = \left(1 - \frac{w2}{w1}\right) \cdot 0.37 = \left(1 - \frac{0.77}{1.89}\right) \cdot 0.37 = 0.22\text{mm}$$

So for the transformation line, the requirements are a length of 8.18mm + 0.41mm + 0.22mm = 8.81mm, and a width of 0.77mm. The best way to work on the patch is to use the length supplied by the *Patch16* program, ie 13.39mm, with a patch width of 20.32mm.

Using a printed circuit board CAD program, centre the patch on the selected circuit board (dimensions 50mm x 50mm), add the transformation line, and finally connect the feed line, with a width of 1.89mm, up to the board edge as in Fig 17.1.

Now the semi-rigid cable, with an SMA plug, must be connected to the circuit board with the minimum of electrical irregularities as shown in **Fig 17.8**: The method is as follows:

- First, saw off the cable and carefully file the end flat at an angle. Do not forget to trim it.
- Using a fine saw (eg a jig saw), make a cut parallel to the cable and a few millimetres long, precisely following the inner conductor.
- Carefully cut perpendicular to the cable to expose the inner conductor completely and remove the internal Teflon insulation.
- Push the circuit board into this cut solder the inner conductor to the 50Ω microstrip feed line. Carefully solder the remainder of the cable sheathing to the underside.

An investigation of the antenna using an HP8410 network analyser, HP5245L microwave counter and an HP5257 transfer oscillator, gave the resonance at 5690MHz, with a value of |S11| = -16dB.

A more precise examination, using a polar display, showed that the input resistance here exceeds the system resistance of 50 ohms and consequently the radiation resistance must have a higher value. These findings were immediately converted into a *PUFF* simulation, and it became clear that in reality a resistance of 407.5 ohms should be assumed on each patch edge (**Fig 17.9**).

The patch length required for 5890MHz should be displayed immediately in the F3 parts list - it amounts to L = 14.65mm. Now, in the F4 field, simply change the design frequency to the required 5800MHz, thus once again simulating the patch reso-

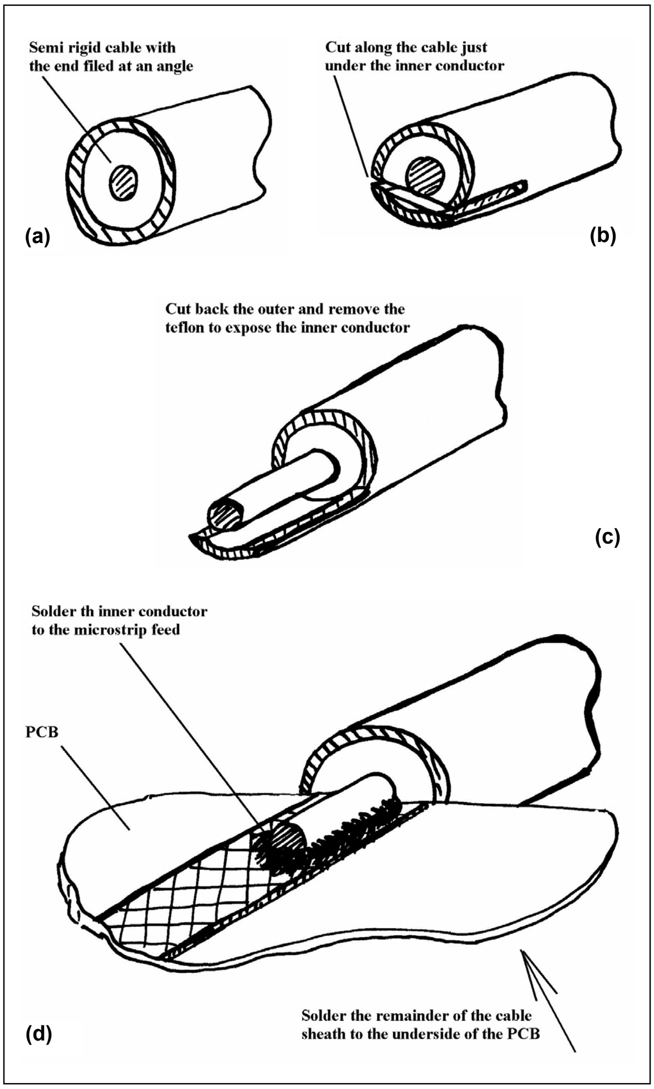


Fig 17.8: Details of how to fit the semi-rigid feeder. (8a) Semi rigid cable with the end filed at an angle. (8b) Cut along the cable just under the inner conductor. (8c) Cut back the outer and remove the teflon to expose the inner conductor. (8d) Solder the inner conductor to the microstrip feed and the cable sheath to the underside of the PCB

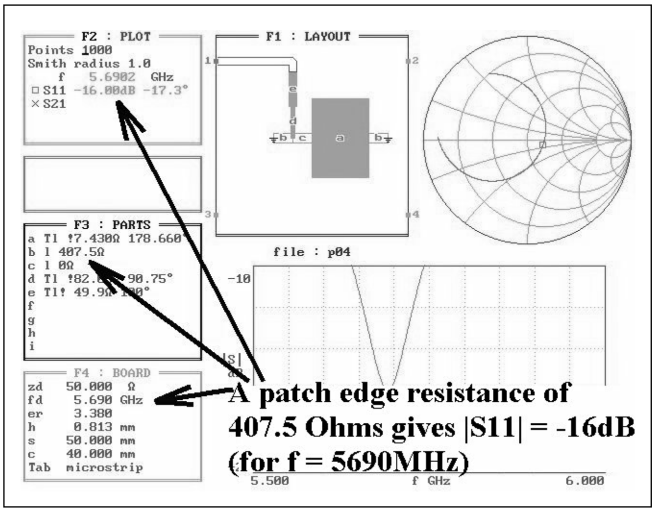


Fig 17.9: *PUFF* simulation showing the patch edge resistance of 407.5Ω and |S11| of -16dB

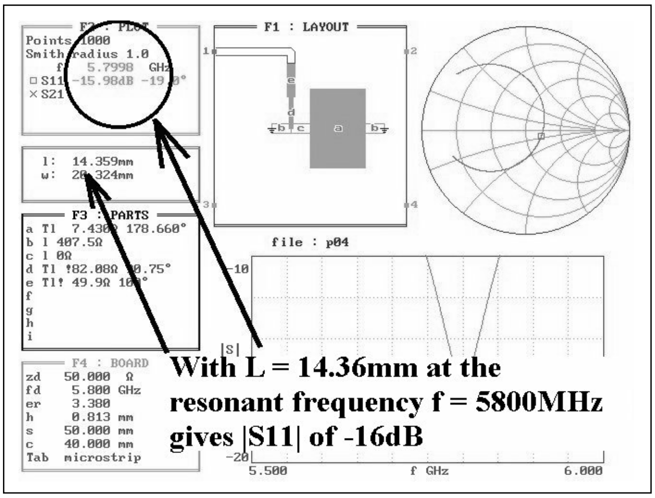


Fig 17.10: Changing the design frequency to 5800MHz gives a length of 14.36mm

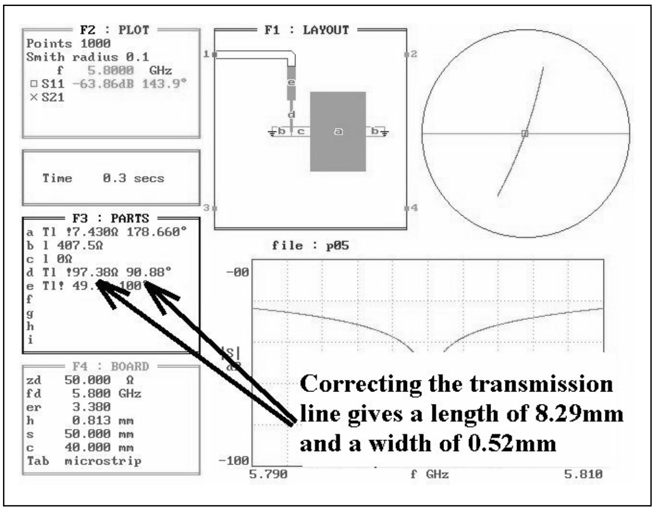


Fig 17.11: Correcting the matching transformer

nance at this frequency. It can be seen from **Fig 17.10** that for this the length must be reduced to 14.36mm - consequently, shortened by 0.29mm! Thus, in the printed circuit board CAD system, the length used for the initial design of 13.39mm is reduced to 13.39mm - 0.29mm = 13.1mm. The patch width, naturally, remains at 20.32mm.

All that remains is the final change - correcting the $\lambda/4$ transformation line to obtain better values for the matching of the measured - 16dB. This is also a very easy matter for *PUFF*, and the result can be seen in **Fig 17.11**. The new values required are: length = 8.29mm and width = 0.52mm. The required open-end extension for each side must be added to this. For the patch connection, the value of 0.41mm used previously is still valid, but something is altered on the feed side:

$$\Delta L = \left(1 - \frac{0.52}{1.89}\right) \text{x } 0.37 = 0.27\text{mm}$$

The transformation line, therefore, has a width of 0.52mm and a length of 8.29mm + 0.41mm + 0.27mm = 8.97mm. Test readings on a second prototype are shown in **Fig 17.12**.

The design was also evaluated with two other simulation programs, *Mstrip40* and *Sonnet Lite*, descriptions of these and/or projects using them can be found in *VHF Communications* [6] and [7].

Sonnet was used on the radiating patch, in order to re-check the resonance frequency and also to investigate the matter of the much higher radiation resistance. Using an online menu made it easy to use this program, but it is important to pay heed to the rules of simulating such antenna structures in the *Sonnet* manual. It is essential to obtain (free) the additional license for extending the maximum usable PC working memory to 16 megabytes, in order to carry out the simulation successfully. **Fig 13** shows the *Sonnet* editor screen with the selected box and cell dimensions, together with the new ‘Quick Start Guide’. Owing to the restrictions on the Lite version, the transformation line is simply omitted and replaced by a 50-ohm power feed taken right up to the box wall. The actual radiation resistance of the antenna can then be determined easily and directly from the reflection factor determined in this way. This is how to do it:

Fig 17.12: A good test result with this antenna

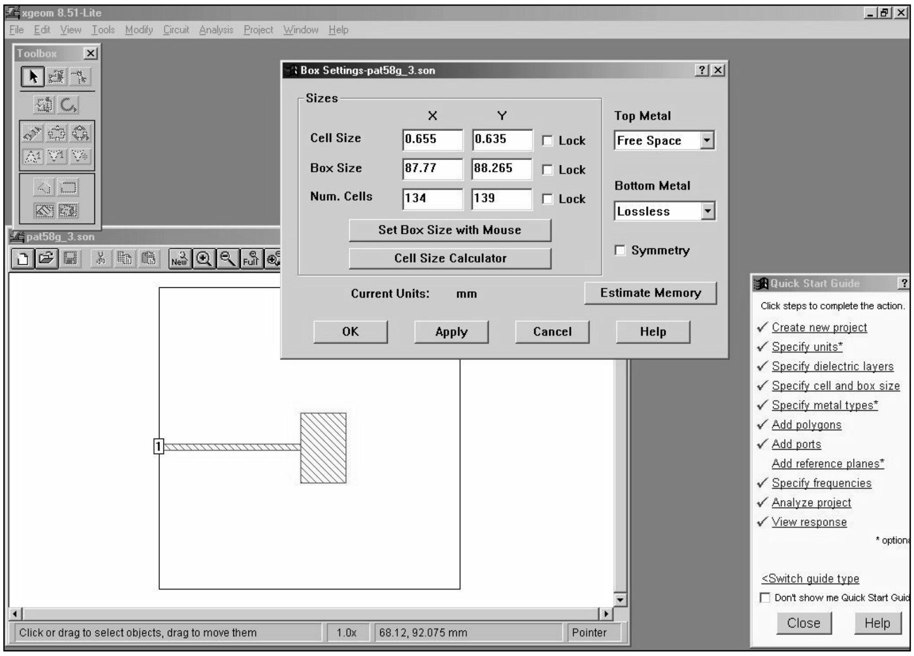


Fig 17.13: Using the *Sonnet-Lite* simulator for the patch antenna

The simulation result can be seen in **Fig 17.14**, with a resonance of 6.03GHz and |S11| = -4.4dB. This gives a reflection factor of:

$$r = \log \frac{-4.4\text{dB}}{20\text{dB}} = 0.60$$

Because a 50Ω feed is being used, it is necessary to reduce the circuit length in the Smith diagram until resistances exceeding 50Ω are arrived at on the real axis. Then, in accordance with the following relationship, the total resistance on the patch edge is obtained:

$$R = \frac{1+r}{1-r} \cdot Z = \frac{1+0.6}{1-0.6} \cdot 50\Omega = 200\Omega$$

Consequently, each radiating edge is affected by a radiation resistance of 400Ω. Compared with the measured value of 407.5Ω, this is an extremely satisfactory result, and thus confirms the validity of the measurement. The resonance frequency was simply predicted too high, with an error of:

$$\frac{6030\,\text{MHz} - 5800\,\text{MHz}}{5800\,\text{MHz}} \cdot 100\% = 3.96\%$$

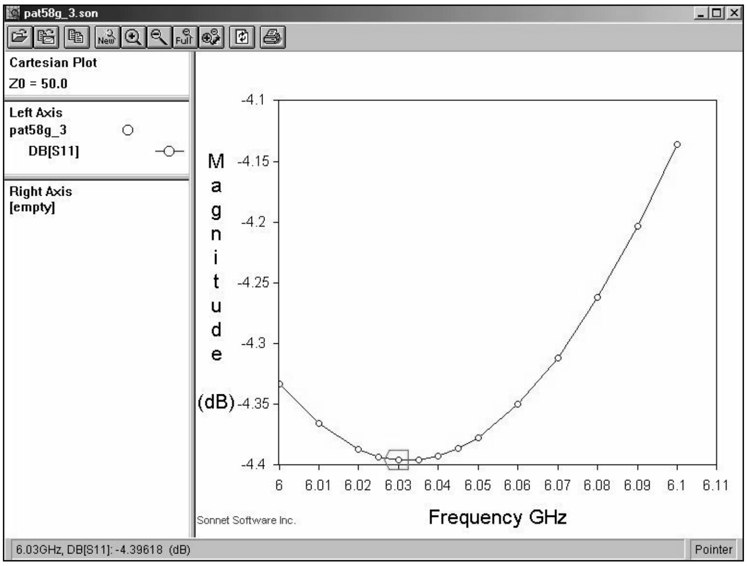


Fig 17.14: Simulation results from *Sonnet-Lite*

For a comparison simulation, entering the cell data used for *Sonnet* into the *mstrip40* program gives precisely this resonant frequency, but with rather larger discrepancies of approximately 10 to 15% in the radiation resistance.

Nowadays, the most modern design aids are available, even to private developers without an expensive industrial scale test rig, and at reasonable cost.

SLOT ANTENNA

The slot antenna that has become known in the amateur world as the *Alford slot* actually derives from work by Alan D Blumicin of London, and is detailed in his patent number 515684 dated 7 March 1938. The work by Andrew Alford was carried out during the mid 1940s and 50s, and not applied to microwave bands but to VHF/UHF broadcasting transmitters in the USA.

Development by M Walters, G3JVL, was carried out during 1978 when designs for the GB3IOW 1.3GHz beacon were being investigated. The initial experiment was carried out at 10GHz as the testing was found to be much easier, especially when conducted in a relatively confined space. A rolled copper foil cylinder produced results close to those suggested in the original work. Initially, it was thought that the skeleton version would be best used at the lower frequencies only. However, several models for use on 144MHz have been constructed and they performed very well, but the design was, at the time, not regarded by G3JVL as being of interest.

Further developments have resulted in working models being constructed for the 50MHz, 432MHz, 900MHz and 1.3GHz bands. However, some aspects were not easy to explain and valuable assistance was provided by G3YGF. This assistance provided more than just an explanation for the fact that early skeleton versions worked at a lower than designed frequency. A working operational theory was developed as a direct result, along with a better understanding of the strange effects that were observed.

The 2.3GHz version developed by G3JVL fulfils the need for an omni directional horizontally polarises antenna. This makes it particularly useful for beacons, fixed station monitoring purposes and mobile operation. Mechanical details of this antenna are shown in **Fig 17.15**. The prototype was made from 22mm outside diameter copper water pipe. Material is removed from one part of the tubing to produce a slotted tube with an outside diameter of 18.5mm and a slot width of 2.6mm. To ensure circularity the tube is best formed around a suitable diameter mandrel. Small tabs are soldered at the top and bottom of the tube to define the slot length of 229mm. A plate is soldered across the bottom of the tube to strengthen the structure.

The RF is fed via a length of 0.141in (3.6mm) RG141 semi rigid coaxial cable up the centre of the tube to the centre of the slot via a 4:1 balun constructed at the end of the cable. The detailed construction of the balun is shown in Fig 17.15. The two diametrically opposite slots are cut carefully using a small hacksaw with a new blade. The inner and outer of the cable are shorted using the shortest possible connection and the balun is attached to the slot using two thin copper foil tabs. If suitable test gear is available, the match of the antenna can be optimised by carefully adjusting the width of the slot by squeezing

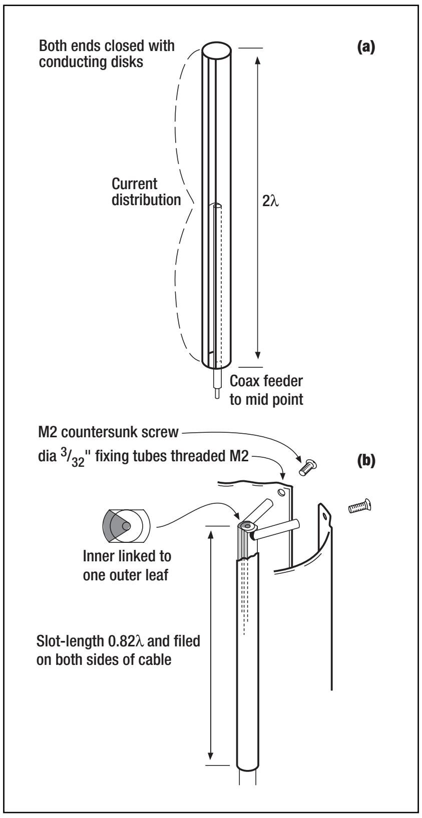
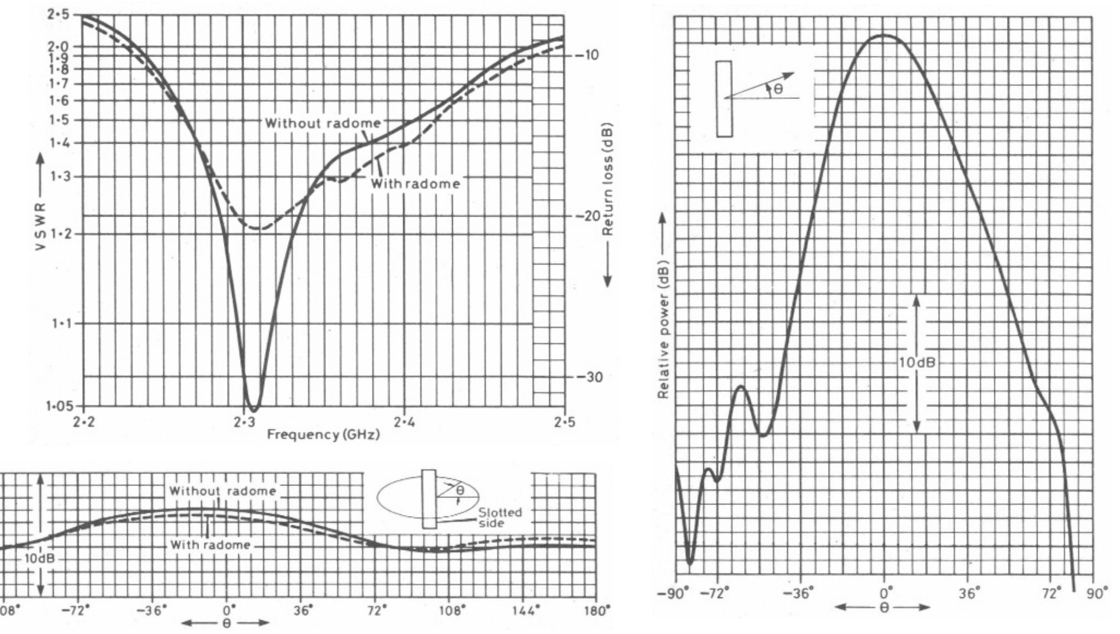


Fig 17.15: Construction of the 2.3GHz Alford slot antenna using a dual slotted cylinder. The feed point impedance is 200Ω. (a) Dimensions for 2,320MHz are: slot length 280mm, slot width 3mm, tube diameter 19mm by 18SWG. (b) Construction of a suitable balun. The balun slots are 1mm wide and 26mm long

Fig 17.16: Performance of a 2.3GHz Alford slot antenna. Top: impedance, Middle: horizontal polar diagram, Bottom: vertical polar diagram



the tube in a vice, or by prising the slot apart with a small screwdriver. Typical antenna characteristics are shown in **Fig 17.16**. The gain of the antenna has been measured to 6.4dBi.

HELICAL ANTENNA

Paolo Pitacco, IW3QBN, designed this array of 4 x 16 turn helix antennas for 2402MHz [8]. Such a project is an interesting challenge for design, manufacture and testing. The designer had no space for a parabolic reflector and required easy mounting and dismounting in case of strong wind. The idea was to design a system capable of operating as a satellite and terrestrial antenna with discrete gain, good capture area and rapid installation. As a starting point a simple 16-turn helix antenna [9] was used to hear signals from the DOVE satellite (2401MHz), and to work with home made ATV systems. The endpoint is an array of four of these helices, shown in **Fig 17.17**.

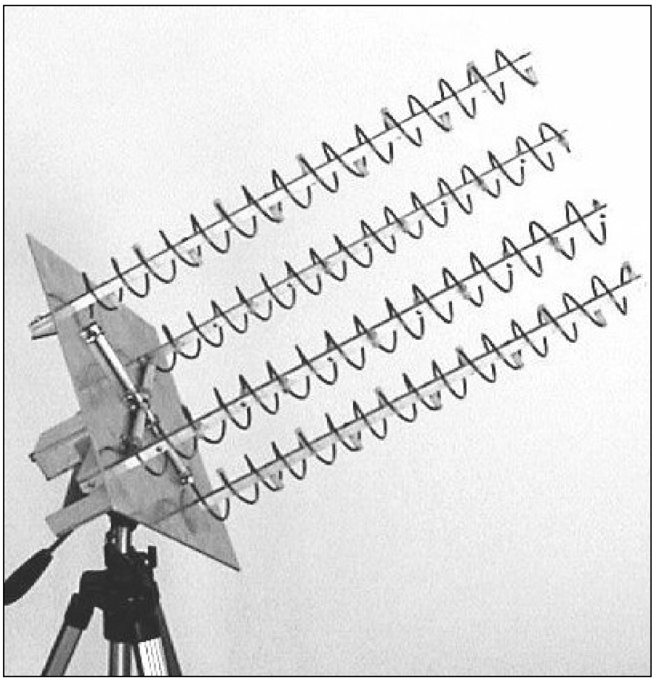


Fig 17.17: The completed 4 x 16 turn helical antenna for 2402MHz

Radio amateurs today have many ‘ready to use’ computer programs available for helical antenna design, from simple DOS to complex Windows or Linux applications. It is possible to choose from any of the following techniques:

- Reproduce the design by G3RUH [10]
- Make a new design using KA1GT [11] program
- Use Peter Ward's *Excel* worksheet, ‘RF2’
- Follow design formulas from antenna engineering literature [12 & 13]

This excludes all commercial and costly programs. A mix of these ways was followed to check the results from outputs of several programs, and validate and refine using formulas [12]. The same input data (central frequency, number of turns and mechanical dimension) were used in each case.

The design was centred on 2402MHz, to obtain sufficient bandwidth to cover AO-40 and ATV frequencies. Using this centre frequency, a support diameter of 38mm was chosen, together with 31mm spacing between turns. Copper wire of 3mm diameter was used because it is self supporting without the need for any type of plastic tube which would cause up to 15% detuning of the helix due to dielectric action.

Matching a single helix is not difficult. It is possible to achieve a broadband match without use of a network analyser or other measuring instruments, but multiple helix arrays are more difficult. Multiple antennas require a coupling system and matching to the transmission line, and the first is related to the second. The *aperture area* of each antenna must be evaluated, and a method found to couple the array to a single cable.

There are four methods:

1) Each antenna matched to 50Ω with a 4:1 coupler to the feeder
2) Unmatched (Z~140Ω) with a coaxial quarter-wavelength transformer and a 4:1 coupler to the feeder
3) Unmatched (Z~140Ω) with a quarter-wavelength wireline transformer to the feeder
4) Unmatched (Z~140Ω) with a coaxial quarter-wavelength transformer to the feeder

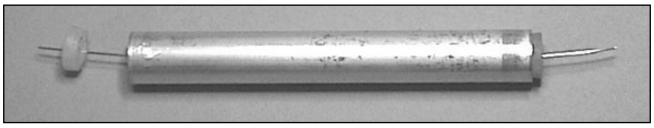


Fig 17.18: Quarter wavelength transformer for 2402MHz 4 x 16 turn helical antenna

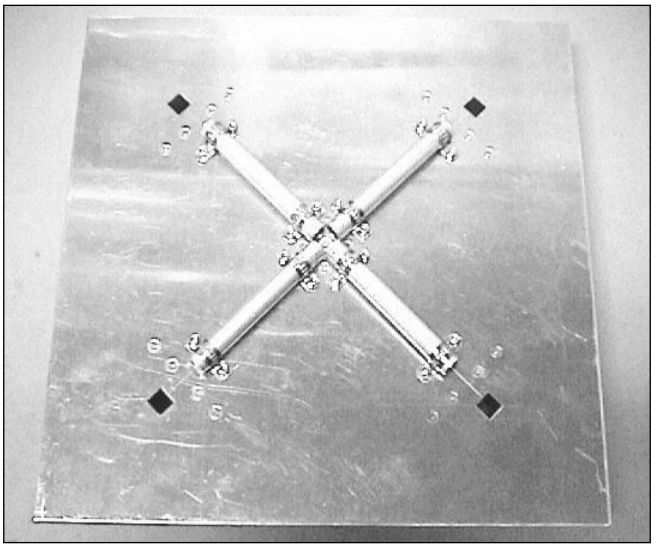


Fig 17.19: Mounting of the four quarter wavelength transformers for 2402MHz 4 x 16 turn helical antenna

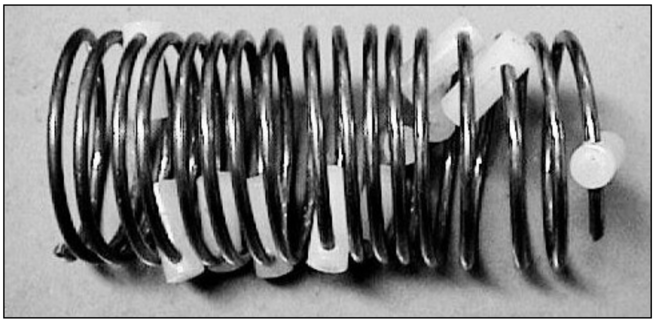


Fig 17.20: Fitting spacers onto wound helix for 2402MHz 4 x 16 turn helical antenna

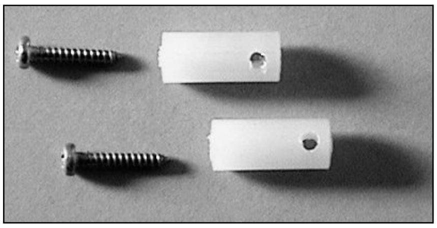


Fig 17.21: Spacers for helix of 2402MHz 4 x 16 turn helical antenna

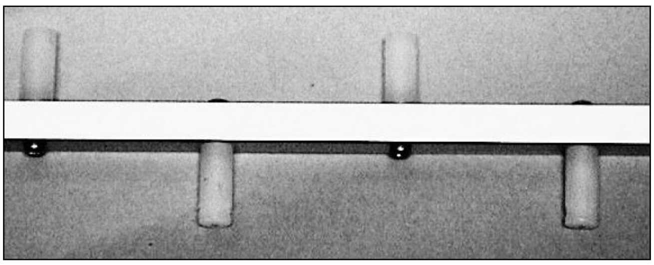


Fig 17.22: Aluminium support tube for 2402MHz 4 x 16 turn helical antenna

Solution 1 is easy and is used by G6LVB. Good connectors and cable, and great precision is needed to make four equal helix antennas and cables.

Solution 2 is difficult and no longer used. Mechanical tools and a lot of connectors and cable are needed to make a good transformer.

By using Solution 3, the helix antennas and feeder can matched in a single pass as a quarter-wavelength transformer with an output impedance equal to 4 x 50Ω is easy, but a wire-line is a potential antenna.

Solution 4 has the advantages of 3, but by using coaxial line you avoid any problem of radiation and the matching line has a more stable impedance. It is a mechanically complex solution, but requires only one connector.

For this project, Solution 4 was chosen,and this drove subsequent mechanical and electrical issues. The helices must be placed at the correct spacing, and a quarter wavelength transformer. must be constructed. For 2402MHz, lambda (λ) is 12.48cm and λ/4 is 3.12cm, but calculations indicate an aperture area of 1.4λ or 17.5cm. A mechanical solution had to be found, using an odd multiple for quarter wavelength, exactly 3λ/4 (93mm) to maintain transformation properties and distance between helices.

Impedance matching with coaxial transformer is straightforward when mechanical machining isn't a problem, using the equation:

$$Z_m = \sqrt{Z_a \text{ x } (Z_l \text{ x } N_a)} \quad (1)$$

Where Z_a is the antenna impedance, N_a is the number of antennas, Z_l is the impedance of main feeder and Z_m the required impedance for a match.

Using equation below, it is possible to determine tube and conductor diameter to build the matching section.

$$Z_{coax} = \frac{138}{\sqrt{\varepsilon_r}} \cdot \log\left(\frac{D_g}{D_p}\right) \quad (2)$$

Where D_g stands for inner diameter of tube, D_p is diameter of wire, ε_r is 1.001 for air).

Because the computed helix impedance is 153Ω, a characteristic impedance of 173Ω is needed for this line. The quarter wavelength transformer was made from a commercially available aluminium tube with an external diameter of 12mm (10mm inside), and a 0.6mm diameter silvered copper wire. This represented a good compromise (about 170Ω).

The wire is held in position with a couple of thin (3mm) centre drilled nylon plugs, this means the transformer's dielectric will be near that of air (see **Fig 17.18**).

All four transformers are locked in position (on the upper side of the reflector) by means of two U-shaped brackets also used as a ground connection. One side is soldered on to an N connector (see **Fig 17.19**).

The reflector plate is a made of a 3mm thick square of aluminium sheet with 30cm sides.

Each helix is made with 3mm diameter copper wire, wound on a 35mm diameter support, then gently relaxed and loaded using 11 spacers (every 1.5 turns), as shown in **Fig 17.20**. The spacers are small cylinders of nylon, 20mm long and 8mm diameter, each pre-drilled with a 3.2mm hole 15.6mm from the bottom (**Fig 17.21**). The first spacer is located at the end of the helix and last, one turn before the feed point. The spacers are subsequently locked on a square aluminium tube (10mm side, 1mm depth) pre-drilled with 3mm holes at distances of 47mm (one each 1.5 turns) as shown in **Fig 17.22**. This tube, which is 57cm long, has no effect on performance, and is used to hold the helix

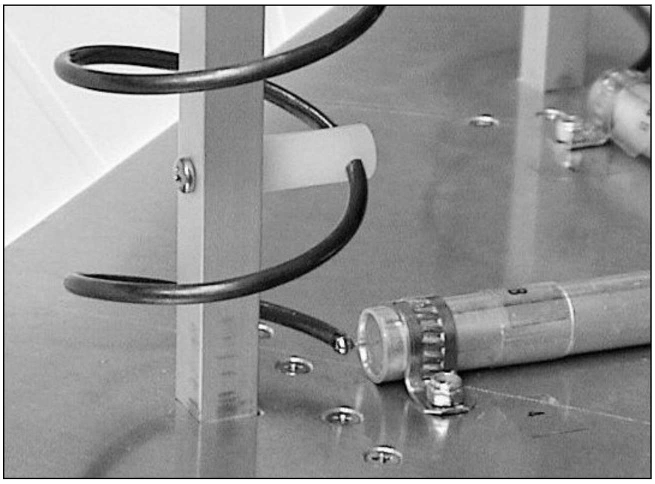


Fig 17.23: Close up view of connection to quarter wavelength transformer for 2402MHz 4 x 16 turn helical antenna

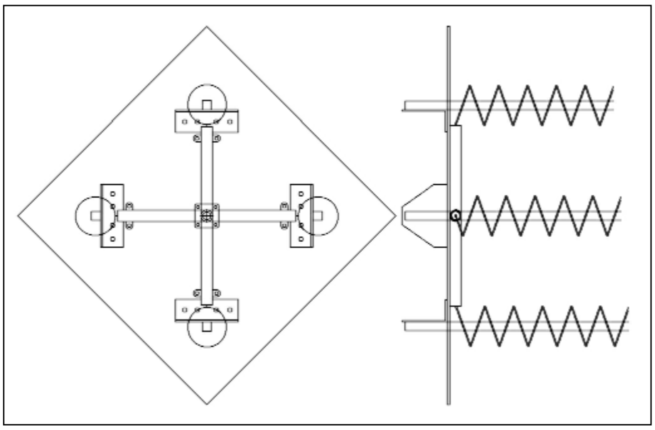


Fig 17.24: Complete mechanical drawing for 2402MHz 4 x 16 turn helical antenna

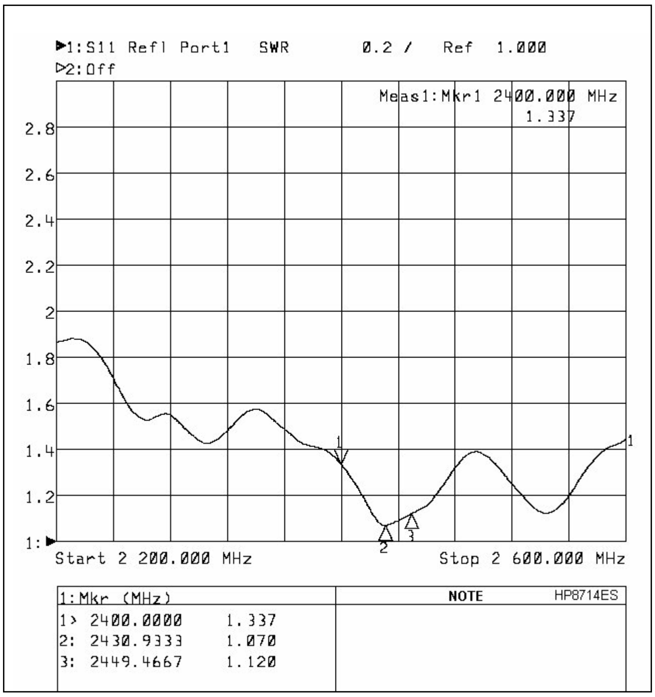


Fig 17.25: Results for 2402MHz 4 x 16 turn helical antenna measured on a network analyser

in position by means of L-shaped aluminium brackets (measuring 25 x 50mm).

Another U-shaped bracket is used to hold converters, preamplifiers or other devices, and as a mounting point (a tripod for example).

All helices are wound in the same direction (counter clockwise as seen from rear) in order to maintain the phase of the feed point. **Fig 17.23** shows the electrical and mechanical connection between the helix and the coaxial transformer. Attention should be given to soldering the inner transformer conductor; pre-solder the 3mm copper wire beforehand. **Fig 24** is a complete mechanical drawing of this array.

The first measurement was made with the aid of an Agilent E8714ES Network Analyser, and the results were close to what was expected as shown in **Fig 17.25**. A low SWR was obtained on 2430MHz (near the centre of S band), but the antenna gives good results over the entire band. Other lengths of transformer (92 and 94 mm respectively) have been tried, but 93mm represents the best compromise for amateur use. The calculated gain is 18dB (including losses), and tests on AO-40 signals demonstrate this figure. A comparison was made with a 80cm dish with 3 turn helix, and this gave 6-8 dB higher gain.

YAGI ANTENNAS

Wide Band Yagi for 23cm

Noel Hunkeler, F5JIO, designed an array of six half-wave dipoles with a reflector plane for a 23cm packet radio link [14]. It provides 10dBd gain and an SWR not exceeding 1.1:1 throughout the band. Curtains of phased dipoles have been used by amateurs since before WWII, examples are shown in the 1937 Jones antenna handbook. F5JIO consulted *Rothammel*, the German antenna bible, which gives the following guidelines for the reflector plane:

> *For best F/B ratio, it should extend at least a half wave beyond the perimeter of the curtain on all sides. If made of wire mesh instead of solid sheet to reduce*

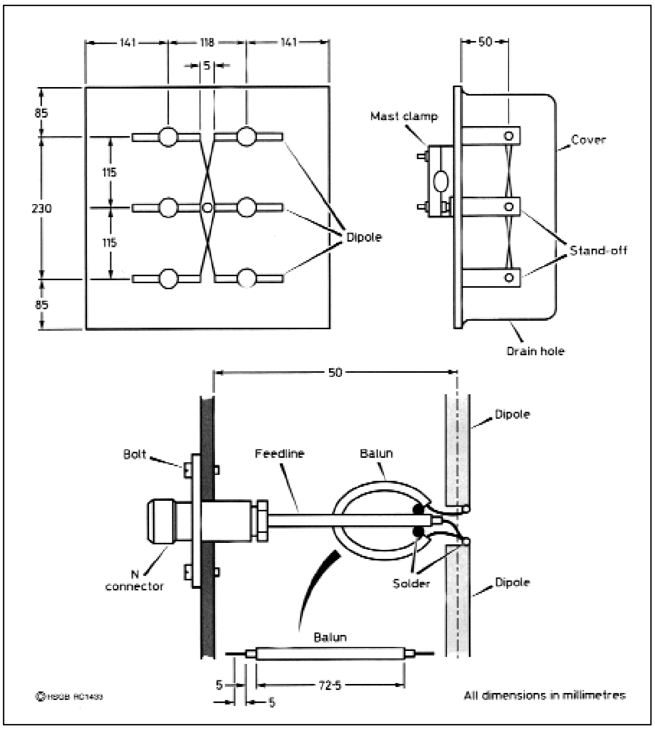


Fig 17.26: Details of wide band yagi for 23cm

Reflector	400 x 400 (340 min) 2.5 thick aluminium sheet (Qty 1)
Stand-off	Teflon (or PVC) 60L x 20D (Qty 6)
Dipole	Brass, silvered, 108L x 6D (Qty 6)
Rod, phasing	Wire, silvered, 2D (Qty 4)
N connector	(Qty 1)
Feedline	Semi rigid coax, 50 , approximately 4D (Qty 1)
Balun	as above, 92.5L (Qty 1)
Bolt	M3 x 8, SS (Qty 4)
Cover	Plastic food container (Qty 1)
Mast clamp	From TV antenna (Qty 1)

Table 17.1: Component list for wideband 23cm beam. All dimensions are in mm

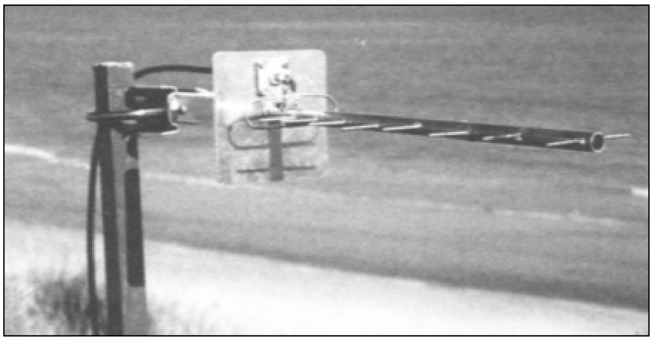


Fig 17.27: Picture of the 22 element Yagi antenna for the 13cm band

windage, the wire pitch should be λ/20 or less. A reflector plane spaced 5λ/8 behind the radiator adds maximum gain, up to 7dB, but a spacing of 0.1 - 0.3λ gives better F/B ratio. If spaced at least 0.2λ behind the curtain, the reflector plane does not affect the feed point impedance of the array.

With the dimensions given in **Fig 17.26** and the parts shown in **Table 17.1**, the feed point impedance of each dipole pair is approximately 600Ω balanced. Three pairs in parallel give 200Ω balanced. The 4:1 re-entrant line balun transforms this to 50Ω, unbalanced. Note that each dipole is supported at its voltage node; hence the standoffs need not be high quality insulators.

For 23cm this antenna is small, so a solid aluminium reflector is practical; this plate supports all other components. Slightly bend the phasing rods so they do not touch at the crossovers. For weather protection, a plastic food container serves as a radome. Its RF absorption seems negligible for our application and it is much cheaper than Teflon. Although precision is required, construction of this antenna is not difficult.

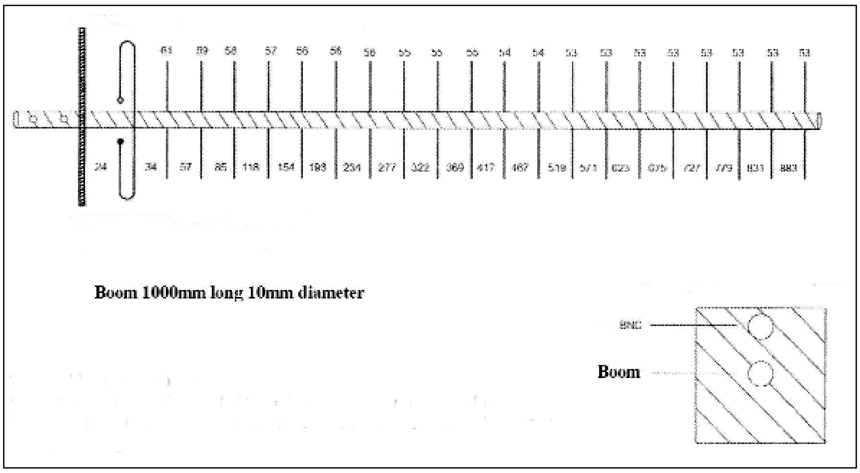


Fig 17.28: Element dimensions for the 22 element 13cm yagi

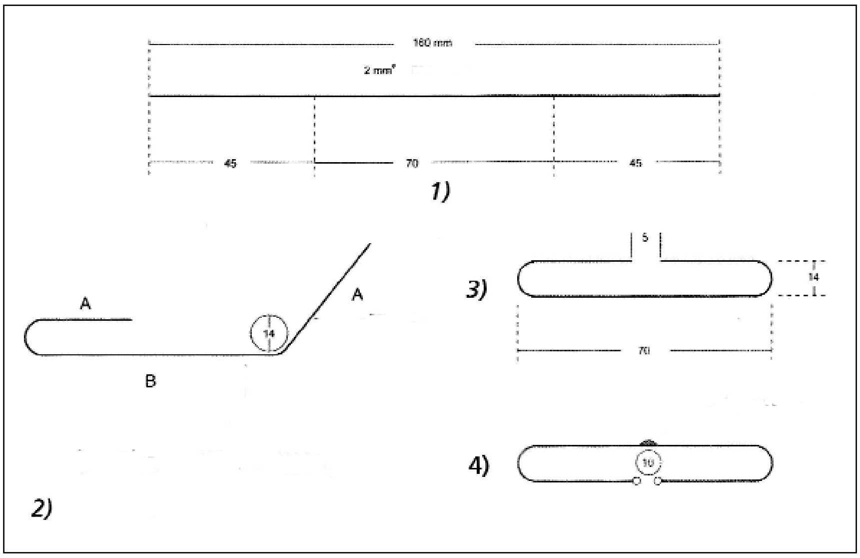


Fig 17.29: Details of the dipole for the 22 element 13cm yagi

DL Design Yagi for 13cm

Leo Lorentzen, OZ3TZ, designed these 10 and 22 element Yagi antennas for 13cm [15]. The design comes from a popular antenna designer, DL6WU, who has been much copied. While very popular, his writings are also courtesy of Mr H Yagi from Japan, dating right back to 1928 (see the Antenna Fundamentals chapters for more on Yagis).

The Danish version of this Yagi (**Fig 17.27**) is made of standard dimension brass materials, worth mentioning, as you will often see measurements for the materials used that are not in stock at your local metal goods dealer. Common standard dimensions like 2.0, 2.5, 3.0mm etc are off the peg goods, so once the shopping has been done and the brass has been delivered, you're well on your way towards your 13cm antenna project.

The customary practice for brass work is to use good tools. Mark out the antenna boom and check the marking an extra time before positioning the twenty centre punch marks and then drilling twenty 2mm diameter holes for the directors, which first need to be soldered into the boom. Solder the dipole on top of the boom. **Fig 17.28** shows the dimensions of the elements and **Fig 17.29** shows the detail of the dipole. Drill two 10mm diameter holes in the 80 x 80mm, 1mm brass plate reflector plate, soldering it firmly to the antenna boom as well.

Behind the reflector, drill two 4mm diameter holes, spaced 75mm apart. On top of the holes two 4mm diameter nuts are soldered so that the antenna can be secured to a mast fixture or something else. Mount a BNC socket in the reflector plate to

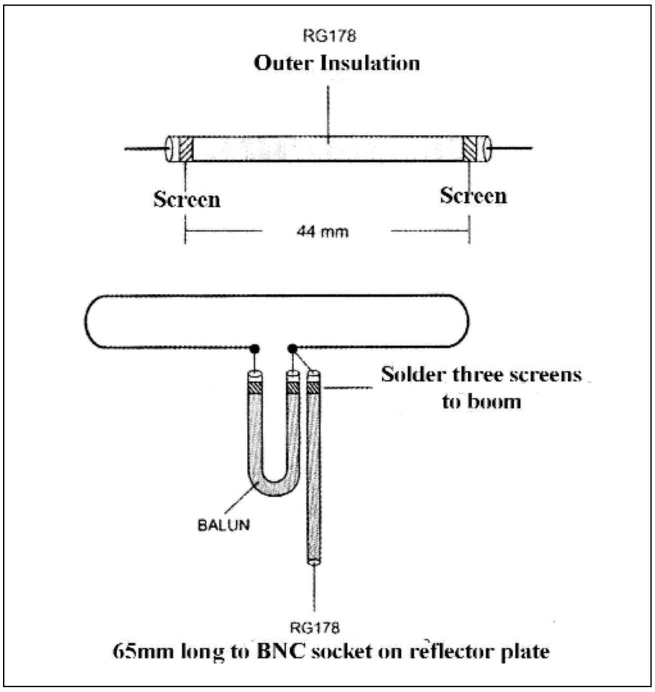


Fig 17.30: Details of the balun for the 22 element 13cm yagi

accept the 65mm RG178s from the dipole/balun, see **Fig 17.30**.

The really important thing is to solder the screen directly onto the antenna socket and allow the screen to go right up to the inside pin on the BNC socket, where the inner conductor in the cable will be soldered. If the antenna is to be sited outdoors, Araldite can be used to make 50Ω cabling etc watertight.

The finished antenna fares well in practical use. To measure the gain, an absolutely stable test signal was received on a half-wave dipole connected to a 13cm converter. With the dipole antenna, an approximately S1 signal was received. A 10 element yagi was then substituted for the dipole and an approximately S3 signal was received. Then the 22 element antenna was connected, and an impressive S7 signal was received. According to the original designer of the antenna, a boom length of seven wavelengths and approximately 20 elements makes for something over 15dBd.

Quad Loop Yagi for 9cm

This antenna was originally designed by M Walters, G3JVL. The design is shown in **Fig 17.31** with the critical dimensions shown in **Table 17.2**. The design is a scaled version of the 1,296MHz design, adapted to the narrow band segment at 3,456MHz. There are 61 directors giving a boom length of 2m. The construction of the antenna is quite straightforward providing care is taken in the marking out process. Measurements should be made from a single point or datum. In marking the boom for instance, measurements of the position of the elements should be made from a single point rather than marking out individual spacings.

Boom:

Boom diameter	12.5mm od
Boom length	2.0m
Boom material	aluminium alloy

Elements:

Driven element	1.6mm diameter welding rod
All other elements	1.6mm diameter welding rod

Reflector size:

Reflector plate	52.4 x 42.9mm

Element lengths:

Length 1 (mm) (see Fig 17.32a):			
Reflector loop	99.2	Directors 21-30	78.2
Driven element	92.7	Directors 31-40	76.1
Directors 1-12	83.9	Directors 41-50	75.1
Directors 13-20	81.2	Directors 51-60	74.6

Cumulative element spacings (mm):

RP	0.0	RL	29.5
DE	38.6	D1	49.2
D2	57.2	D3	74.1
D4	91.1	D5	103.0
D6	125.0	D7	158.9
D8	192.8	D9	226.7
D10	260.6	D11	294.5
D12	328.4	D13	362.3
D14	396.2	D15	430.1
D16	464.1	D17	498.0
D18	531.9	D19	565.8
D20	599.7	D21	633.6
D22	667.5	D23	701.4
D24	735.3	D25	769.2
D26	803.1	D27	837.0
D28	871.0	D29	904.9
D30	938.8	D31	972.7
D32	1006.6	D33	1040.5
D34	1074.4	D35	1108.3
D36	1141.2	D37	1176.1
D38	1210.0	D39	1244.0
D40	1277.9	D41	1311.8
D42	1345.7	D43	1379.6
D44	1413.5	D45	1447.4
D46	1481.3	D47	1515.2
D48	1549.1	D49	1583.1
D50	1617.0	D51	1650.9
D52	1684.8	D53	1718.7
D54	1752.6	D55	1786.5
D56	1820.4	D57	1854.3
D58	1888.2	D59	1922.1
D60	1956.1	D61	1990.0

Table 17.2: Dimensions of 3.4GHz loop quad

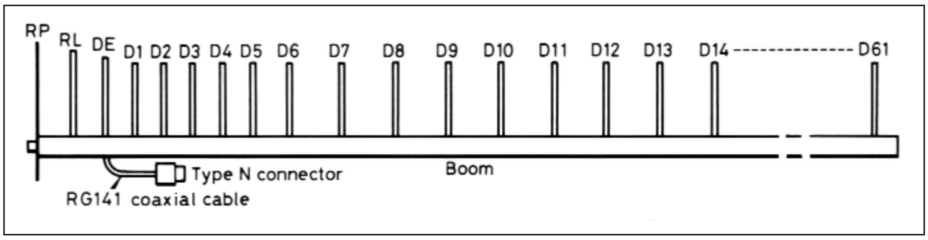


Fig 17.31: The 9cm quad loop yagi. Dimensions are shown in Table 17.2

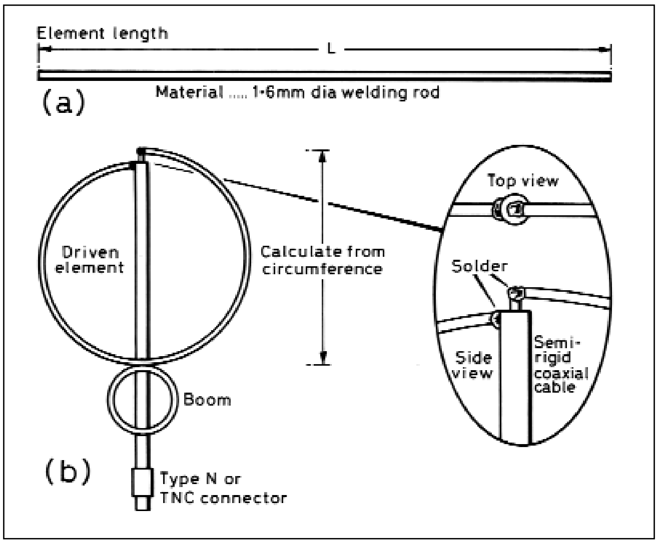


Fig 17.32: (a) Detail of element construction. (b) Assembly of the driven element for the 9cm quad loop yagi

All elements are made from 1.6mm diameter welding rod cut to the lengths shown in the table, then formed into a loop as shown in **Fig 17.32a**. The driven element is brazed to a M6 x 25 countersunk screw drilled 3.6mm to accept the semi rigid coaxial cable. All other elements are brazed onto the heads of M4 x 25 countersunk screws. All elements, screws and joints should be protected with a coat of polyurethane varnish after assembly. If inadequate attention is paid to weatherproofing the antenna, its performance will gradually deteriorate as a result of corrosion.

Provided the antenna is carefully constructed, its feed impedance will be close to 50Ω. If a suitably rated power meter or impedance bridge is available, the match may be optimised by carefully bending the reflector loop toward or away from the driven element.

The antenna can be mounted using a suitable antenna clamp. It is essential that the antenna be mounted on a vertical support, as horizontal metalwork in its vicinity can cause severe degradation in its performance.

HORN ANTENNAS

3cm Horn

Large pyramidal horns can be an attractive form of antenna for use at 10GHz and above. They are fundamentally broadband devices showing virtually perfect match over a wide range of frequencies, certainly over an amateur band. They are simple to design, tolerant of dimensional inaccuracies during construction and need no adjustment. Their gain can be predicted within a dB or so (by simple measurement of the size of the aperture and length) which makes them useful for both the initial checking of the performance of systems and as references against which other antennas can be judged. Their main disadvantage is that they are bulky compared with other antennas having the same gain.

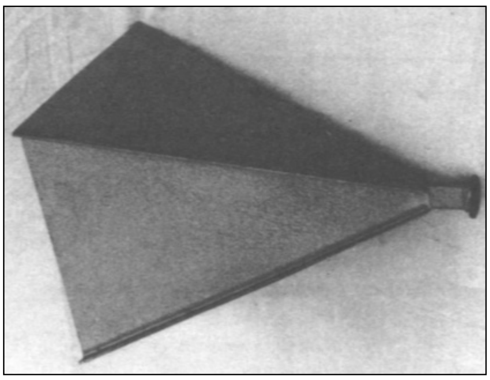


Fig 17.33: Picture of a large 10GHz horn

Large (long) horns, such as that illustrated in **Fig 17.33**, result in an emerging wave which is nearly planar and the gain of the horn is close to the theoretical value of $2\pi AB/\lambda^2$, where A and B are the dimensions of the aperture. For horns which are shorter than optimum for a given aperture, the field near the edge lags in relation to the field along the centre line of the horn and causes a loss in gain.

For very short horns, this leads to the production of large minor lobes in the radiation pattern. Such short horns can, however, be used quite effectively as feeds for a dish. The dimensions for an optimum horn for 10GHz can be calculated from the information given in **Fig 17.34** and, for a 20dB horn, are typically:

- A = 5.19in (132mm)
- B = 4.25in (108mm)
- L = 7.67in (195mm)

There is, inevitably, a trade off between gain and physical size of the horn. At 10GHz this is in the region of 20dB or perhaps slightly higher. Beyond this point it is better to use a small dish. For instance a 27dB horn at 10GHz would have an aperture of 11.8in (300mm) by 8.3in (210mm) and a length of 40.1in (1,019mm) compared to a focal plane dish that would be 12in (305mm) in diameter and have a length of 3in (76mm) for the same gain.

Horns are usually fabricated from solid sheet metal such as brass, copper or tinplate. There is no reason why they should not be made from perforated or expanded metal mesh, provided that the size and spacing of the holes is kept below about λ/10. Construction is simplified if the thickness of the sheet metal is close to the wall thickness of WG16, ie 0.05in or approximately 1.3mm. This simplifies construction of the transition from the waveguide into the horn. The geometry of the horn is not quite as simple as appears at first sight since it involves a taper from an aspect ratio of about 1:0.8 at the aperture to approximately

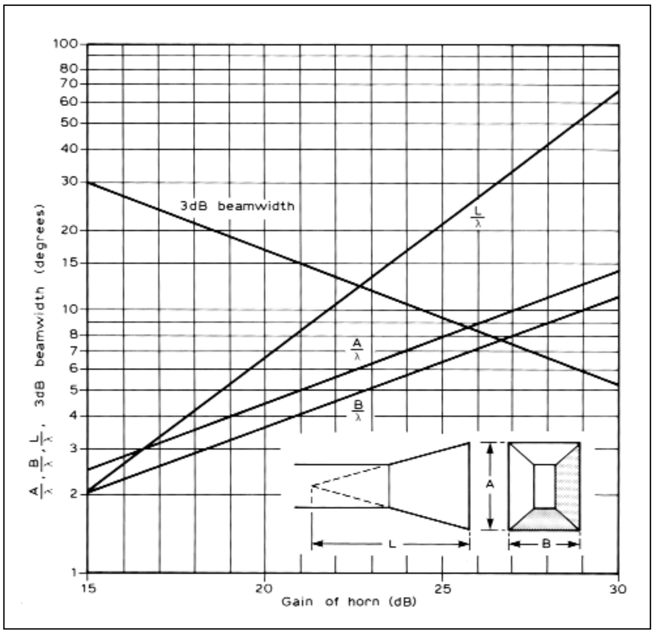


Fig 17.34: Horn antenna design chart

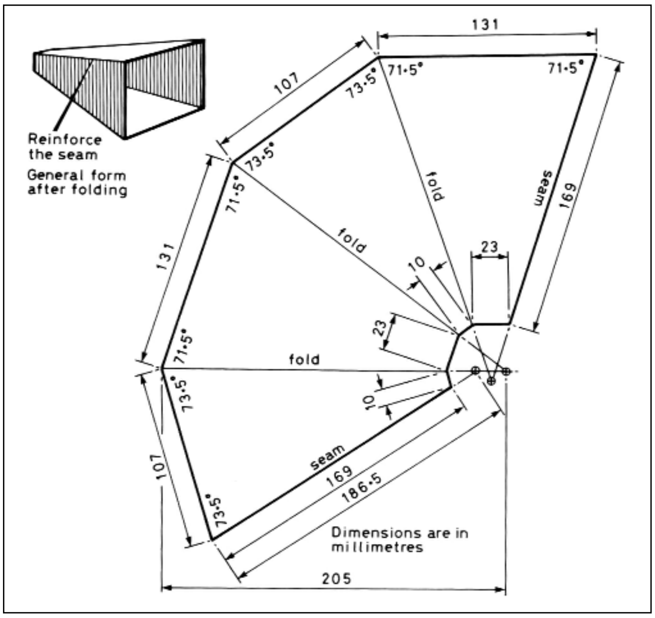


Fig 17.35: Dimensioned template for single piece construction of a 20dB horn

2:1 at the waveguide transition. For a superficially rectangular object, a horn contains few right angles, as shown in Fig 17.35 an approximately quarter scale template for a nominal 20dB horn at 10.4GHz. If the constructor opts to use the one piece cut and fold method suggested by this figure, it is strongly recommended that a full sized template be drafted on stiff card that can be lightly scored to facilitate bending to final form. This will give the opportunity to correct errors in measurement before transfer onto sheet metal and to prove to the constructor that, on folding, a pyramidal horn is formed!

The sheet is best sawn (or guillotined) rather than cut with tin snips, so that the metal remains flat and undistorted. If the constructor has difficulty in folding sheet metal, then the horn can be made in two or more pieces, although this will introduce more soldered seams which may need jigging during assembly and also strengthening by means of externally soldered angle pieces

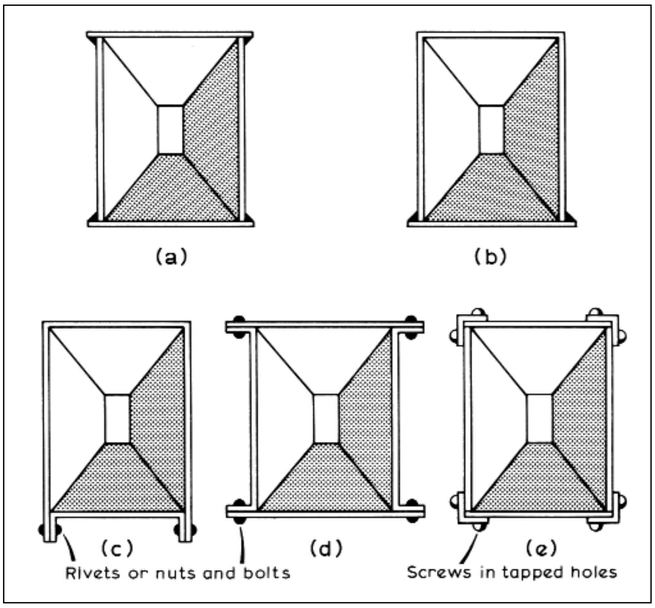


Fig 17.36: Alternative construction methods for constructing horn antennas

running along the length of each seam. Alternative methods of construction are suggested in Fig 17.36.

It is worth paying attention to the transition point that should present a smooth, stepless profile. The junction should also be mechanically strong, since this is the point where the mechanical stresses are greatest. For all but the smallest horns, some form of strengthening is necessary. One simple method of mounting is to take a short length of Old English (OE) waveguide, which has internal dimensions matching the external dimensions of WG16, and slitting each corner for about half the length of the piece. The sides can then be bent (flared) out to suit the angles of the horn and soldered in place after carefully positioning the OE guide over the WG16 and inserting the horn in the flares. One single soldering operation will then fix both in place. After soldering, any excess of solder appearing inside the waveguide or throat of the horn should be carefully removed by filing or scraping. The whole assembly can be given a protective coat of paint.

An alternative method would be to omit the WG16 section and to mount the horn directly into a modified WG16 flange. In this case the thickness of the horn material should be a close match with that of WG16 wall thickness and the flange modified by filing a taper of suitable profile into the flange.

Whichever method of fabrication and assembly is used, good metallic contact at the corners is essential. Soldered joints are very satisfactory provided that the amount of solder in the horn is minimised. If sections of the horn are bolted or riveted together, it is essential that many, close spaced bolts or rivets are used to ensure good contact. Spacing between adjacent fixing points should be less than a wavelength, ie less than 30mm.

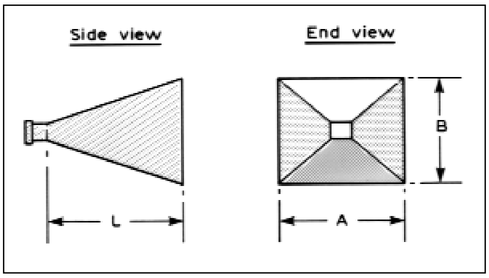
24GHz Horn Antenna

A 24GHz horn is a very easy antenna to construct, as its dimensions are not critical and it will provide a good match without any tuning. The dimensions, as per Fig 17.37, for optimum gain horns of various gains (at 24GHz) are shown in Table 17.3. Above 25dB the horn becomes very long and unwieldy and it becomes more practical to use a dish.

Suitable materials are PCB material, brass or copper sheet, or tin plate. If PCB material is used, the doubled-sided type will enable the joins to be soldered both inside and out for extra strength. An ideal source of tin plate is an empty oil can.

The transition from the guide to the horn should be smooth. Use either a butt joint, or file the waveguide walls to a sharp

Fig 17.37: Dimensions of horn antenna for 24GHz



Gain (dB)	Beamwidth (degrees)	Length (mm)	A (mm)	B (mm)
15	30	26	31	25
20	17	81	55	45
25	9	270	98	79
30	5	819	174	141

Table 17.3: Gain of 24GHz horn antennas

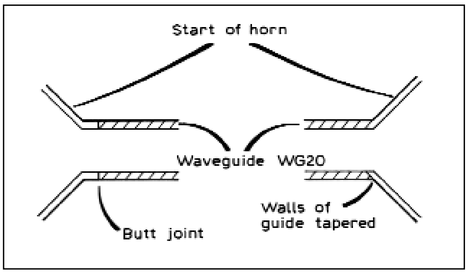


Fig 17.38: Joining a 24GHz horn directly to a waveguide

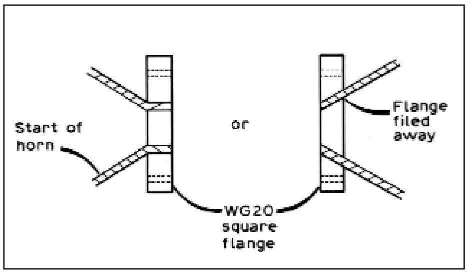


Fig 17.39: Joining a 24GHz horn directly to a flange

edge, see **Fig 17.38**. The material should be cut to size and then soldered together and onto the end of a piece of waveguide. Alternatively the horn may be coupled directly to the inside of a flange. In this case the material should be the same thickness as the waveguide would be and it is bent as it enters the flange, or the flange may be filed to be part of the taper, see **Fig 17.39**.

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