The G3FEW Multi-Band Antenna

by E A Rule G3FEW (1487)

The search for the perfect antenna started with the birth of amateur radio and to my knowledge it hasn't yet been found ! All antennas are a compromise in one or more aspects, although of course one expects to get fairly close to the ideal.

Amateurs with large estates don't have to much of a problem getting a decent antenna installed, but we lesser mortals have to make do with what we have. In my case it's a garden of 50 ft. width by 60 ft. long with a field backing on to it which I have permission to put a wire across. Many amateurs have much less than this.

I decided to set some goals for my "perfect" antenna.

1. Must cover at least five HF bands.
2. Low SWR at the design frequencies.
3. Not need an ATU.
4. Have same radiation pattern on each band.
5. Be easy to repeat the construction.
6. Be adaptable for different locations.

The prototype.

Using an antenna design program a number of different models were tried to see which would come closest to my "perfect" antenna. It was decided to go for a full wave system fed a quarter wave in from one end. The reasons for this choice will become clearer later on. In order to maintain the same radiation pattern on each band, Traps would be used.

A prototype was constructed for the 10, 12, 15, and 17 metre bands. Traps were constructed using standard receiver type components and these were found suitable for QRP up to about 20 watts, enabling tests to be carried out.

The SWR was 1:1 on each band at the design frequency. It was then decided to build Traps suitable for full legal power and this is where problem number one arose !

After two days searching the web and telephoning manufactures it became obvious that suitable capacitors were not readily available. I had also tried coaxial Traps, (more about these later). It soon became clear that a solution was needed for the capacitor problem. Some years ago I had designed a lowpass filter for transmitters using double side printed circuit board for the capacitors, this was very successful and it was decided to try this approach for the Traps. A visit to the local pcb manufacture resulted in a generous supply of double sided 1mm thickness Fibreglass off-cuts (some quite large). As the Traps would be wound on 40mm o/d tube 6.5cm long a piece of pcb board was cut to 3.5cm x 6cm and checked on a bridge for its capacity value. This was 96pf. Several pieces were cut and checked and all came within the range 96 to 98pf. Consistent enough to design using 100pf as the design value (this was to allow a little extra capacitance for the ends and anchor points.

The new traps were inserted into the prototype antenna. Tests at 100 watts continuous showed only a slight heating in the 28Mhz trap and some lesser heating in the 24 Mhz Traps. Under normal SSB and CW no heating was detected. No heating was detected at the lower frequencies.

Some contacts were made on 28 Mhz which confirmed that the Traps behaved well and no sign of flash over.

L C Traps.

As traps are an important part of multi-band antenna systems, some aspects of the various types may be of interest. There are two main features of using a trap. It can be used as an insulator at the design frequency or it can be used as a loading device by operation at other frequencies.

Consider the dipole antenna of fig 1. This can be used on more than one band, using one trap in each section. The first section operates on 40 metres and the whole works on 80 metres. The Traps are tuned to 7.1Mhz. If the operating frequency is lower than the trap resonant frequency it acts as an inductance, if above, it acts as a capacitor. Inductive loading will electrically lengthen the antenna and capacitance loading will electrically shorten the antenna..

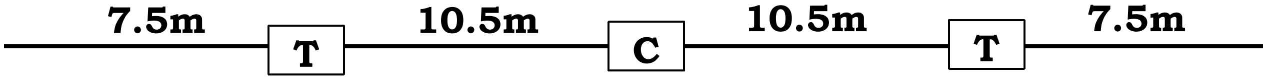
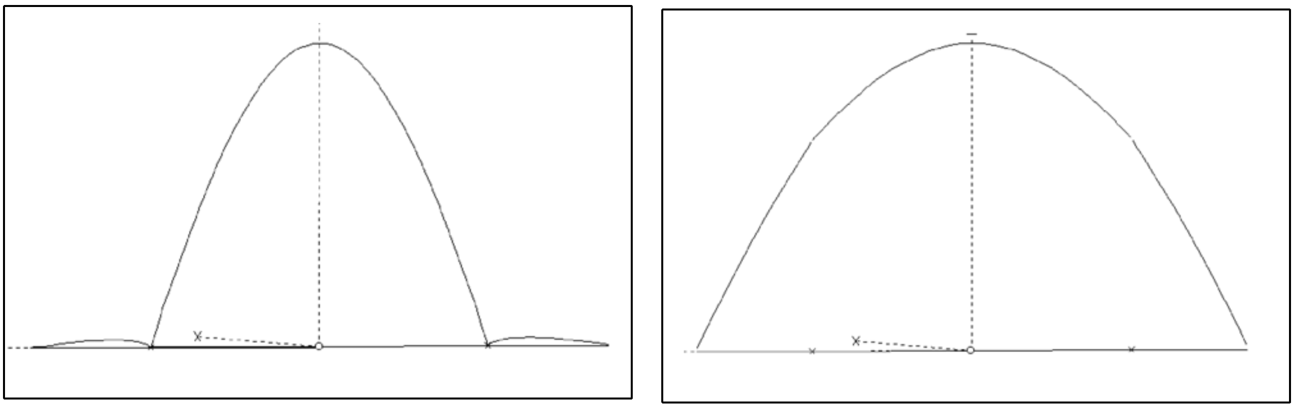


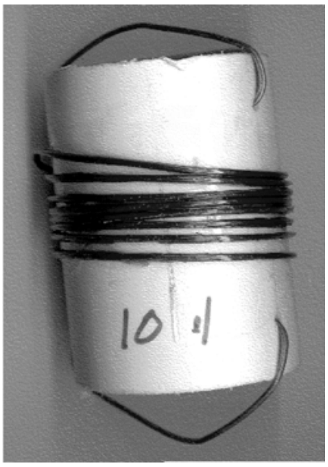
Fig 1.
Traps tuned to 7.1MHz.



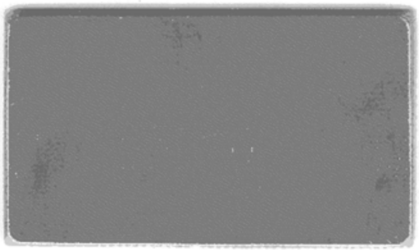
Showing current distribution for 7.1 and 3.7 Mhz in a trapped dipole.

First section to the trap is 10.5 metres long and overall length is 18 metres. a reduction on 80 metres of 12% in length. The trap used a 100pf capacitor. L == 5.025 microH. Because the trap is operating at 7.1 Mhz it acts as a high impedance (insulator) at that frequency as can be seen by the current distribution. On 80 metres it acts as a loading coil reducing the wire length required.

The finished traps where given a good coat of Yacht varnish for weather protection. Changing the values of L or C in a trap will effect the final design considerably. One can not "just fit a trap" and expect good results. In general, the smaller the C means a larger L (to maintain resonance) and a shorter antenna wire length. In some quarters a value of 1pf per metre wavelength has been suggested for the capacitor value, however for ease of construction I settled of a value of 100pf for all Traps and in practice this proved to be satisfactory. The general view is shown below.

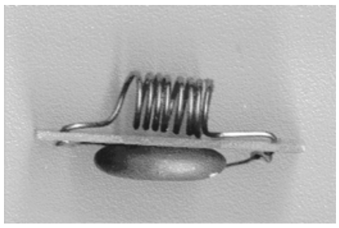


Typical LC trap. The one shown is for 10.1 MHz. turn spacing is adjusted for resonance.



pcb capacitor 3.5 x 6 cm x 1mm. Note; copper on edges (both sides) is trimmed back from edge to avoid flash-over.

End view showing pcb capacitor mounted inside former. also end anchor points.



Original trap using receiver components. C = 150pf

Cutting the pcb board

I found the easy way was to scribe the place you want to cut. Clamp the capacitor section in the jaws of a bench vice. Deeply score along the scribe line (both sides) using the vice jaws as a guide. Then a firm push and pull of the unwanted section and a clean break will occur. This method is quicker and cleaner than using a saw.

Cutting the waste pipe.

I found this was best cut using a wood workers tenon saw, with the waste pipe clamped in a bench vice.

Coax Traps

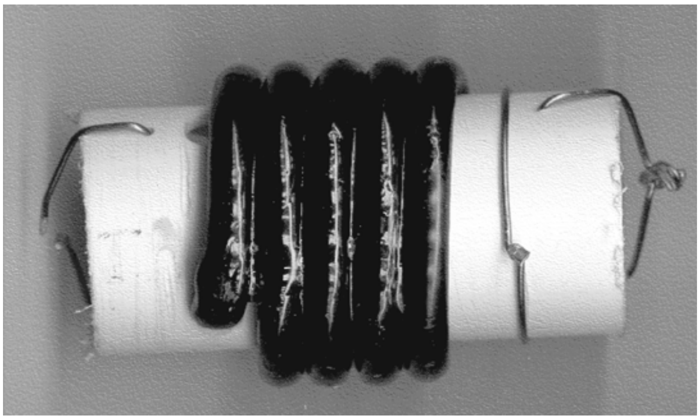
Traps constructed from coax are used by many amateurs, however they operate in a different manner to LC Traps.

The use of coaxial-cable to construct antenna traps was first described in amateur literature in 1981. Coaxial-cable traps are inexpensive, easy to construct, stable with respect to temperature variation and capable of operation at surprisingly high power levels.

Coaxial-cable antenna traps are constructed by winding coaxial-cable on a circular former. The centre conductor of one end is soldered to the shield of the other end, and the remaining centre conductor and shield connections are connected to the antenna elements. The series-connected inner conductor and shield of the coiled coaxial-cable act like a bifilar winding, forming the trap inductance, while the same inner conductor and shield, separated by the coaxial-cable dielectric, serve as the trap capacitor.

The resultant parallel-resonant LC circuit exhibits a high impedance at the resonant frequency of the trap and effectively disconnects everything after the trap from the previous section. Traps which are operating below their resonant frequency function as loading coils and shorten the overall physical length of the antenna. This shortening can be very large and for example a half wave dipole covering 10, 12 or 17 metres the shortening effect can be so large that a "negative" element length would be required!

I have included construction details for those amateurs who want to try them, but be prepared for a frustrating time in establishing the correct element lengths !



I used a similar construction to the LC type and can be seen in the photo's.

Tuning coaxial traps to resonance.

Traps are normally tuned to resonance by adjusting the spacing between turns. However with coax traps this can be difficult due to the "springiness" of the coax. A solution that I use is to make the traps natural frequency slightly lower than required and to use a "shorted turn" to bring to the correct frequency. This is a well known way of increasing the frequency of a tuned circuit. It was used for many years in broadcast receivers to adjust the padding of oscillator circuits (used in the HRO receiver).

The single turn of copper wire (fitted at the braid end) can be seen in the photo of the coax trap. This has no effect on the working of the trap apart from adjusting the frequency. The capacity is distributed along the length of the coax winding and coax traps do not operate in the same way as a LC trap, they act more like a stub.

Element lengths are effected by many things, type of trap used, height above ground, nearby objects, etc.. Always start by getting the higher frequencies correct first. Because each trap isolates the next lower frequency section, adjustments made there will not effect the previous higher frequency section.

General.

Traps should be adjusted to the exact frequency *before* connecting into the antenna. This is best done by using a GDO held close to the coil. The GDO should be calibrated against the station receiver.

It is very important that each trap is tuned to the same frequency as the previous section of the antenna is designed for. Once final adjustment has been made a good coat of Yacht varnish should be applied.

Coax traps should always be connected the same way round. I.E. The braid conductor should go towards the centre of the aerial. They will work either way but failure to observe this simple procedure may result in an unbalanced system and increased SWR. Do not expect to change from an LC trap to a coax type without major changes to element lengths. The reduction in length can be quite considerable at the higher frequencies.

Some amateurs have raised concern about losses in trap antennas. These losses are very small in practice and compared to the advantages of having a multi-band antenna can be ignored.

Full details of the LC traps and element lengths used in the full wave multi-band antenna are given in table 1. Be sure to follow the instructions carefully.

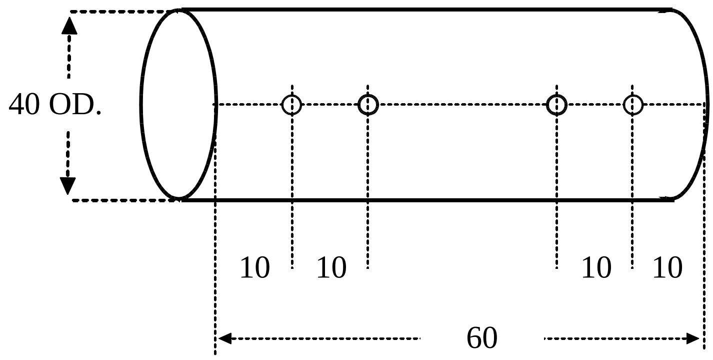
Limited for space?

If space is limited you can reduce the number of bands covered. for example to cover 28, 24, 21, 18 MHz. In this case you will need traps for 28, 24, 21, MHz only. No trap needed for 18 Mhz as it is the last section.

My reason for using a full wave fed at the quarter wave point is that it suited my situation. My shack is approx. 15 metres from the house and the coaxial feeder would be almost directly above the shack. A 12 metre mast is attached to the shack end wall, giving support to the weight of the coax. This prevent the antenna sagging at the feed point. The three quarter wave section goes out across the field and is attached to a tree.

LC Trap Former Material 40 mm OD. White waste pipe.

Type = Plumfit PP Pushfit System 40mm/1.1/2



Ends holes also drilled on reverse side.

All Hole Dia = 2mm

All dimensions in mm

Wire used = Enamelled copper 1.2mm od.
For winding details see table.

Note:- some traps will need a hole drilled for the winding end at the half turn position.

Table 1. LC Trap winding details.

Freq	Turns	microH	Capacity
28.4	2.5	0.312	100pf
24.94	3	0.407	"
21.225	3.5	0.562	"
18.118	4	0.771	"
14.2	5	1.256	"
10.15	8	2.458	"
7.1	10.5	5.024	"

Amateurs who have a supply of 100pf high voltage capacitors can of course use these instead of the pcb ones. Values outside the range 90pf to 110pf may need a change in antenna element lengths.

Equipment used for this project.

Kenwood TS530s. AT 230. Howes SB32 SWR bridge

Lafayette TE18 Grid dip meter.

Wayne Kerr Universal Bridge B221

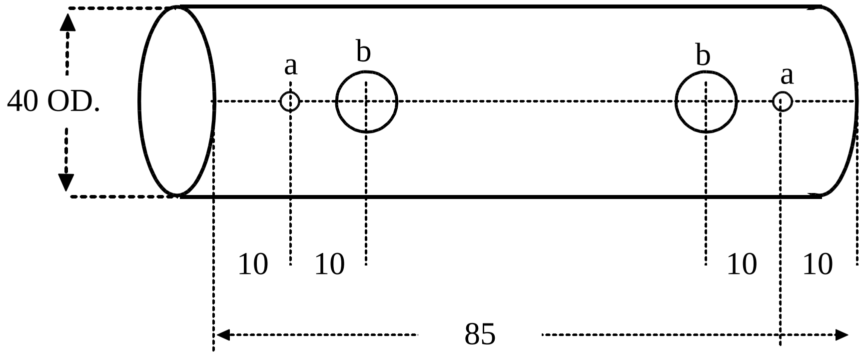
Computer program; MMANA-GAL v 1.0.0.45 by JE3HNT.

(this can be downloaded free via the link on the RAOTA Web site)

Total cost of materials used in final antenna estimated less than £25 (not including the coax traps, coax cost £14)

Coax Trap Former Material 40 mm OD. White waste pipe.

Type = Plumfit PP Pushfit System 40mm/1.1/2



Ends holes -a- also drilled on reverse side.

Hole Dia

a = 2mm

b = 8mm

All dimensions in mm

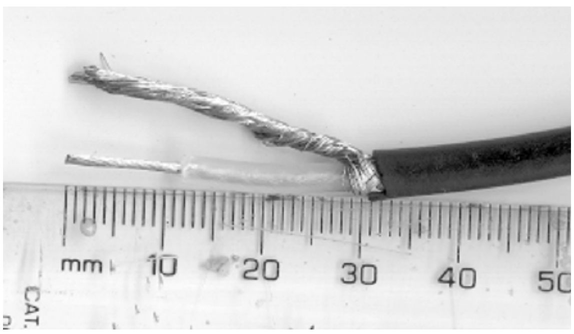
Coax used = Samson BSEN 50117 Low loss 75 ohm copper braid and copper foil. Available from good Radio/TV stockists.

for winding details see table 2.

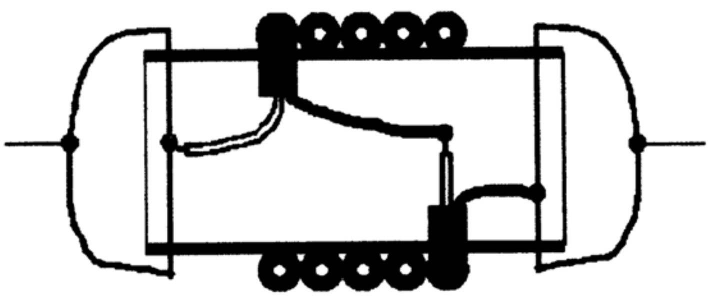
Table 2. Coaxial Trap winding details.

Freq	Turns	coax length	Capacity
28.4	4.25	0.8 m	56pf
24.94	4.75	0.85 m	60pf
21.225	5.5	1 m	72pf
18.118	6.0	1.06 m	76pf
14.2	7.75	1.34 m	96pf
10.15	10.25	2.36 m	164pf
7.1	15	2.5 m	173pf

Important: Coax length includes 30mm prepared for each end (see diagrams below), and 20mm (not prepared) inside former at each end. Length is very critical as you are effecting both inductance and capacity with any changes. Shorted single turn added at Braid end. Increase former length to 115mm for 10 MHz and to 145 mm for 7.1 Mhz trap.

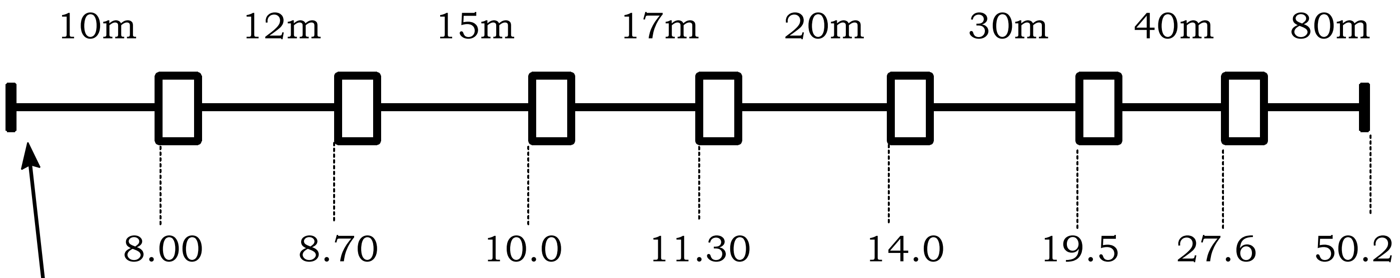


Details of coax ends.



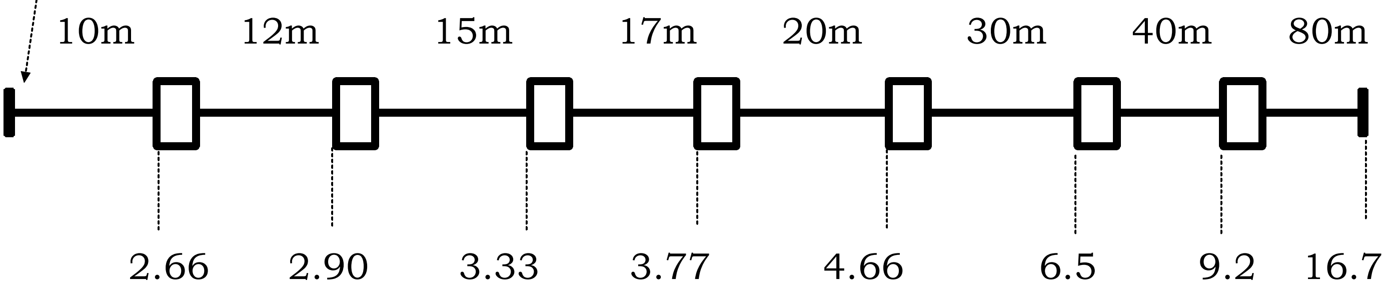
Showing trap connections.

Full Wave Antenna Quarter wave feed point. For LC Traps.
Element lengths in metres from feed point to start of each trap.



Dimensions is for the $^3/_4$ wave section using LC traps.
Important :- element lengths in metres. from Feed Point to trap start.
This takes trap length into account.
Centre Feed point. (using 4:1 balun)

Balun Feed Point



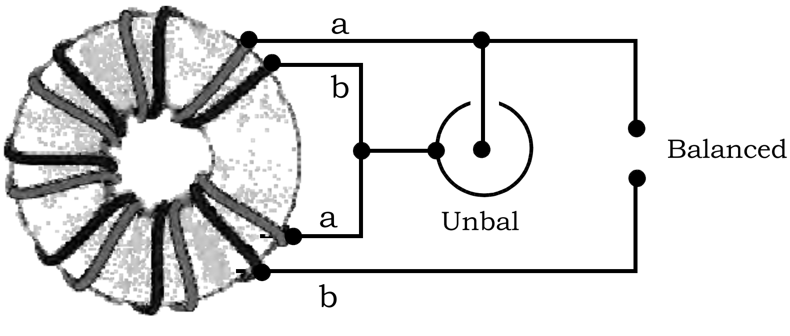
Elements lengths for $^1/_4$ wave section using LC traps.

BALUN at antenna end of coaxial feeder.

As we are using a full wave antenna it will have a higher quarter wave feed point impedance and a 4:1 Balun was found to be optimum for low SWR. You may like to try your own design but I used a ferrite core taken from a "dud" computer power supply. Most dealers will have these and as they throw them away it should be possible to obtain one. Strip the ferrite cores out and remove the wire. The thicker wire can be used for the balun. I suggest you "hard draw" the copper wire before reuse to remove any kinks.

The two coils need to be close together and I pushed both wires into a length of heat shrink tubing. After this was heated the tube shrank and pulled the two wires very close The tubing also insulates the wire from the core. Two coils (inside tubing) each of seven turns were used.

Core used, (yellow), 10mm thick, 23mm od, 13.5 id.



It is interesting to compare the computer predictions with the actual result obtained in practice. My antenna is at an average height of 10 metres. The table below shows the resonant frequencies and the bandwidth for an SWR of up to 2:1.

	Computer			Actual		
Band	Freq Mhz	2:1 B/W KHz		Freq MHz	SWR	less than 2:1 B/W KHz*
80 m	3.61	94		3.65	1.05	300
40 M	7.1	106		7.1	1.5	200
30 m	10.142	123		10.125	1.3	50
20 m	14.129	188		14.0	1.0	350
17 m	18.1	197		18.07	1.5	100
15 m	21.2	260		21.2	1.1	450
12 m	24.94	377		24.9	1.1	100
10 m	28.5	433		29.0	1.2	1700

Computer showed that with a matched source the SWR was 1:1 at resonance. The actual SWR is shown for the resonant frequency. All these are without an ATU. The bandwidth in practice is wider than the computer prediction. I don't know why this is but suspect it's due to the type of traps used, it was a welcome bonus ! (* band limits prevent a full assessment).

For Transistor rigs an ATU is recommended to keep within the rigs SWR limits across the bands..

Coax feeder, 4:1 Balun and SWR.

It is important that you know if your SWR reading is correct. Many SWR meters are inaccurate. I have three different SWR bridges and all give different readings ! Only one is accurate enough to obtain true SWR readings. I use The Howes SWB30 for accurate reading but also have a Kenwood AT230 and one of unknown make. They all give indications of SWR and can be used to adjust for a low SWR. However SWR can be greatly effected by the coax used and this should be checked before relying on SWR measurements.

The way to do this is first connect a 50 ohm dummy load directly to the output of the SWR bridge. If the bridge is accurate it should show a 1:1 SWR. Next connect the coax you are going to use in place of the dummy load and transfer the 50 ohm load to the far end of the coax. The SWR should still be 1:1 if the coax is OK and 50 ohm.

I did this at 3.7MHz and 28.5 MHz and obtained 1:1.

I then connected the 4:1 Balun described to the far end of the coax and connected a 200 ohm dummy load to the output (antenna) side of the balun. The SWR was still 1:1 on all bands except 3.7 MHz where is was 1.2. This was considered reasonable but indicated that the ferrite (which aids coupling at low frequencies) could do with improvement at a later date.

These tests showed that the feeder system was satisfactory and that SWR reading with the antenna connected would be reliable.

Another useful check is to add an additional length of the same coax into the feed line. If all is OK the SWR readings should stay the same. If the SWR vary it may be do to standing wave on the feeder due to an unbalanced system. This check should be carried out on each band.

These are all simple checks but help to ensure you are getting optimum results from your antenna system. A well balanced antenna system will not only help avoid TVI, BCI and breakthrough on neighbours telephones but also greatly reduce noise and interference which would otherwise be picked up on the vertical section of the coaxial feeder. When conducting these tests always use the minimum amount of power that will give a full scale calibration with the SWR bridge in its most sensitive setting. Also check that the frequency in not in use before conducting tests with the antenna connected. You should also give you call sign during any tests to comply with licence conditions.

Bargain buy.

I had managed to buy (for £5) a 300 metre reel of unknown coax at a car boot sale. It had an aluminium braid and sheath, solid dielectric and copper inner wire. I was told by several amateurs (in the know !) that it was not suitable for amateur radio. Conducting the tests described it proved to be 50 ohm very low loss and give a 1:1 SWR at all test frequencies, and, it was also less weight than normal coax.

Connecting to the braid posed a problem because it was impossible to solder, but I solved this be fitting a double screw brass connector to the braid and then soldering the brass connector to the balun. The finished spreader with balun and coax in place was coated with a generous amount of Yacht varnish.

SWR

The standing wave ratio along the feeder is dependant entirely on the load presented at the antenna end, and no amount of alteration at the transmitter end can alter the actual SWR.

Take an example of where the SWR is 2:1 due to a mismatched antenna.

The SWR meter at the transmitter will show 2:1 (assuming no loses in the feeder system). Using an ATU to reduce this to 1:1 at the transmitter will not change the actual SWR and a second SWR meter placed in circuit between the ATU and feeder will still show that it is 2:1. However matching the transmitter in this way will ensure that (with a transistor rig) the P.A. is protected and also delivering its full power output to the antenna system.

However a 2:1 SWR means that some of the transmitted power arriving at the antenna end of the feeder is being reflected back down to the transmitter end. As this is mismatched some of that it reflected back up to the antenna. This goes back and forth until it is dissipated in the feeder line. This loss is why a "lossy" coax will show less SWR than a low loss cable. In other words, if you improve the quality of the coax used you may well find the SWR has increased !

What is the effect of this high SWR in practice?

In an effort to find out I set up a remote RF indicator to measure the radiation from the antenna. Starting at the resonant frequency of the antenna on 80 m the SWR was 1.05:1 without an ATU. I set the RF indicator to read full scale.

Changing frequency to get an SWR of 2:1 the RF indicator showed only a very small reduction in radiation. I then used an ATU (AT230) to adjust the SWR to 1:1, the indicated radiation dropped slightly more ! Most likely due to losses in the ATU. Checking at both band edges showed the same results. Only when the SWR was higher than 3:1 did the ATU show an improvement in the radiated signal.

SWR up to 3:1 seems to have little effect on the radiated signal. In fact the introduction of the ATU showed a loss of about 0.5dB in radiated power !

However it is important to keep SWR low with transistor P.A. stages to protect the P.A. transistors and also ensure maximum power output, as some transistor transmitters automatically reduce power output if the SWR is high. It is also good practice in any case to aim for a low SWR with any antenna system.

These findings should not be taken as conclusive but were unexpected and seem to indicate that we may worry far to much about high SWR .

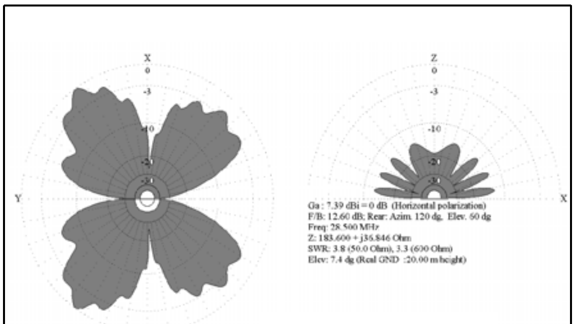
Balun.

There was a very considerable reduction in received local noise. I believe this is due to having a balanced system and using a balun, greatly reducing noise picked up on the coax down lead. On 80 metres the reduction was around 5 'S' points.

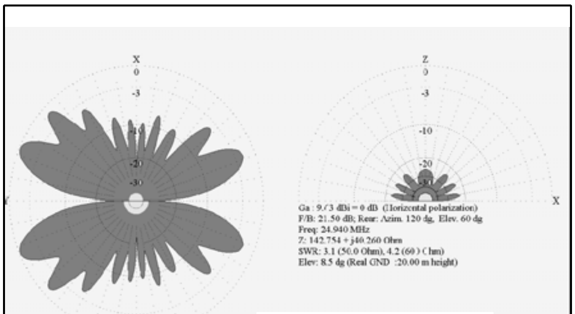
Results in practice.

On transmit reports were good on all bands even though conditions were very poor. It will take a longer period to fully check the performance, but first signs are very encouraging.

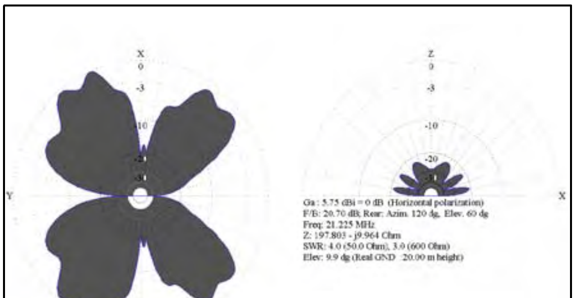
It's a real joy to be able to switch bands without having to tune an ATU !



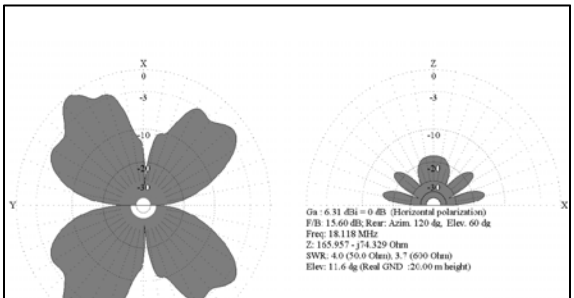
28.5 Mhz



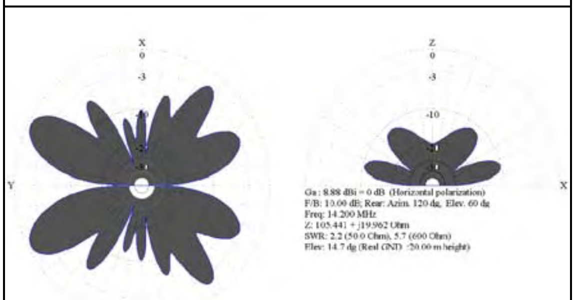
24.94 Mhz



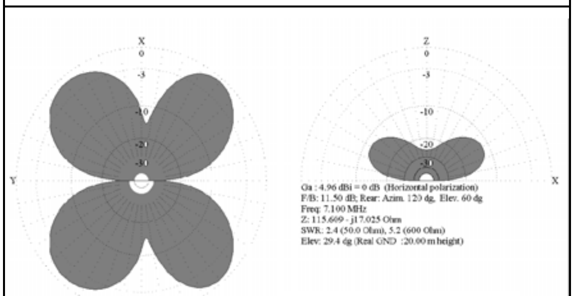
21.225 Mhz



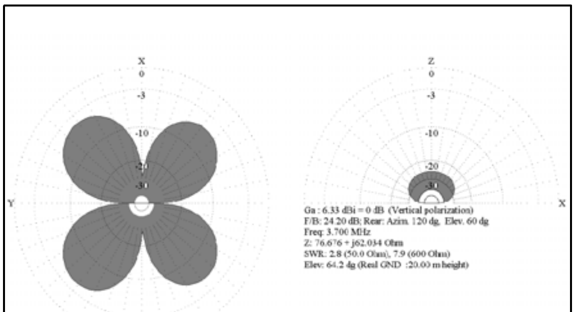
18.1 Mhz



14.2 Mhz



7.1 Mhz

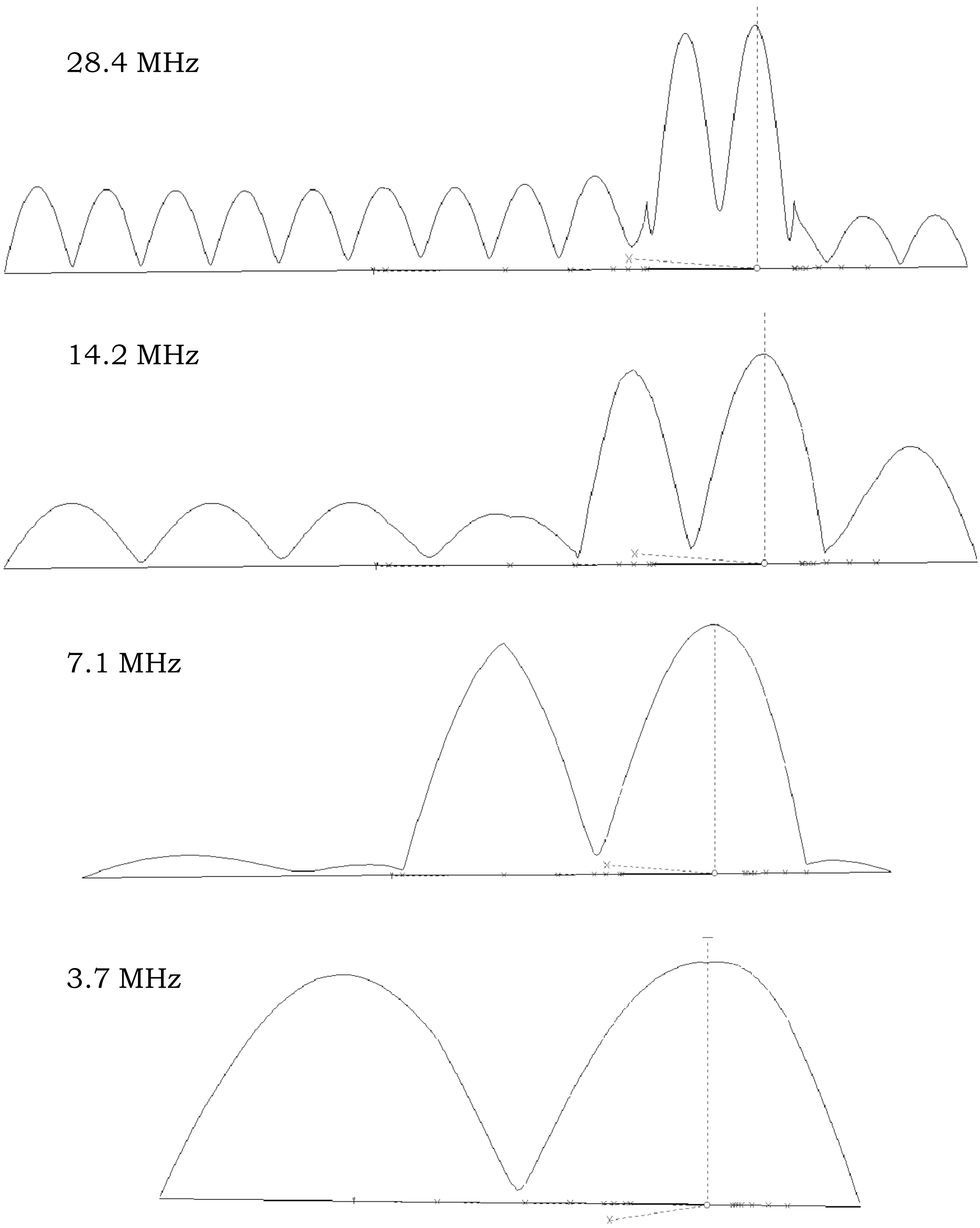


3.7 Mhz

Computer prediction of Antenna Polar Plots 28.5 MHz to 3.7 MHz at a height of 20 metres.

The extra lobes at some frequencies are due to the current distribution in the unused elements due to the harmonic relationship between various amateur bands. This has not proved a problem in practice (see current distribution plots). The plots shown are at the first major elevation lobe (small diagram on right hand side of each plot).

The antenna height will change these elevation angles of radiation.



Computer prediction of the current distribution.

These are typical of what happens due to the harmonic relationship of amateur bands. The smaller currents flowing in the other sections causes minor extra lobes to appear in the radiation patterns.

Note 3.7 MHz uses whole antenna so no extra current points.

Alternative Versions of the Multi-band Antenna.

Depending on the amount of space available, you may like to try one of these.

1.5 wavelength centre fed, overall length 101 metres

For this use the $^3/_4$ wave element lengths on both sides and a 4:1 Balun.

Half wave centre fed, overall length 33 metres.

For this use the $^1/_4$ wave element lengths on both side a 1:1 Balun (not 4:1) may be better in some installations. This version may work without a Balun but this is not recommended.

Radiation.

The 1.5 wavelength will have similar radiation to the fullwave version but with some extra lobes.

The half wave version will be similar to a normal dipole, but with some extra lobes.

Height

The height used for the antenna will have considerable effect on the elevation angle radiation. The effect of this can be seen in the Polar diagram plots shown. On 80 metres it will be very high angle unless you happen to have a 80 metre tower !

Element Lengths.

Also nearby trees, buildings and diameter of wire used can effect the element lengths required. Be prepared to make minor adjustments although the wide antenna bandwidth found in practice will cover most situation. If required the use of an ATU will enable a 1:1 match to be obtained at all frequencies 80m to 10m.

Finally

Did I meet my goals?

1. Must cover at least five HF bands.	- Covers Eight.
2. Low SWR at the design frequencies.	- Yes
3. Not need an ATU.	- No, except for large changes in frequency.
4. Have same radiation pattern on each band.	- Similar.
5. Be easy to repeat the construction.	- Repeatable
6. Be adaptable for different locations.	- Yes

Did I meet my goals ?

You be the judge !