Antenna Workshop

Peter Dodd G3LDO comes into the antenna workshop to explain the ideas behind the cubical quad loop antenna, and describes models for the higher h.f. bands.

The Cubical Quad Antenna

I'll start with a little bit of history. In 1939, a group of radio engineers from the United States of America (USA) installed a high powered broadcast station, high in the Andes mountains at Quito in Ecuador. The high powered station, Missionary Radio HCJB, operated in the 25m short-wave broadcast band and to ensure the best possible reception of HCJB in the United States a large four element parasitic beam was designed and built.

However, although this beam worked well there was a problem as corona discharges occurred at the tips of the driven element and directors. The discharges were caused by the altitude of the station and operating the high-*Q* beam antenna at high power in the thin air at 2700m (10,000 feet). The corona was quite destructive, often with molten bits of aluminium from the antenna elements falling to the ground!

Clarence C. Moore W9LZX, one of the engineers of HCJB eventually solved the problem by designing a lower *Q* antenna from the idea of a pulled-open folded dipole. The concept of a loop antenna without high impedance ends to the elements was developed and this solved the corona problem. A reflector was added to produce the necessary directional gain. Later, W9LZX scaled his quad loop antenna for the Amateur Radio bands.

The Single Loop

The basic single quad loop antenna, often called a full-wave loop, can also be considered as two spaced dipoles fed separately as shown in **Fig. 1(a)**. The gain of these two dipoles together is around 1.5dB over a single dipole. A more simple way of feeding such an arrangement is to bend the ends of the elements of both dipoles towards each other so that they touch as shown in **Fig. 1(b)**.

When the lower element is current-fed in the centre, the ends of the element voltage feed the top element. The gain of this full-wave element is about 1.4dB over a single dipole and has a very similar azimuth polar diagram, as shown in **Fig. 2**, to the dipole.

The feed impedance of a single quad loop antenna is around 125Ω. The current distribution is shown in **Fig. 3** and shows that the maximum current occurs in the horizontal sections of the loop. Relative current amplitude in Fig. 3 is shown as 'separation' from the element and you will see that current minimums occur half way up the vertical sections of the loop.

The polarisation of the quad loop antenna fed in this way is horizontal and the same loop antenna fed halfway up one of the vertical sections would be vertically polarised. The relative phases of the currents in the loop are indicated by relative positions of the current distributions to the element. Note that the current in the top vertical section is 180° out of phase to the current flowing in the bottom of the antenna.

The Cubical Quad Antenna

Just as in the case of a Yagi antenna, parasitic elements can be added to the loop and in this instance it's often called a cubical quad antenna. Higher gain quad loop antennas can be constructed using a reflector and any number of directors. However, here I will restrict the description to a two element quad loop antenna.

The cubical quad beam is a parasitic array with a driven element and a reflector. It has two elements that consist of closed loops with circumferences at, or near, one-wavelength long at the design frequency. The parasitic reflector element can be re-tuned as a director but, in this instance, both the gain and the front-to-back ratio are inferior to the reflector element arrangement.

The basic configuration is shown in **Fig. 4**, with the dimensions given in **Table 1.** From this it can be seen why the antenna has been called the cubical quad antenna. The reflector may be constructed using the same dimensions as the driven element. A variable stub is then used to lower the resonant frequency of the reflector. This stub can be used to tune the reflector for the greatest gain or the greatest front-to-back ratio of the beam, the latter is often the most desirable.

Dimensions for the driven element (DE), reflector (RE), element spacing (SP) and element support length (ES), for several h.f. bands are given in both metric and Imperial lengths. The dimensions given are for a quad loop antenna using an element spacing of 0.14λ.

Note, that the dimensions given in the table are for plain copper wire **and not for insulated wire**. Plastic insulated wire has a velocity factor of about 0.95. So, to derive lengths using insulated wire from Table 1 values, you have to multiply the values given by this figure for the element lengths.

The feed impedance of the two-element antenna shown, is about 65Ω, so the driven element can be connected directly to 50Ω feedline with only minimal mismatch. The 0.14λ spacing was chosen because it is the most prevalent in antenna literature. However, the spacing for a two-element quad loop antenna can be reduced down to 0.1λ without any real deterioration in performance. And reducing the separation off the two elements reduces the feedpoint impedance too! So, this can give an improved match to 50Ω coaxial cable.

The quad loop antenna described above, can be made into a multi-band antenna by interlacing loops for the different bands on to a common support structure. But in this case the element support length (ES) should be the length for the lowest frequency band. The only disadvantage of this arrangement is that the spacings between the driven and the parasitic elements, expressed in wavelengths (SP), is different for each band.

Element Support Spreaders

Ideally, the element support spreaders should be made from tapered fibre-glass rods. These are expensive and rather hard to come by, although they have the outstanding advantage of being strong and durable. A much cheaper and more easily obtained material is bamboo and comes in the form of garden canes, normally found in garden centres.

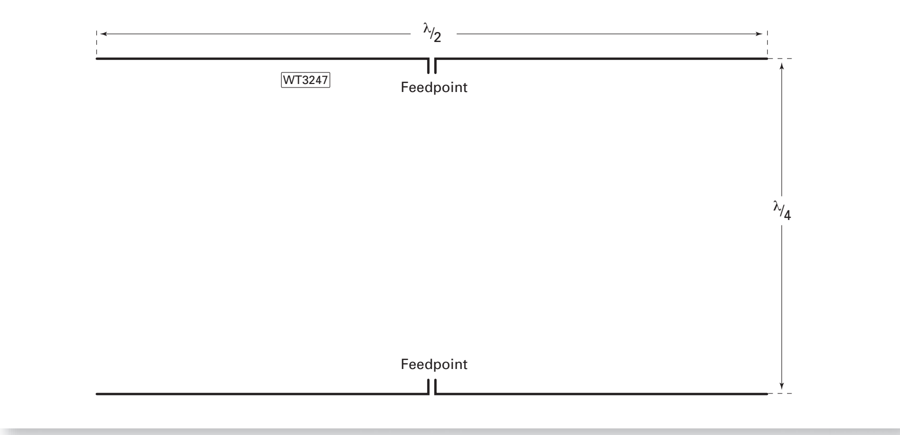
Bamboo canes need weather protection if they are to last more than a year or so. My favourite method is to treat them with a couple of coats of outdoor shellac or varnish. I've not tried any one of the various wood preservatives that are available these days, but these products should prolong the life of cane spreaders. Four bamboo poles are required for each loop and these should be clean, straight and free of splits and cracks between the 'rings' on the stems.

A local garden centre used to supply green plastic coated canes that were almost ideal for antenna and loop spreaders. I used them for a while but unfortunately, after two or three years, the plastic covering deteriorated after exposure to weather and ultra-violet (u.v.) in sunlight.

The 'canes' that the centre now sells, look like plastic covered canes but they are, in fact, plastic covered metal tubes. The clue to their makeup is that, unlike cane, these items have no taper and give a metallic sound if dropped. **These, most definitely, cannot be used as antenna spreaders**.

The Spider

The structure required to fix the bamboo spreaders to the boom is often regarded as rather a challenge. The method that I propose here, fixes the canes to the boom using shelf brackets. These items are cheap, easy to obtain and are strong. The brackets are fixed at 90° to each other around the boom using Jubilee clips, or hose clamps as they're called in the USA.



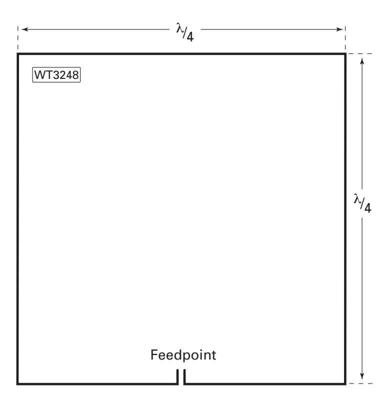


Fig. 1:(a) Two half-wave dipoles spaced quarter wavelength apart. (b) Two half-wave dipoles with the elements bent so that they form a full-wave loop.

The spreaders are then fixed to the brackets, again using Jubilee clips. Then you add another four bracket at the other end of the boom. Of course, you must check that the brackets align with those that you put on first!

Each spreader cane is then fixed to the shelf bracket with two Jubilee clips per cane. The portion of the cane clamped to the shelf bracket is encased in a short length of hose-pipe as shown in **Fig. 6**; this minimises the chance of the cane splitting when the clips are tightened up.

The chances are, that you will not get a cane and a piece of hose that will fit together. The trick is **very carefully** to slice the short length of hose lengthwise using a strong, sharp-bladed knife. The hose can then be opened out so as to fit over the cane.

The main advantage of the method of construction I've described, is that you don't need special tools, other than a screwdriver and a sharp knife. Two Jubilee clips are required to fix the four shelf brackets to the boom as shown in **Fig. 5**. This is a rather cumbersome job and is more easily accomplished by two people (four hands!), although I did manage on my own.

The quad structure with two spiders uses 20 hose clips. To avoid the possibility of some sort of repetitive injury that might accompany fixing all these clips, a rechargeable electric screwdriver might be in order.

Almost all Jubilee clips have a 7mm hexagonal-headed nut as well as the screwdriver slot for adjustment. For this reason I find it best to use the electric screwdriver with a 7mm socket, rather than a conventional screwdriver blade.

Shelf brackets have considerable strength along the axis of the boom – after all they are designed to hold a considerable weight. The small brackets that can be used to build the 28MHz quad shown in the photographs are, according to the label, capable of supporting 25kg. If you want to build a larger quad loop antenna for 14MHz

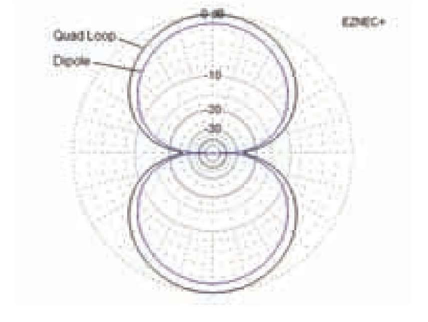


Fig. 2: Azimuth polar diagrams of a dipole and a full-wave loop compared.

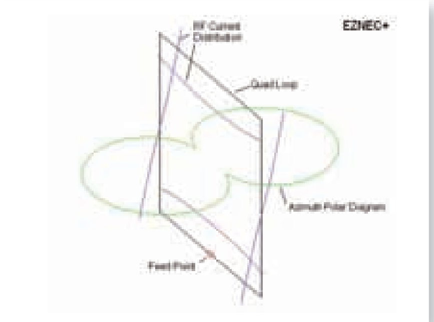


Fig. 3: Full-wave loop showing the current distribution and polar diagram.

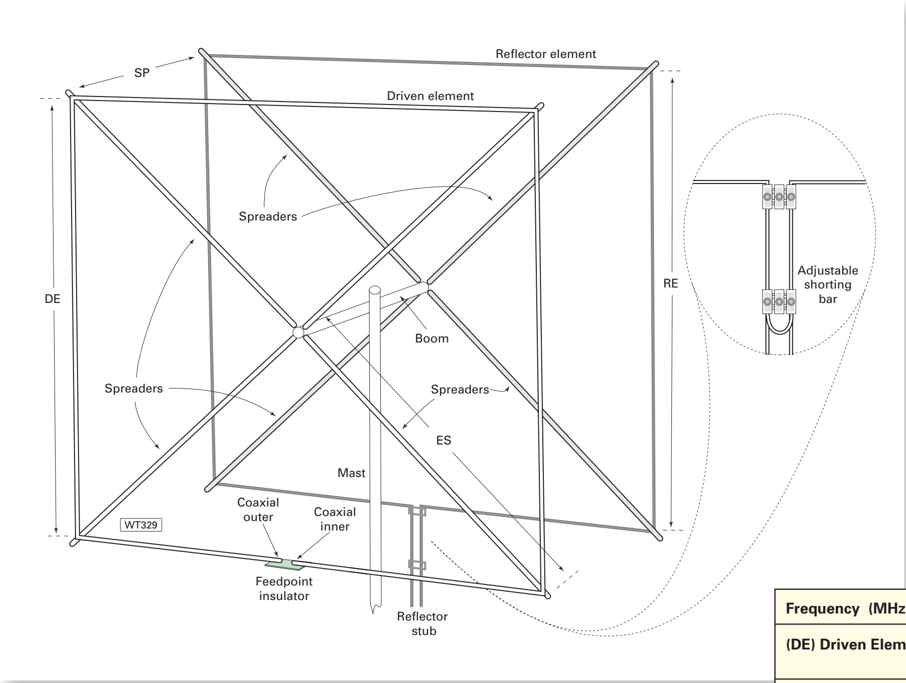


Fig. 4: The general layout of a two-element wire quad. Dimensions DE, RE, SP and ES are given in Table 1.

Fig. 5: Method of fixing the shelf brackets to the boom using Jubilee clips to construct a spider.

then larger brackets rated at 32kg would be more suitable.

If you want to build a really robust antenna, then the spider shown in **Fig. 7** is recommended. It comprises two lengths of aluminium angle fixed to the boom at 90° to each other, using exhaust pipe clamps. The spreaders are then fixed to the angle stock using Jubilee clips in the manner described above.

Wire Elements

Cut the wire elements to length as shown in Table 1. My personal preference for h.f. antennas, is Imperial unit measurements when cutting element lengths. Working in millimetres I find rather tedious with the longer h.f. antenna lengths.

Remember to multiply the Table 1 figures by 0.95 if you are using plastic covered wire. I use plastic tape markers along the wire, spaced every 2.65m (105in) for this antenna so, marking positioning the corners to be attached to the element support.

If you're using insulated wire for the elements, the loops can be fixed to the element supports using just plastic insulating tape. Another method is to fix short lengths of thin plastic tube to the element supports and run the wire through the tubing. This method is suitable for elements made from bare stranded copper wire.

Feeding the Driven Element

With all the quad loop antennas that I've built, the method used to connect the coaxial cable to the driven element has always been the simplest. Arrange the 'break' in the driven element to be in the centre of the lowest horizontal section. Hold the ends close together with an insulator. Then connect the coaxial cable inner to one side of the element and the braiding to the other side.

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

*
Note: These dimension are for one side of the quad. The total length of the element is four times this figure.

Table 1: Dimensions for a two-element quad loop beam. These dimensions, see Fig. 4, 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.

As I mentioned earlier, the feedpoint impedance of this antenna is around 65Ω, so the driven element can be connected directly to 50Ω coaxial cable with only minimal mismatch. Purists will deem this unsatisfactory because it's a balanced antenna that's being fed via an unbalanced feeder. But I've never found this to be a problem. And you can quite easily fit a 1:1 current balun near the feedpoint if you wish.

With wire antennas, I often use an electrical connector block as an insulator, as this provides a very convenient method of connecting the coaxial line to the element. Also shown in the heading photograph is a section of aluminium angle to support the feeder from the mast to the feedpoint.

Testing & Setting-up

When it come to testing and setting up the antenna, like any other parasitic beam, it can be tuned for either maximum forward gain or maximum front-to-back ratio. Setting it up for maximum front-to-back ratio is easier because the characteristics of the antenna are easy to check. Determining the point of maximum forward gain is far more difficult. Computer modelled azimuth plots of a quad loop antenna are shown in **Fig. 8**.

The computer model with the slightly 'larger' reflector gives a greater front-to-back ratio while the one with a 'smaller' reflector gives greater forward gain and a reduced front-to-back ratio. In practice, the best way to design the reflector is to make it the same size as the driven element and to have a variable stub as shown in Fig. 4.

The s.w.r curves for the quad are shown in **Fig. 9**. The line labelled curve A, is the computed curve of the quad loop antenna when tuned for maximum gain. The line shown as curve B, is the computed curve for the quad loop antenna tuned for maximum front-to-back ratio and it has a wider s.w.r. bandwidth. The line labelled curve C is the actual measured s.w.r. plot of the antenna described here.

You'll notice that the actual measured s.w.r. (C), although having a similar characteristic to curve B, is actually flatter and lower than curve B. The reason for this peculiarity, is that the calculated s.w.r. was as 'measured' at the antenna feedpoint. But the measured s.w.r. plot was made via a 15m length of RG58, with its length loss and subsequent reduction of measured s.w.r. at the rig end.

Computer Models

I have used quite a few computer models and plots in this article all using *EZNEC4*. For those of you who may doubt the veracity of these programs you may be interested to see how they compare with the real world. For those of you who read *PW* regularly you should read my article about the program *Polar Plot* in the June 2006 issue of *PW*.

In the article of June last year, I described a system that can plot the actual signal strength of real antennas using a receiver, a computer sound card and appropriate software, in this case *Polar Plot*. The polar diagram of a v.h.f. 145MHz quad loop antenna is shown in **Fig. 10** that shows the effect of changing the size of the reflector element using a stub as mentioned earlier.

You can see that the results are similar to those shown in the computer model of antennas built along the lines of Fig. 4. Some asymmetry is evident, the cause of which is not known. ●

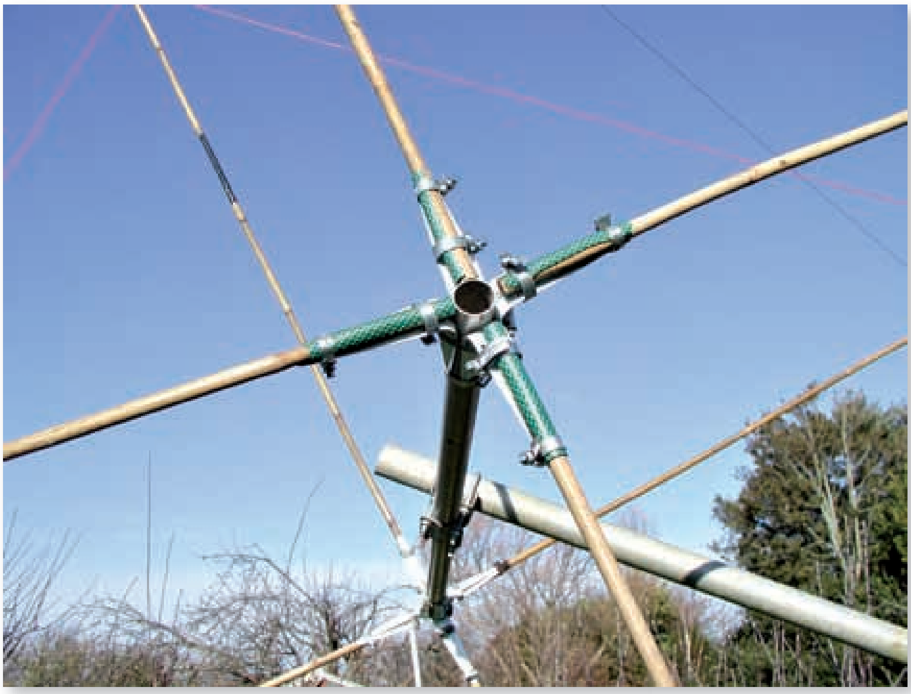


Fig. 6: Method of fixing the cane spreaders to the shelf brackets using Jubilee clips and protective garden hose sections.

Fig. 7: A method of constructing a robust spider for a large quad using angle aluminium and car exhaust clamps.

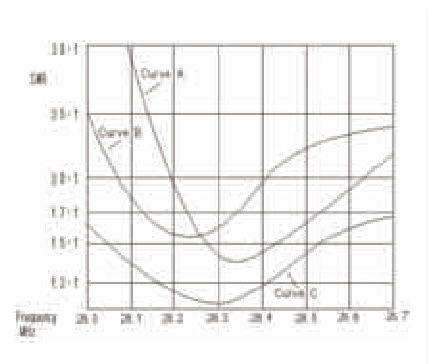


Fig. 9: Standing wave ratio (s.w.r.) curves. A is the computed curve of the quad tuned for maximum gain. B is the computed curve for the quad tuned for maximum front-to-back. C is the actual measured s.w.r. plot of the antenna described in the text.

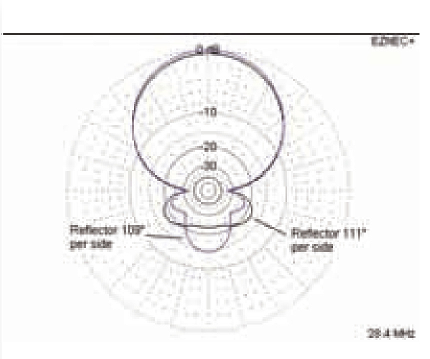


Fig. 8: Computed free-space azimuth polar plots of a 28MHz quad loop antenna. The slightly larger reflector gives a greater front-to-back ratio while the smaller reflector gives greater gain.

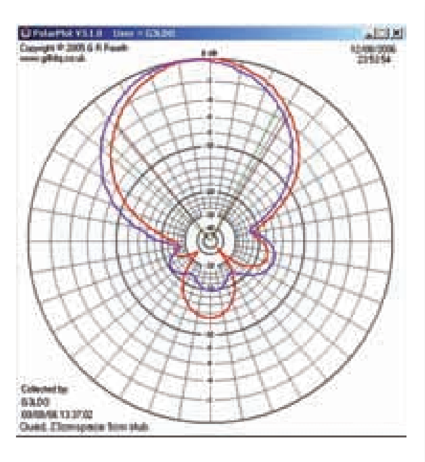


Fig. 10: Polar plot diagram of a v.h.f. quad loop antenna, showing the effects of altering the size (and resonant frequency) of the reflector.