T-boom Yagis

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This article provides very detailed, indeed quite specific, instructions on how to fabricate a multi element VHF Yagi, in this instance for 1296 MHz. While being quite specific in measurement detail and construction techniques for the frequency chosen, the methodology could be applied to a very wide range of amateur (and non-amateur) antennas.

Introduction

About a year ago, I started considering increasing the size of my 1296 MHz antenna. I currently use a home-brew 39-element DL6WU-design Yagi.

It was designed using the Microsoft® Excel spreadsheet created by David Tanner VK3AUU in SuperCalc and translated to Excel by Peter Freeman VK3KAI. I used 12 mm box-profile aluminium for the boom material, and 4.74 mm aluminium tube for all the elements (except the driven element, which was 3.175 mm copper tube). I also wanted to build a couple of Yagis scaled for use with my 1090 MHz ADS-B receiver.

I was aware that, at 4.74 mm, the diameter of element material was larger than ultimately desirable for 1296 MHz, and that it would also be preferable to reduce the cross-section of the boom material. Finding small element material was, well, elementary… Aluminium TIG welding rods are available in a couple of suitable diameters; it was easy to obtain 2.5 kg of 1000 mm long rods, of 2.4 mm diameter. Brass rod of the same diameter would be used for the driven element (a folded dipole). Wondering how best to approach the boom issue, I asked about…

Theory

One person I asked was Gordon MacDonald, nee VK2ZAB, till recently VK3ACC and currently VK3EJ. Gordon mentioned an idea he had had a few years earlier, but had never acted upon: that of using "Tee" profile aluminium as boom material.

"Tee" profile looks, in cross section, like the letter T. The idea was to turn the material upside down, and mount the elements through the top of the upright portion of the T (within a millimetre of the top). With the element in its final position, the top of the boom would be punched down using a cold chisel, holding the element firmly in place – full metal-to-metal contact.

The "Tee" profile chosen for this project has a wall thickness of 3 mm, and the "upright" and "base-plate" portions of the T measure 25 mm (refer Diagram 1: Tee Profile). It is available in lengths up to 6.5 m long from Capral, and should be available elsewhere in shorter (2 m) lengths. The Capral Product Code for this profile is currently 841506, though it used to be called "E20193MF605400" in the old Capral "Little Blue Book".

This article is to document how I implemented Gordon's idea.

Tools

Firstly I will run through the list of tools I used in making this Yagi. You may not have all of these available but, whilst this is what I used, others may be substituted.

For cutting the element material to length:

- 150 mm vernier callipers
- 300 mm steel ruler
- Fine tip permanent marker
- Cable shears
- Small mill bastard file

For marking, cutting and drilling the boom:

- Scriber
- Centre punch
- Hammer
- Ruler or tape measure
- Marking gauge
- Try square
- Drill (preferably a drill press)
- 2.5 mm drill bit
- 16 mm drill bit
- Hacksaw
- Small round file
- M3 x 0.5 tap
- Tap wrench

For fitting the elements:

- Cold chisel
- Soldering iron

Materials

- 25 x 25 x 3 mm "Tee" profile for boom material
- 2.4 mm aluminium TIG welding rod
- 2.4 mm brass rod
- N socket – with four hole flange
- 4 x M3 x 0.5 mm machine screws, with split or external star washers, preferably stainless steel
- UT-141 or QF-141 for 4:1 balun
- Epoxy resin (Araldite™)
- Solder

Construction

As mentioned in the Theory section, this article is to document a method – not an antenna design. For this example, I made use of the VK5DJ Yagi Calculator, which produces dimensions based on the DL6WU design, to produce a 10-element Yagi for 1296.150 MHz. Feel free to use whatever design you like, but be aware that you are **experimenting**!

Firstly, cut the passive elements to length from the aluminium rod; and cut the driven element to length from the brass rod. Mark the rod with either the scriber or a fine tip marker, and cut using the cable shears. Check the length with the Vernier callipers and, if a little long, use the file to reduce to the desired length. (Using this method, I found it easy to make near-to square ends when cutting with the shears; and length was within 0.5 mm of the desired figure. This was handy when cutting the 196 passive elements for my new four-Yagi array – an exercise that only took four hours in total – and practice does make perfect…)

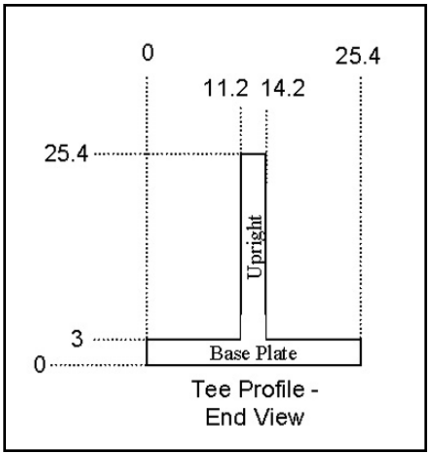


Diagram 1: Tee profile – end view.

Secondly, cut your boom material to the required length.

Next, use a ruler/tape measure, the try square and a scriber to mark the position of all the elements, with a scored vertical line on the "Tee" upright.

In order to suit the 2.4 mm element material, I decided to centre the 2.5 mm element mounting holes 2 mm down from the top of the "Tee". This leaves 0.75 mm of boom material to "punch down". Using the marking gauge (or a ruler) mark a line parallel to the top of the "Tee", 2 mm down from the top, over each of the element position marks.

Then use the centre punch to make a small locating mark for the drill hole – do this for all the elements *except* the driven element.

Now, and with the boom clamped firmly, drill the holes for all the passive elements with a 2.5 mm drill bit, using kerosene as the drill bit lubricant/ coolant.

Once you have drilled the holes for all the passive elements, it is time to prepare the boom for the active element – the driven element assembly. This involves removing a portion of the "Tee" upright; and drilling clearance and mounting holes for a flanged N socket.

Using the try square, mark a line on the "Tee" upright; it should be 5 mm towards the driven element location from the reflector location. Also mark a line 5 mm towards the driven element from the first director. Refer Diagram 2: Side View.

Turn the boom over and, using the ruler and the try square, mark the location of the driven element. This is done by marking a line across the "Tee" base-plate, then mark the centre of this line. Use the centre punch to make a locating hole at this spot.

Next thing to mark are the four locating holes for the flanged N socket. See Diagram 3: Top View, for measurements for the lines to be marked. Once marked, centre-punch these four spots.

For the Yagi I have built, I tapped these four holes to suit M3 x 0.5 mm machine screws; this meant drilling the four holes using a 2.5 mm bit, to suit the M3 tap. You do not have to do this, if you are not confident about tapping holes. The alternative is to drill the holes using a 3 or 3.5 mm bit, and use M3 nuts and split washers with the bolts. Drill the four holes using whichever size bit you decide on; use the same bit to drill a pilot hole for the body of the N socket.

At this point you have a choice as to the order you proceed; you can drill the clearance hole, and then remove the portion of "Tee" upright, or you can remove the portion of upright first then drill the clearance hole. I chose to drill first, as keeping the "Tee" upright intact maximises the strength of the boom whilst drilling the hole, which is quite large. Of course, if you do not have a 16 mm bit, you can use the largest bit you have and then use a file to enlarge the hole to the required diameter.

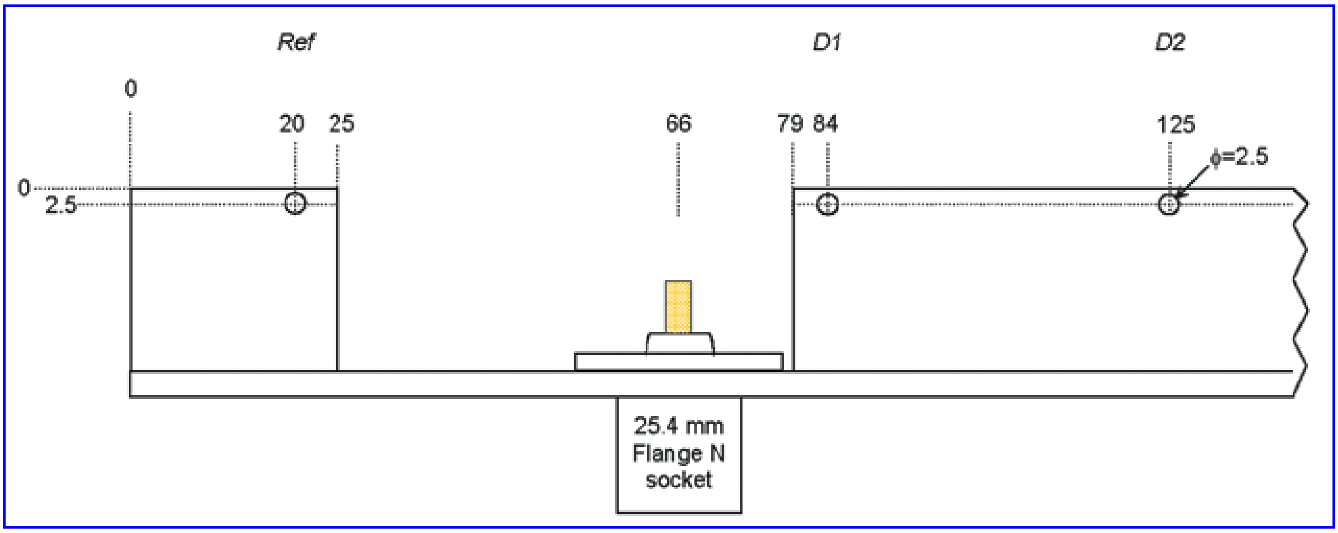


Diagram 2: Tee profile - Side view.

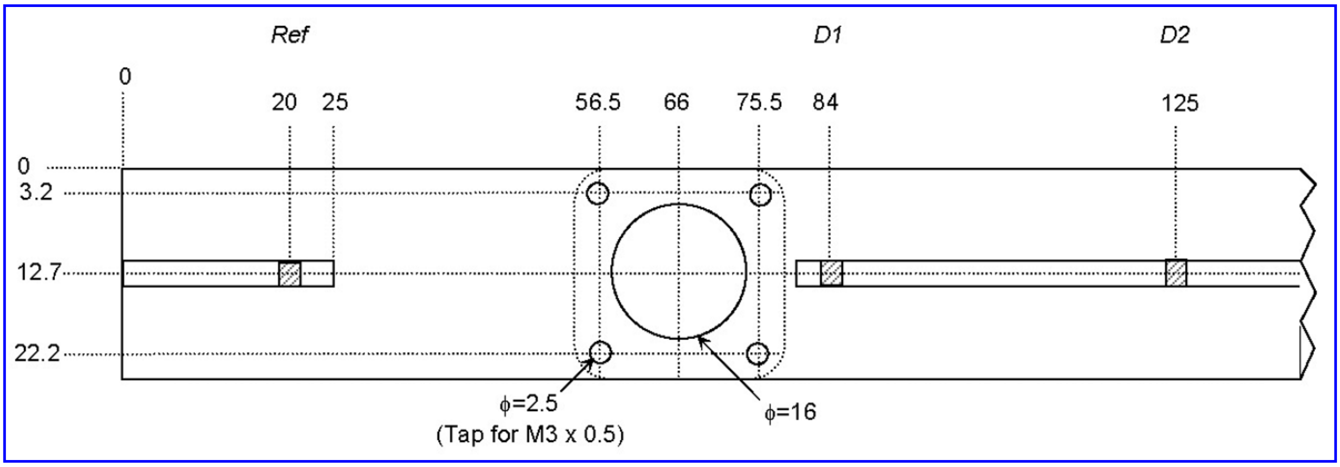


Diagram 3: Tee profile – Top view.

If you have chosen to drill the hole first, do so. Once done, turn the boom over, and use a hack saw to cut down the lines marked between the reflector and first director. Continue with the hacksaw and a mill bastard file to remove the "Tee" upright portion; refer to Diagram 4: Cut View, for a visual description of how I did this. Clean up the area around the clearance and mounting holes. Take the N socket and check that it fits, and that the mounting holes line up. If you decided on tapping the mounting holes on the boom, do this now.

Finally, before fitting any of the elements, there is the matter of a boom/mast mount to attend to. To some extent, the mount arrangement will have to be personalised to suit your mast arrangement. What I will describe is the basic mount design I have used in an H-frame configuration – it has also proved suitable for the 1090 MHz ADS-B Yagi, which is vertically-polarised. For a single, horizontally-polarised Yagi, modifying this design to create a single, small, "trombone"-style mount is a relatively simple task. (See Photo 1)

For long boom Yagi, I attached a length (1000 mm) of 25.4 mm square profile tube to the base plate. This tube is placed so that the middle of the length is over the balance point of the Yagi.

Of course, as the Yagi has not been fitted with all the elements, finding the true balance point is difficult! However, as there is very little weight in the Yagi anyway, not having the balance point exactly right should not cause any structural hazard. You can estimate where the point should be, or you can place the elements temporarily in the mounting holes for a more accurate idea. I drilled four 5 mm holes through the square profile tube. Another four 5 mm holes were drilled through the "Tee" base-plate. Four M4 x 35 mm bolts are passed through the base-plate and the square profile, to secure the two together.

Photo 1: The Boom/Mast Bracket.

I then cut two pieces of 3 mm aluminium sheet, in the shape of a right angle triangle. The two legs of the triangle should be 180 mm, giving a hypotenuse of 255 mm. Refer to Diagram 5 Boom-Mast Bracket for dimensions and bolt-hole locations. Diagram is on page 35

Another length of 25.4 mm square profile is cut to be the outrigger arm – it could be cut to whatever length suits your application, but in my diagram it is shown as 300 mm long. Again, the diagram shows dimensions and locations for these bolt-holes. Two M4 x 35 mm bolts are passed through the triangular plates and the square profile supporting the boom. Another two M4 x 35 mm bolts are similarly passed through the plates and the outrigger arm. Two holes would also be drilled through the opposite end of the outrigger arm, to hold a U-bolt which would clamp to your mast. The hole-size for the U-bolt depends on the U-bolt you have available!

You can now fit the passive elements. The dimension provided by the VK5DJ calculator includes an insertion length – the distance between the element tip and the point on the element where it emerges from the boom. Mark this point on each element, using a fine permanent marker, and insert the element into the appropriate hole. When the element is in to the correct depth, place the cold chisel above the mounting hole, and hit it down with the hammer – this needs to be a firm tap, but don't go berserk; it is aluminium, not steel! Through trial and error, I found the best results were obtained by making two hits per element; one from each side, holding the cold chisel at a 45° angle.

If the element holes have been drilled squarely and cleanly, when the elements

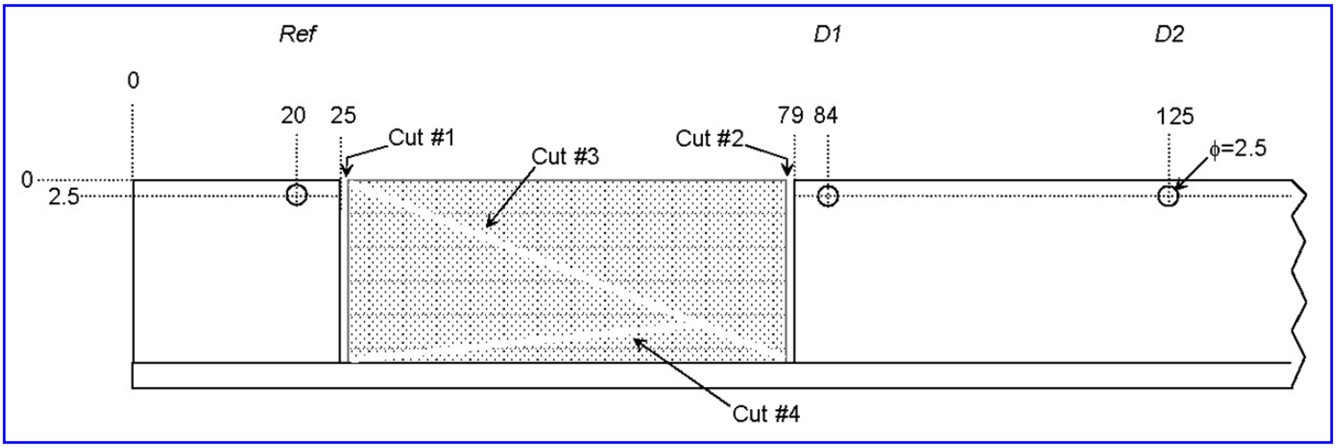


Diagram 4: Tee profile – the cut view.

are punched down they should sit inline and square to the boom.

Next is the construction of the driven element assembly. (See Photo 2)

The VK5DJ Calculator provides all the dimensions for cutting and bending to shape a folded dipole. The dipole material used was 2.4 mm brass rod; the gap at the feed-point was 3 mm and the bend radius was 4.5mm. I used a 9 mm drill bit as a bending former. Cut the brass rod to length; file square the ends and clean about 5 mm of each end of the rod with steel wool or fine grit sandpaper. Mark the rod as per the directions and dimensions provided by the VK5DJ calculator, and fold the rod to shape.

The half wave 4:1 Balun is made from UT-141 hardline (though semi-flex QF-141 could be used and would be easier to form) and for 1296 MHz is 81 mm long (end-of-shield to end-of-shield) plus leads (allow 10 mm of inner at each end). Refer Diagram 6: Balun. Once cut to length, the hardline needs to be formed into a "U" shape, with the gap between the inside faces of the shield ends measuring about 5 mm. Check that the Balun, together with the N socket, will actually fit into the gap cut in the boom. If it does not, reshape the Balun so that it does fit, or enlarge the gap a little.

Now for some soldering! Tin the two sides of the feed-point. Also tin about 5 mm of each end of the hardline Balun shield, and the exposed inner. Finally, you need to tin the centre "pin" of the N socket, along with a section of the rear of the flange.

Holding the dipole in position, solder side "A" of the feed-point to the centre pin. Take the Balun and solder the shield to the flange; the Balun needs to be positioned so that the inners can be bent in a curve up to the feed-point. When the shield is soldered in place (and the flange has cooled suitably!) bend the Balun inner tips up to meet the feed-point. Solder the inner tip that connects to side "B" of feed-point ***first*** (that is, the feed-point that is not connected to the centre pin). When that has cooled, bend the other inner tip towards the centre pin/ feed-point junction, and solder it, too.

When you are happy with how the assembly looks and the quality of the solder joints, you can place the assembly on the boom, and bolt it down using the M3 bolts. Use either split or star washers, or a thread-lock liquid (such as Loctite®) to ensure the bolts don't work loose.

(See Photo 3)

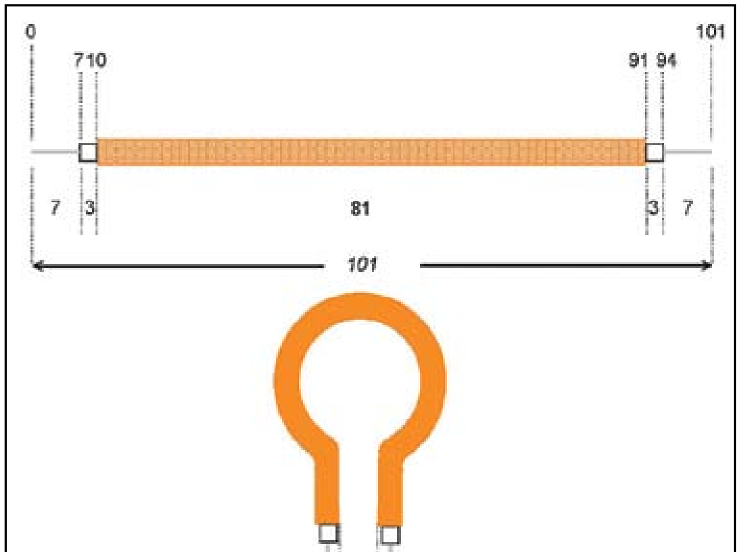


Diagram 6: Balun


Photo 2: Driven Element Assembly


Photo 3: Fitting the Driven Element Assembly

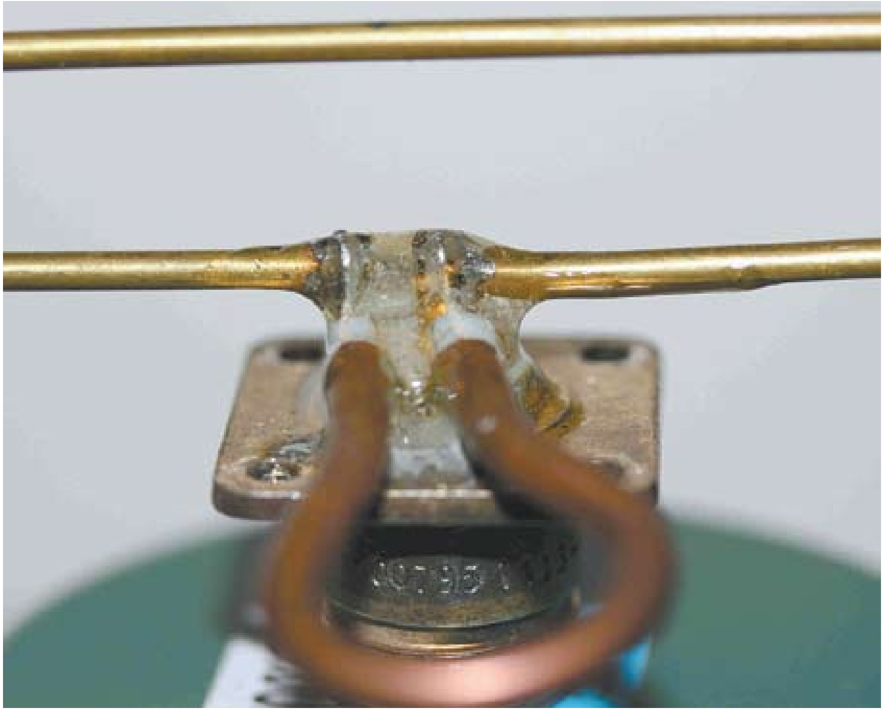
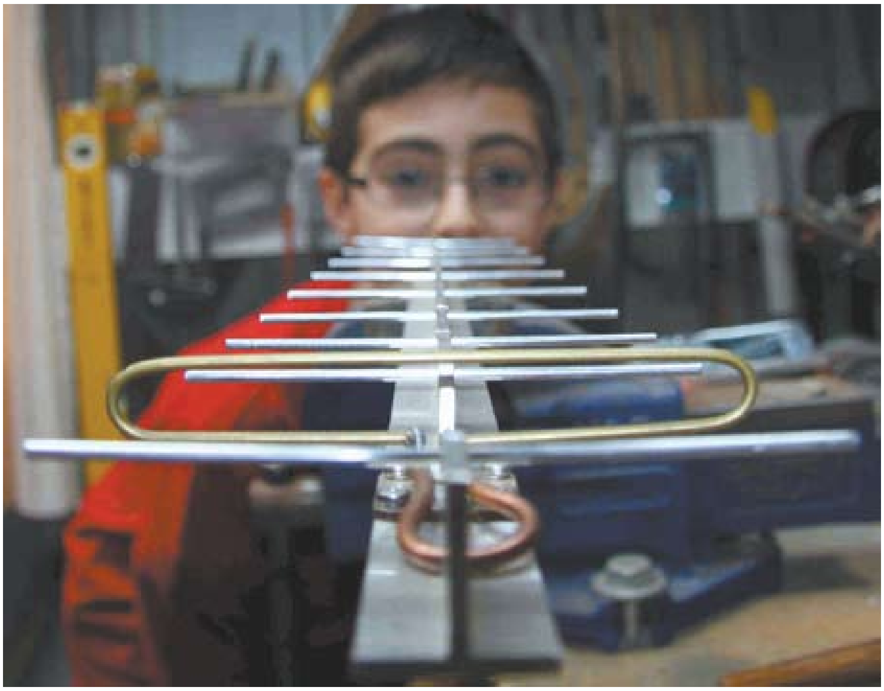


Photo 4: (above) Epoxy weatherproofing

Photo 5: (below) Finished!



A quick test should be performed on the antenna; if you are happy with the Return Loss, or VSWR, the Balun ends/Feed-point/centre pin area should be coated with a suitable epoxy resin.

Araldite® proved suitable (after a blast in my microwave oven resulted in no warming of the resin), to weatherproof and add rigidity to the assembly. (See Photo 4)

Alignment and adjustment

The 1296 MHz 10 element was tested at home with ye olde Revex® W-570 VSWR meter and, without any adjustment to the elements, the Yagi gave a reading of 1.3:1.

The 1090 MHz 10-element Yagi was swept with the assistance of Alan VK3XPD; with a little tweaking, a return loss of 23dB was achieved. This tweaking amounted to a little filing of the first director ends, and tilting the driven element forward slightly.

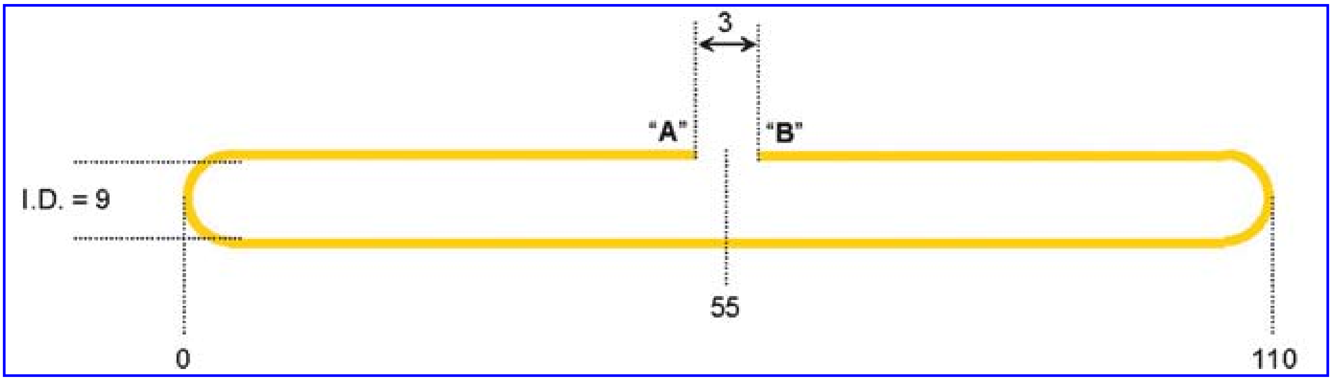
Summary

I have built three Yagis using this method, so far. Two (one 10-element and one 28-element) are for use at 1090 MHz with my ADS-B receiver, and the third is a small 10-element "test-bed" Yagi for 1296 MHz. I have four more under construction – f
our 50-element Yagis to be used in an array on 1296 MHz.

The 1090 MHz 28-element Yagi is currently in use at the top of my tower, and is a considerable improvement over the 16-element co-linear that I was using with my ADS-B receiver.

Proper tests to establish cleanliness of the radiation pattern are yet to be performed, mainly due to lack of spare time (what's that?!) and the need to set

Diagram 7 (below): The folded dipole.



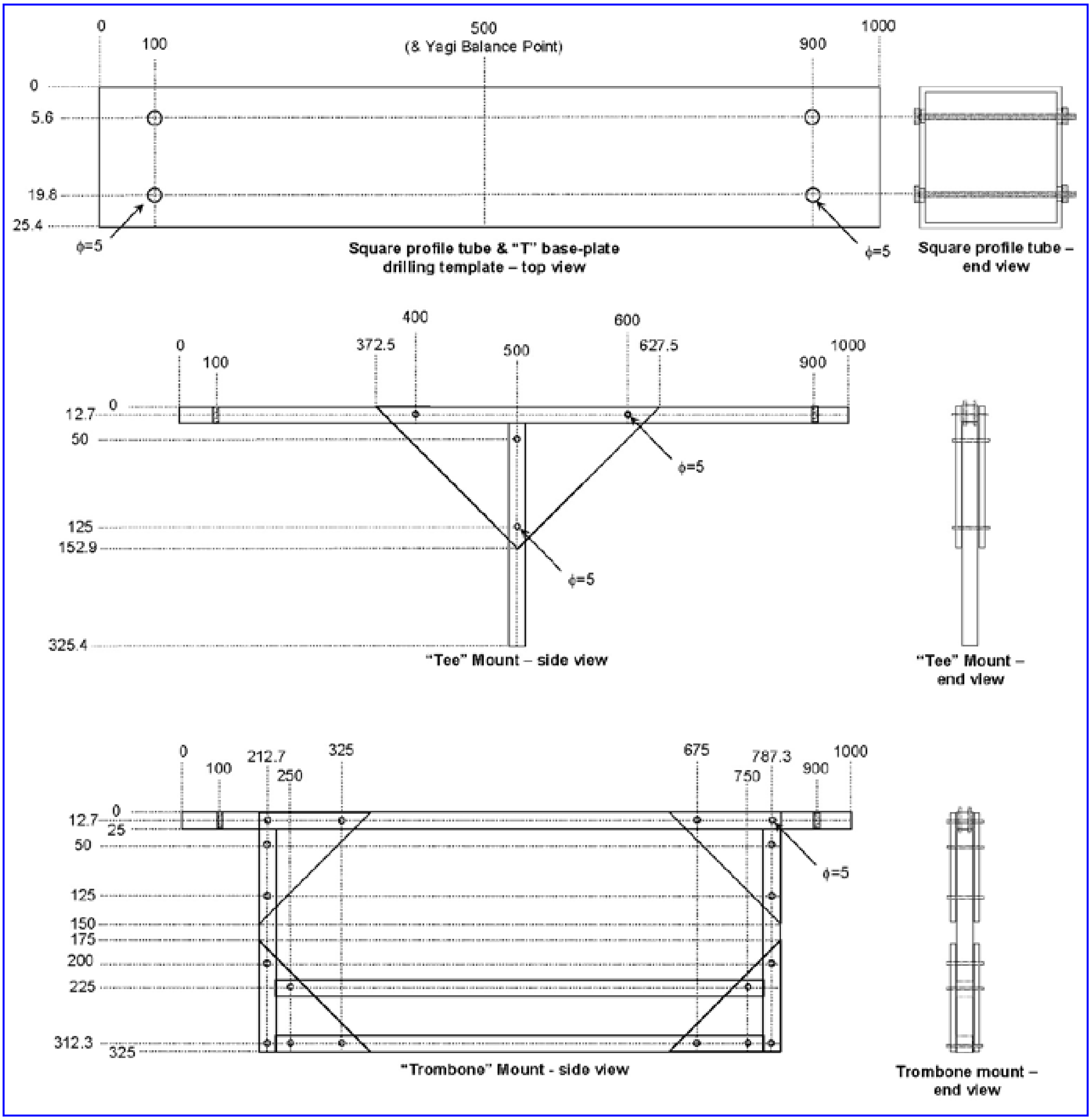


Diagram 5: The boom to mast bracket.

up a suitable antenna range facility.

That said, day-to-day use of the 1090 MHz 28-element Yagi suggests a good pattern.

The method certainly results in an antenna that is strong but light, and minimises the cross-sectional area of the boom. Use of the N socket in the dipole assembly obviously means that connecting multiple antennae together in an array involves using coaxial cable and a power divider.

I will be interested to see if anyone can come up with a method of constructing a dipole assembly that will suit connection to balanced feed-line.

I would like to acknowledge the following for various ideas and assistance in getting to this point: Gordon MacDonald VK3EJ, John Drew VK5DJ, Jim Klitzing W6PQL, and Alan Devlin VK3XPD.

All photographs were taken by Barry Miller VK3BJM, Cameron Miller and Adrienne Walker.

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