

Construction of a 20m Vertical Moxon for use Adjacent to Salt Water



Based on a Design by Pete Mills, M3KXZ

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Acknowledgments

This project to construct a vertical Moxon antenna for the amateur 20m band was inspired by the work and experience of Pete Mills, M3KXZ, and the Moxon Antenna Project group (www.moxonantennaproject.com). Collectively we have all drawn on the experience of Les Moxon, G6XN, and his work to transform the VK2ABQ 2 element beam into the antenna that is collectively known as “The Moxon Rectangle”.

Introduction

The desire to construct this antenna was born out of a search for an efficient vertical array that could be used in a portable set up adjacent to salt water for the Workington Radio Club (MX0WRC) annual trip to the Scottish islands.

During our trip to Mull we experienced some of the worst propagation in recent history. I’m sure some of you will remember the flare that caused this and resulted in almost total HF blackout for a period of time. From our location we were struggling horribly to make contacts on 20m so we decided to take a trip out and try for ourselves the advantage of a salt water takeoff.

One of our operators, Mark (M0WCR) had taken a little Yaesu ATAS120 antenna with him that we set up on a beach adjacent to the tide line. In a few minutes we were making more contacts with this little device than we had in the previous day. Needless to say we were sold on the concept! The following day we returned with a push up mast and a single 20m delta loop and ran until our separate radio battery went flat.

On the basis that this approach gave us a significant benefit I decided that this was the future for our trips and on my return home set about looking for something with directivity that made the most of the sea path. What became clear after a few hours trawling the internet and reading about the experiences of “big” DXpeditions, was that the key to success in these situations was the effectiveness of an antenna at producing gain at low angles of radiation (typically below 14 degrees above the horizon) and thankfully for us that meant some kind of vertical antenna or array. I say thankfully, because this immediately simplifies the equipment needed.

During my travels around the internet I came across the work the Pete Mills had done with vertical Moxon rectangles and it looked very promising: computer modelling in EZNEC predicted salt water figures of 9.5dBi gain at 8 degrees above the horizon and a 20dB front to back ratio. Construction was relatively simple using PVC insulated stranded wire and a couple of 10m glass-fibre fishing poles.

I built this antenna (I’ll refer to this as MK I) and we duly took it to Skye to see how it performed. Equipped this time with a generator we set our station up on the shores of Staffin bay and did some A/B comparisons with our trusty single element delta loop and very quickly discarded it. The Moxon was streets ahead and DX contacts came in thick

and fast. Anecdotal evidence from Australian and Japanese stations that were coming in over the top of the European pile up suggested that we had quite a potent station on our hands with just 100W.

On the next day we returned to the same spot and set up as before. This time we discovered a weakness in the design as the weather worsened significantly. As the wind got up the fishing poles began flapping around quite alarmingly (they were guyed about half way up) totally destroying the rectangular shape of the antenna. We also realised that it would be very difficult to erect if you were on your own as there are two supports to put up with the wire attached and the guy lines.

This led me to come up with the current design that is much more substantial, can be put up by one person, and does not flap about in the wind. We used this revised design (MK II) on our trip to Barra last year very successfully, without any weather related problems (and it did rain and blow a heck of a lot). We did have one canine related problem when a local dog decided that our coax looked appetising and chewed clean through it mid QSO!

The following sections provide a little bit of theory behind why the antenna works so well and how to build one should you wish. Some of the materials I used are a little pricey but there will be suitable alternatives and where there is scope for this I have tried to point it out. I don't possess a well equipped workshop and the entire construction was done in my garage using nothing more exotic than a power drill and an electric diamond circular tile saw (not really needed but it makes life easier with the materials I used).

None of the construction is beyond anyone who can measure accurately and drill a few holes.

Performance

In order to try and demonstrate why this is such an effective DX antenna I've included the following sections that illustrate the gain distribution of the vertical Moxon in it's intended salt water environment and for comparison purposes how it performs on land, and how it performs compared to a 5 element horizontal Yagi in a realistic portable installation. You will need to be ready to challenge some common beliefs and antenna marketing hype regarding gain, and to accept the fact that in isolation the gain of an antenna actually tells you a very limited amount about how it will perform. I hope I can convince you that an antenna with less peak gain can actually out perform one that appears to look better on paper.

In-land Performance

The following graph compares the performance of a 5 element Yagi mounted at 10m above average ground with the vertical Moxon mounted with the lowest portion of the rectangle 1m above the same ground. The Yagi has a gain of 13dBi and a front to back ratio of 21dB – quite an impressive set up for a portable operation. In fact 5 elements is probably stretching it a bit as a 3 element beam would be more likely.

The outer trace is the Yagi and the inner trace is the Moxon. At all angles the Moxon is nearly 10dB down on the Yagi so it is not an ideal choice in this location (to put it mildly).

At this stage you're probably thinking why bother? If you have access to a beach read on and all will be revealed.

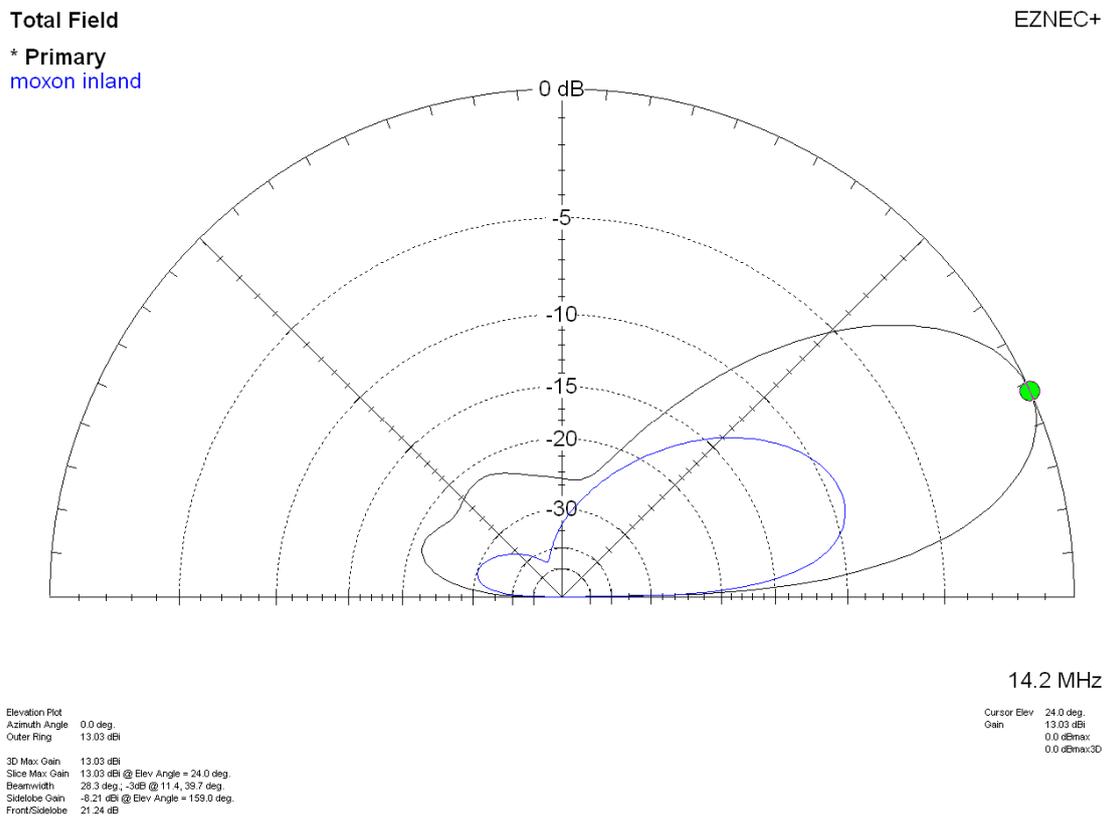


Figure 1 - Comparison of Moxon / Yagi Inland

Salt Water Performance

The first thing to notice from this plot is that the same Yagi mounted at the same height but now over salt water has not changed in pattern or gain by any measurable amount. In fact the computer model predicts a 0.8dB increase in gain that would not even be measurable let alone noticeable. The Moxon is a different story however. Notice that at angles below 10 degrees above the horizon the Moxon has significantly more gain than the enviable 5 element Yagi at 10m. At this point several questions could pop up such as “The beam has 13dBi gain while the Moxon has only 9.3dBi gain so why is it better? Surely more gain is preferable?”

This may actually be true for shorter distance contacts when signals are arriving at higher elevation angles. In these cases the Yagi has a considerable advantage. However, if you are chasing DX contacts where signals arrive at much lower angles the Moxon wins out for this very reason. Because it has less gain than the Yagi at higher angles but more gain than the Yagi at lower angles it attenuates local stations in favour of DX stations which I suspect is why we heard Japanese and Australian stations over the top of the European pile-up. For our particular requirements that is a real plus. I hope this shows also why gain and front to back ratio alone are not necessarily good measures of antenna performance – you also need to know the horizontal and vertical patterns in your environment.

Total Field

EZNEC+

* Primary
moxon sw

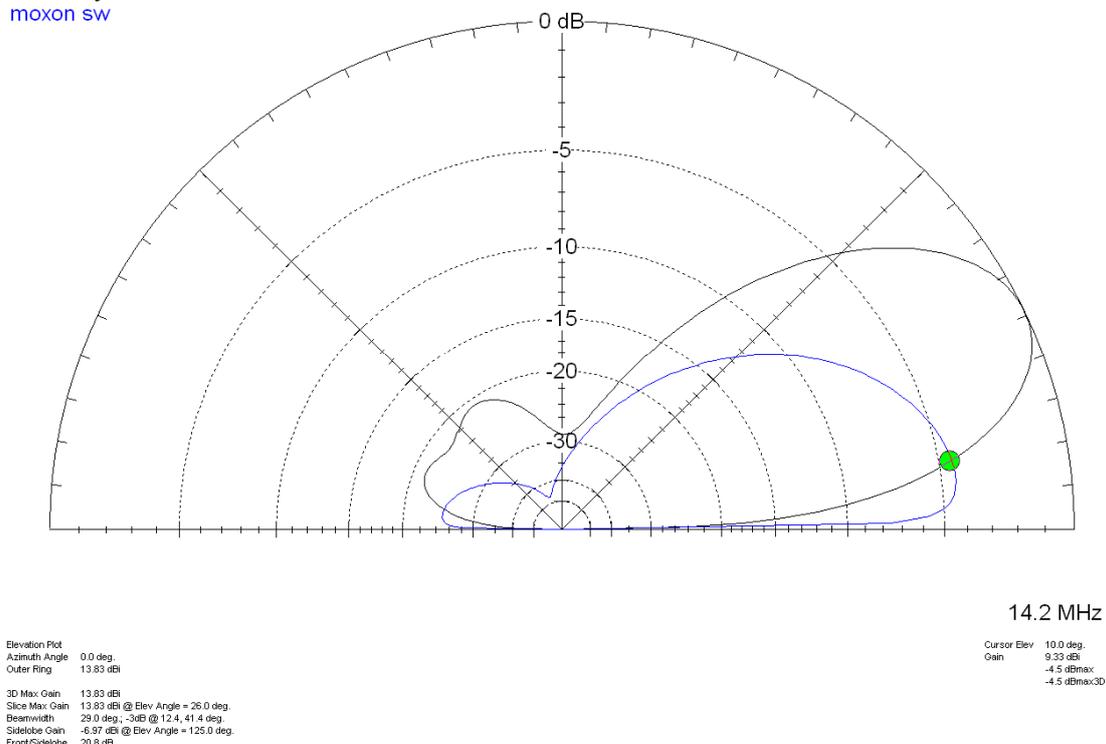


Figure 2 - Comparison of Moxon / Yagi Over Salt Water

Construction

If you've read this far and have decided to have a bash at building this antenna then fear not – it's actually not that difficult. The antenna is comprised of two elements, a driver and a reflector, made from insulated stranded wire. Each element forms a “U” shape with the ends of the elements spaced a set distance from one another. To maintain the antenna in the shape of a vertical rectangle two horizontal booms attached to a 9m push up mast (one at the top and one at the bottom) provide the anchor points that keep the wires in tension vertically and horizontally.

Material Selection Considerations

In order to preserve the radiation pattern of the antenna and to prevent coupling issues the mast, booms and mast / boom plates need to be manufactured from a material that is not RF conductive. I elected to use a 9m GRP push up mast with GRP booms and Tufnol® mast/boom plates. Tufnol® is interesting material and there are many grades and types so you need to be sure you use the correct one if you go down this route. I'm sure other materials such as varnished plywood would be suitable or other engineering plastics providing they are not RF conductive and are not water absorbent. Avoid the temptation to use metal for the mast to boom plates as they are in close proximity to the element gaps and these are critical to the driver/reflector coupling mechanism (they actually act as capacitive coupling).

It's impossible to eliminate all metalwork – mounting bolts are required as a minimum. There is a way to eliminate U bolts for securing the plates to the booms and mast and I recommend this method as it also reduces the likelihood of crushing the GRP tubing. I used tubing clamps that are designed to support pipe work in hydraulic systems. They are available in incremental mm sizes so you can obtain them to exactly fit the tubing you are trying to clamp. As I live in a rural community the internet came to my rescue and I obtained them from a hydraulic specialist for a very modest amount (I seem to remember they were £3.00 each). DX Engineering (www.dxengineering.com) also sells them for reasonable prices but shipping to the UK can be costly.

Sturdy GRP tubing can be used for the booms. I used 30mm diameter thick wall tubes from Spiderbeam in Germany (www.spiderbeam.com) because they come in 1m lengths that slot together. This is not a requirement for the design but it does make packing and transporting easier. There are no doubt many suitable suppliers and materials so go with whatever you can get but it does need to be fairly stiff when used as a 3m length. Again, I suspect dry varnished timber could also be used if weight isn't a consideration. One approach I did consider was to use lighter materials for the booms supplemented by bracing guys attached to the mast and you might want to try this as an alternative.

The key to the whole thing is that there are many ways to achieve the required support structure but it must not be RF conductive and must not absorb water – either will detune

the antenna and degrade it's performance. The design I have provided here is just one way of achieving this and it works. If you can't achieve the design use your imagination!

Wire lengths are optimised for PVC insulated heavy duty loudspeaker cable. The material I used was 79 strand as is readily available (at least in the UK) from DIY stores.

One final note regarding guying arrangements. This antenna does need guying and if you wish to erect the antenna single handed the first set of guys needs to be at the first clamp on a push up mast. Two additional sets of guys should be provided at the centre and 1m below the top of the mast. Again, avoid the temptation to use metal hardware. I made guying rings from the same Tufnol® material that I used for the mast / boom plates but you could substitute other non RF conductive non water absorbent materials.

Tools and Safety

Always, and I mean always, use eye protection and a dust mask when drilling, sanding or cutting GRP. The dust is very nasty stuff if inhaled and you really don't want to get in your eyes either – it's extremely abrasive and some of the resins can be carcinogenic. It's also a good idea to wear gloves as sharp edges can occur especially if you use a power saw.

No really special tools are required. You could get away with a hand drill and hacksaw as a bare minimum but power tools make the process easier. If you have access to a pillar drill or a stand for your power drill that's even better, but you can use a steady hand instead. Use good, sharp, drill bits and fine tooth saws with fresh, sharp, blades. I found that a tile cutting hacksaw blade (they look like a thin rod coated with abrasive) works very well and is better than a conventional saw blade for cutting GRP.

If you have one handy and are using the Tufnol® material a water cooled circular saw used for cutting ceramic tiles that has a diamond coated blade is very useful. It makes very short work of cutting and eliminates dust problems. I don't recommend using a jigsaw as it can cause the material to delaminate.

If you need to make guying rings a power drill and a set of hole saws make short work of this.

For marking out you will need an engineers square, a fine tip marker pen, a ruler and a compass that you can fit your marker pen into or a protractor. A Vero board cutter is also useful for marking the centre of holes to be drilled but it's not strictly necessary.

You will also need some sandpaper or a flap wheel for you power drill to take off sharp edges.

Parts Lists

The following table identifies the parts you will need to build the antenna exactly as I built it. Bear in mind the material selection notes above if you intend to go down a different route. I have no association with any of the suppliers and have provided the manufacturers web site for reference only. Fixings are stainless steel where possible as the antenna is designed for use in a salt water environment.

Description	Qty.	Supplier	Part Number	Web Link
9m GRP push up mast	1 off	Moonraker	TMF-15	www.moonrakerukltd.com
30mm diameter tubing clamps with stainless steel backing plates	6 off	Hydraulic specialist or DX Engineering		www.dxengineering.com or ebay
60mm diameter tubing clamps with stainless steel backing clamps	2 off	Hydraulic specialist or DX Engineering		www.dxengineering.com or ebay
Tufnol® Plate	1 off	RS Components	771-370	www.rscomponents.co.uk
1m heavy duty GRP tubes	6 off	Spiderbeam		www.spiderbeam.net
Eye bolts	4 off	Local DIY (B&Q etc.)		
Nylon dog bone insulator	6 off	Any radio equipment supplier		
Dipole centre piece	1 off	Any radio equipment supplier		
25mm dia PVC conduit	1 off	Local DIY (B&Q etc.)		
2 core 79 strand PVC insulated wire	15m roll	Local DIY (B&Q etc.)		
Small stainless steel snap links	4 off	Chandlery		
Kevlar guy line	100m roll	Any radio equipment supplier		
Xmm Stainless steel M6 bolts	12 off	Your favourite fastenings supplier		
Xmm Stainless steel M6 bolts	4 off	Your favourite fastenings supplier		
Stainless steel M6 penny washers	16 off	Your favourite fastenings supplier		
Stainless steel M6 washers	16 off	Your favourite fastenings supplier		
Stainless steel M6 nuts	16 off	Your favourite fastenings supplier		

The total cost for the above parts is around £295 but bear in mind that the mast can be used for a lot of different things and if you already have one it cuts the cost dramatically.

Coupling Insulators

The coupling insulators provide the anchor points for the ends of the reflector and driven elements and provide the spacing required. They are made from a nylon dog bones and PVC conduit to give the correct length and to provide an easy method of splitting the antenna if you need to rotate it without it getting tangled in guy wires.

The objective is to space the ends of the wires exactly 110mm apart. The dog bones I have are too short to use 1 and too long to use 2 back to back so I adopted a simple method. I cut down 2 insulators to the correct length and then mounted them inside a length of PVC conduit as per Figure 3. There are no hard and fast measurements for this as the dog bones I have all vary in length. The key is to achieve 110mm spacing to the outside edges of the holes. You could use other materials such as a strip of Tufnol® or plexiglass.

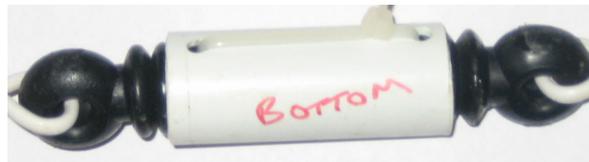


Figure 3 - Coupling Insulator

Antenna Elements

The diagram in Figure 4 shows the configuration of the antenna and the wire dimensions are in the accompanying table. Note that segments 4, 5 and 6 are a single length of wire and segments 1, 2 and 3 are a single length of wire split at the exact centre for the feed point (shown by the double red circle in the diagram). Note the gap between segments 1 and 4 and 3 and 6. The booms and mast are not shown for clarity.

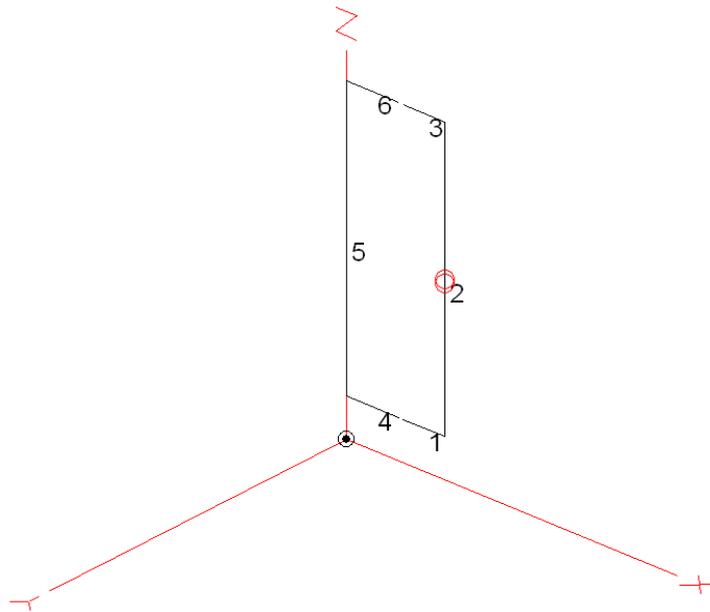


Figure 4 - Wire Arrangement

Section Number	Wire Length
1	1.15m*
2	7.26m
3	1.15m*
4	1.42m*
5	7.26m
6	1.42m*

*These sections need a little extra length to allow for tuning and making off the ends

1. Begin by measuring a 10.3m length of the two core speaker cable. This is long enough to make the reflector which is the longer element, so by default is also long enough to make the director which is the shorter element.
2. Check your measurement carefully a couple of times with the wire taugt to make sure you have it correct and then cut to length.

3. Split the two core cable into two separate wires and mark one as the reflector and the other as the driven element.
4. Take the wire that you marked as the driven element and measure exactly 540mm from one end.
5. Again, check your measurement carefully a couple of times with the wire taugth to make sure it is correct and then cut to length.
6. Double check the dimensions – the reflector should be 10.3m long and the driven element should be 9.76m long.
7. Set the driven element wire to one side.
8. Measure 100mm from one end of the reflector wire and mark with your marker pen.
9. From the mark you just made measure 1.42m and make another mark.
10. Repeat this process for the other end of the reflector.
11. Check the dimension between the two innermost marks – it should be exactly 7.26m. If it's not go back and re-measure and mark.
12. Slide a dog bone insulator onto the reflector wire from one end and position it at the second mark (1.52m from the end of the wire).
13. Use two heavy duty cable ties, one either side of the dog bone insulator, to lock it into position as shown in Figure 5 (it should still be able to rotate on the wire but not slide side to side).



Figure 5 - Corner Insulator

14. Repeat this process for the other end of the reflector wire.
15. Now take the two coupling insulators made in the previous section and slide one onto each end of the reflector wire.

16. The coupling insulator should be positioned on the mark you made 100mm from the end of the wire.
17. Fold the reflector wire back on itself and secure with 3 heavy duty cable ties as per Figure 6.



Figure 6 - Wire / Coupling Insulator Connection

18. Repeat this process for the other end of the reflector wire.
19. Set the reflector aside.
20. Take the driven element wire and mark the exact centre (fold in half and mark with the marker pen)
21. From one end of the wire measure 100mm and mark it.
22. From the mark you just made measure exactly 1.15m and make another mark.
23. Repeat this process for the other end of the wire.
24. Using the same method as you did for the reflector secure two dog bone insulators at the marks 1.25m from the end of the wire. Again, they should not slide but should be free to rotate.
25. Now take your dipole centre piece and measure the distance between the outside edges of the bolts used to connect to the dipole.
26. Divide this measurement by 2 and make a mark either side of the driven element centre marking corresponding to this measurement. E.g. if your dipole centre piece has a measurement of 40mm between the outside edges of the bolts, measure 20mm either side of the driven element centre mark and mark it there.
27. Cut the driven element at the centre marking, and strip the insulation back to the mark corresponding to the edges of the dipole centre fixings.

28. Attach the dipole centre piece making sure that there are no stray strands and that the wire insulation butts up to the fixing bolts as per Figure 7.



Figure 7 - Dipole Centre Piece

29. Now attach the free ends of the driven element to the free end of the coupling insulator in the same manner as the reflector element.
30. You should have a rectangle at this point with a dog bone insulator at each corner.
31. Now, cut 4 xmm lengths of the Kevlar line and securely tie loops in each end so that the overall length is 200mm. I prefer to use a figure of 8 knot because it's easy to tie and is quite neat.
32. Attach these 4 lines to the 4 snap links by threading the loop through the centre of the snap link and then threading the other end of the line through the loop and pulling taught as shown in Figure 8.



Figure 8 - Snap Link Connection to Corner Insulator

33. Use a similar technique to attach the 4 lines to the 4 dog bone insulators at each corner of the rectangle.

That's all there is to building the antenna, the rest of this section is concerned with constructing the support system.

Boom and Mast Clamps

Assuming you are using the pipe supports that I recommend, some may come with top and bottom steel plates. The bottom ones are designed to be welded onto something and have threaded bosses for the support mounting bolts. Discard the bottom plates as they are not required.

Boom to Mast Plates

The drawings in Figure 9 and Figure 10 show the dimensions for both of the boom to mast plates. Begin by cutting two identical square pieces of material 170mm each side. Mark a line 20mm in from the edge of the plates on all 4 sides. Mark the centre of each side (85mm from either end of the edge) and mark the centre line positions. Now mark the hole positions as per the drawings. Note that the bottom plate has two different hole spacing's to accommodate the larger clamps for the lower mast section.

Now mark the diagonal lines for the corner cuts by marking a point 45mm away from each corner on both of the associated sides. Using a ruler mark a line between these two marks.

Before you do any cutting or drilling check your measurements against the drawings in Figure 9 and Figure 10.

Drill the 6mm holes first. If you have a pillar drill you don't really need to punch or pilot the centre of the hole. If you are drilling the holes free hand I suggest that you mark the centre point with a vero board cutter or a drill bit held in your hand (be careful if you do this as drill bits can be very sharp). Once you have drilled the holes cut off the corner pieces and smooth off the edges with sandpaper or a flap wheel to eliminate the risk of any nicks or cuts when assembling the antenna.

Boom to Mast Plates - Bottom

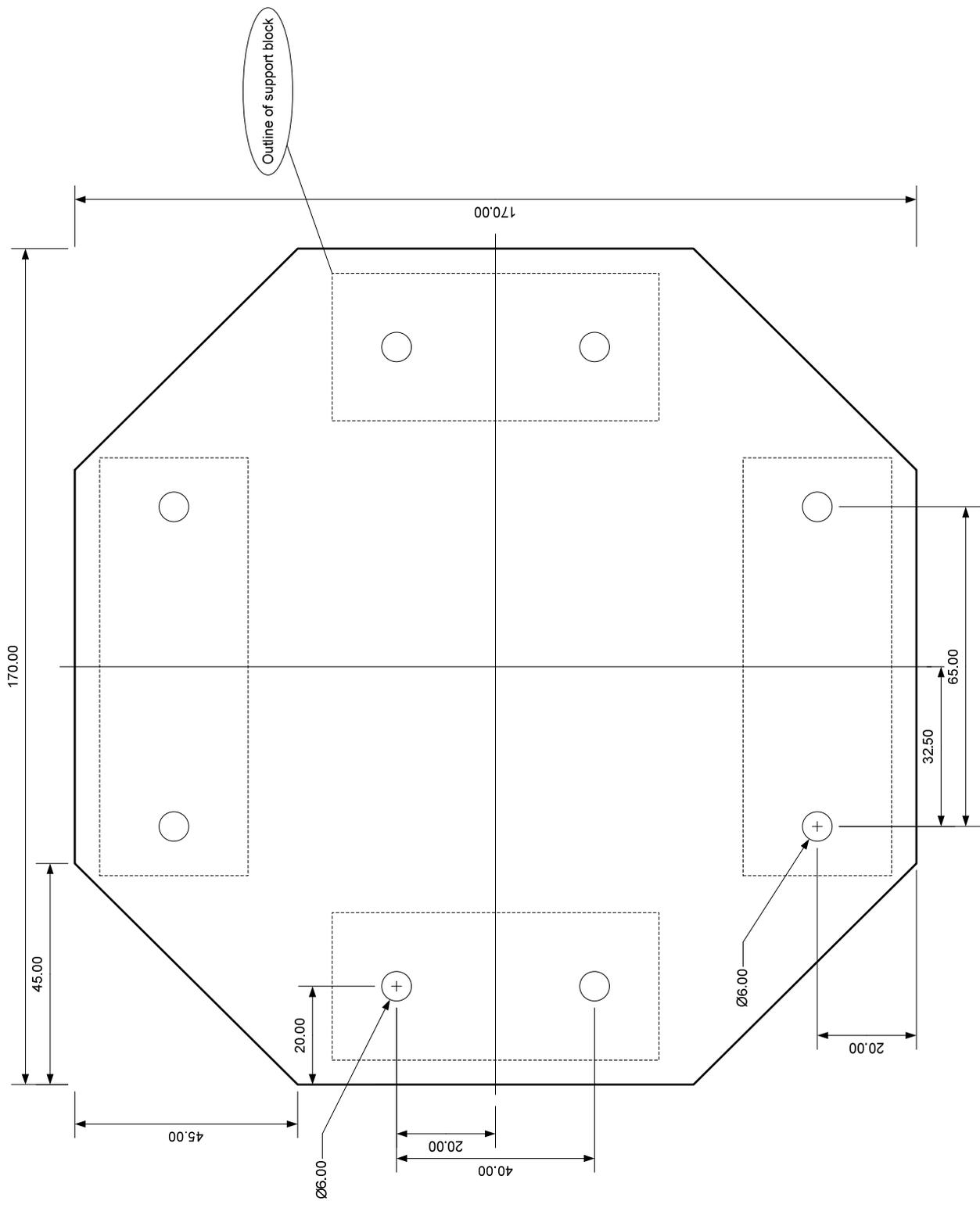


Figure 9 - Bottom Boom to Mast Plate

Boom to Mast Plates - Top

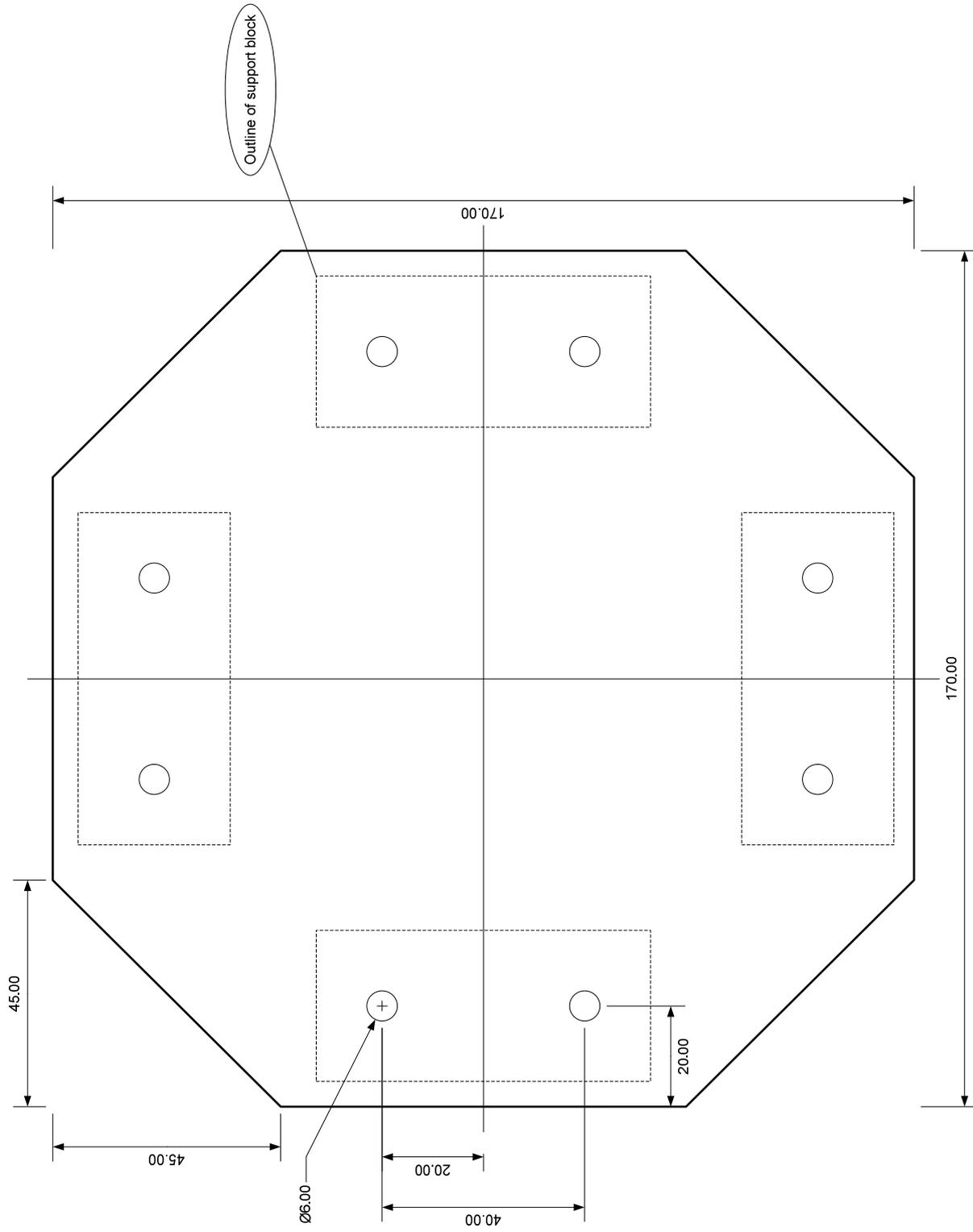


Figure 10 - Top Boom to Mast Plate

The pictures below show the completed boom to mast plates mounted to the centre section of the booms.

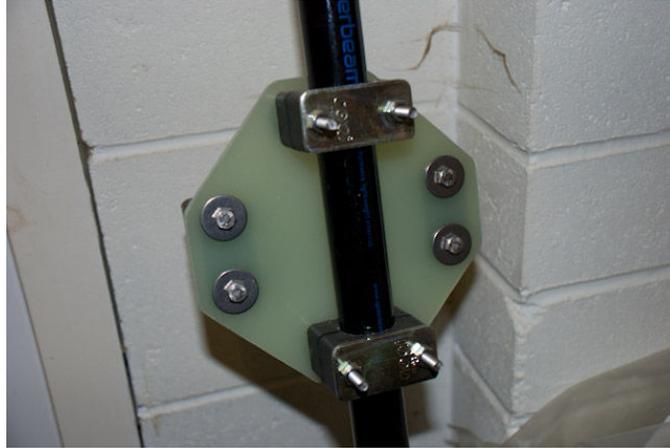


Figure 11 – Rear View of Plate



Figure 12 - Completed Upper Plate

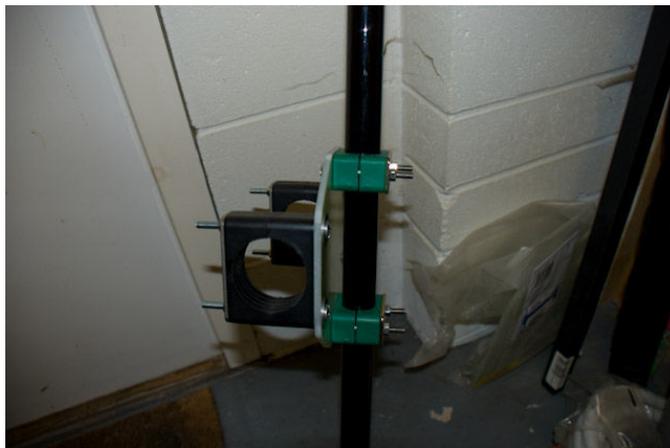


Figure 13 - Completed Lower Plate

Booms

The GRP tubes from Spiderbeam have a spigot at one end and they are designed to slot together to form longer sections.

1. Two of the tubes need to have the spigot removed. They should be cut flush with the shoulder without damaging the spigot or the main body of the tube. If you use a vice to hold the tube be very careful not to over tighten the vice as you may crack the tube. Do not discard the spigots you cut off.
2. Set the tubes that you cut the spigots from to one side.
3. Take another two tubes and glue the spigot sections you cut off in the earlier step into the larger diameter end (they will only fit in one end) using epoxy resin so that they are flush with the end of the tube. This provides a double wall thickness where the eye bolts are mounted to the boom.
4. Set them aside and leave for 24 hours for the epoxy to cure fully. At this point you should have 2 GRP tubes that are untouched. These are the centre sections for the boom.
5. You should have 2 GRP tubes that have a spigot on one end and a double thickness at the other end and you should have 2 GRP tubes that have a double thickness at one end and a full diameter opening at the other end to accept a spigot.
6. Set the centre sections of the boom to one side.
7. The following steps should be performed at the double thickness end of the remaining 4 GRP tube boom sections.
8. Measure 15mm from the end of the tube and mark a line around the circumference of the tube. Drill a 6mm hole straight through the tube and out of the other side. Make sure the drill is vertical.
9. Fit an eye bolt as shown in Figure 14 and tighten the nut securely but be careful not to over tighten. You might prefer to use Nyloc nuts to prevent them coming loose rather than risk over tightening them and cracking the tubes.



Figure 14 - Boom With Eyebolt Installed

Mast

The only preparation needed for the mast is to make provision for guying. I cut some rings from the sheet of Tufnol® material with three holes drilled in each to accept guy lines.



Figure 15 - Mast With Guy Rings Installed

Assembly

Assembly is fairly straight forward.

1. Begin by extending the mast fully and laying it on the ground.
2. Measure 70cm from the bottom of the mast and mark it with a felt tip pen.
3. From this mark measure 8.2m up the mast and make another mark.
4. Collapse the mast so that the upper mark is still visible (it's easier to bolt the pieces together in this configuration).
5. Mount the top and bottom mast/boom plates to the mast being careful not to over tighten them.

6. Take the two sections of the booms that do not have the eye bolts fitted and fit them horizontally to the mast/boom plates, making sure that the sections are centred horizontally (ignore the length of the spigot section when checking the measurements for this as it doesn't contribute to the boom length).

The next steps are a suggestion only – you may find a better way to erect the mast and antenna.

7. Guy the mast at the lowest point to support it while putting the antenna in the air.
8. Slot the booms together and clip the antenna onto the ends of the booms (make sure that you get the orientation correct – the feed point should be in the vertical section).
9. Connect an electrical half wave of coax to the feed point.
10. Push the mast up until the rectangle is under tension and then guy the mast – the booms may need a little vertical adjustment to get the rectangle tensioned with the bottom of the rectangle 1m above the ground.

Stand back and admire your work – it should look like this!



Figure 16 - Completed Antenna

Tuning

Use an antenna analyser to check the resonant frequency of the antenna – it should be around 14.150 MHz but may need a little adjustment.

To tune the antenna shorten or lengthen it at the insulators in the horizontal sections. You must change the length of all wires by the same amount.