Construction Plans for the 8-9+ dBi Omni directional PX3* (PX4, PX5, PX6 – PXn) 2m antenna

Index

1) Introduction

The PX3 is an easy-to-build, high gain, vertically polarised antenna with a low radiation pattern.
I have taken the original Super J Pole antenna design and extended it to have 3, 4, 5, 6 or more half wave radiation elements. I've also non-inductively wound the horizontal radiators to make a neat practical antenna. To aid identification I have called these antennas:-

PX1 – Portable x 1 half wave radiator (The 'J Pole')
PX2 – Portable x 2 half wave radiator (The 'Super J Pole')
PX3 – Portable x 3 half wave radiators (the one shown here)
PX4 – Portable x 4 half wave radiators
PX5 – Portable x 5 half wave radiators
PX6 – Portable x 6 half wave radiators
PXn – Portable x n half wave radiators *(where 'n' represents the number of half wave vertical radiators)*

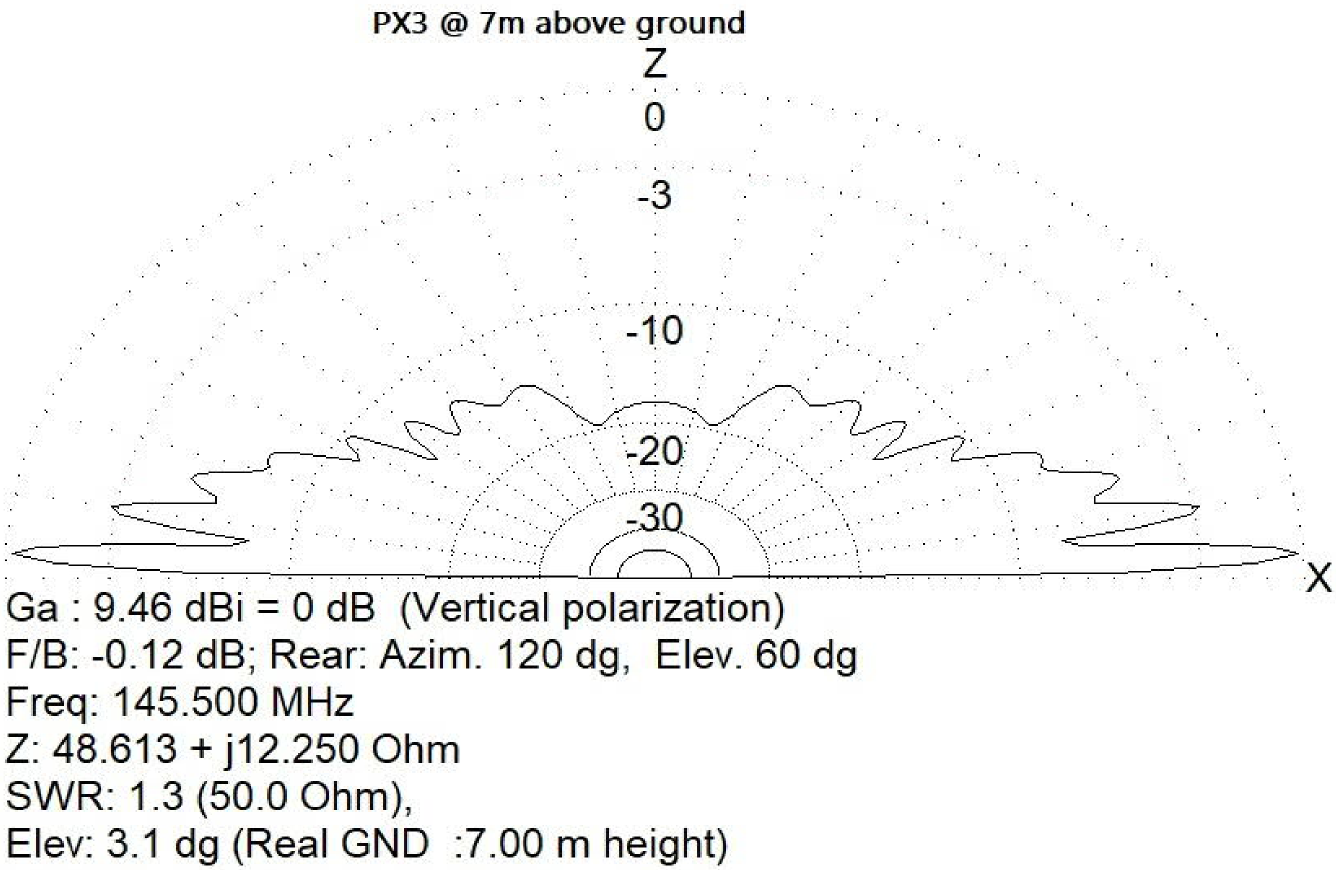
I stopped after building the PX6 but there is no reason why larger PX antennas can't be built. Although the gain increases with more half wave radiators the amount of additional gain diminishes as you add more elements.
Note: Tuning does become more of an issue the higher number of radiators you use.

The PX3 is ideal for SOTA (Summits On The Air) use and measures around 3.5m (11 ½ feet) and weighs less than 260g. It can be mounted on a typical 7-10m fibreglass SOTA pole while in the field. Although my goal was to build and share plans for the PX3 as a SOTA antenna, it can also be used for static mobile and home shack use.
For the remainder of this document I will use SI units for measurements.
The PX3 could be built for less than £15 / $20 and 2-3 hours construction/tuning time.

2) Performance

This document is going to focus on the PX3 and its construction / performance when used on the 2m amateur band, 144 MHz– 146 MHz (although bandwidth is 143 MHz – 147 MHz).
(It can be adapted for other frequencies, not covered here)

The PX3 gives around 2-3 dB more gain than the Slim Jim. In practice I got 2-3 more 'S' points. It not only transmits with greater gain but also receives with greater sensitivity too, making it ideal for VHF QSOs when on a summit. In practical tests I frequently achieved 150+miles (240Km) QSOs using just 2.5W. Not bad for an antenna which weighs less than 260g!



The above far field plot shows MMANA's computer modelling of the PX3, mounted at 7m above the ground.
It will produce less gain for heights less than 7m (see Appendix)

Strengths
- High gain, low radiation angle both in TX and RX operation
- Low weight (pole excluded) just 260g or less
- Cheap to build (£15/$20)
- Deploys quickly. Once tuned doesn't need SWR meter in the field
- Allows for greater SOTA reach on 2m compared to many SOTA 2m antennas on the market

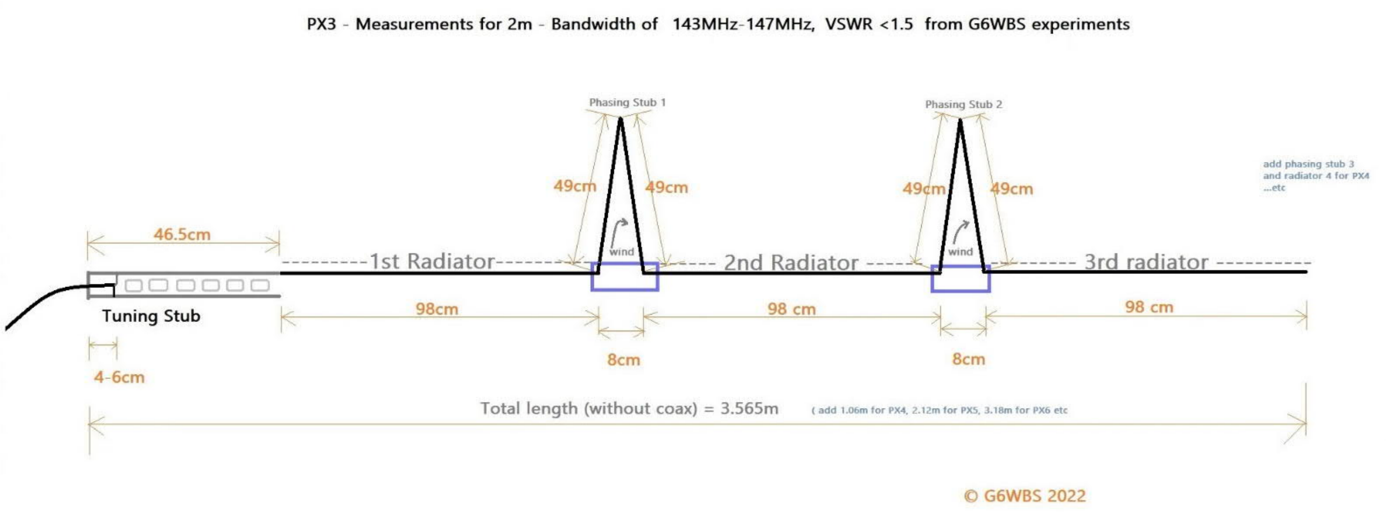
Weaknesses
- QSO pile up. As it's radiating in all directions it's very likely you'll need to manage many stations after making a CQ SOTA call when in populated areas.
- In windy conditions, lowering the antenna does reduce the gain slightly and increases the angle of maximum gain. See Section 6 to view gain/lobe patterns at different heights.

Skills & Equipment Required
- To construct the PX3 you will need some practical skills, some basic tools and a soldering iron. To tune you will need either a SWR/VSWR meter or preferably an antenna analyser.

Beginners may want to build this at a local club!

WARNING: Using a soldering iron and other tools is not without risk and can cause injury. Use these entirely at your own risk. G6WBS will not accept responsibility for any loss of life or injury in making / using this antenna.

3) Calculations



The PX3 has three main radiators, two phasing stubs and a tuning stub (see diagram above). The phasing stubs ensure that the three main radiators of the PX3 are in phase. The tuning stub allows us to match the high antenna impedance with our 50 Ohm coax.

- The main radiators are half wavelength each (λ/2) and are made of wire.

- Each phasing stub is also λ/2 of wire but folded back on itself.
  (We are going to non-inductively wind this wire around our PVC pipe. Winding it this way reduces the radiation from the phasing stub)

- The tuning stub is made of 450 Ohm ladder line λ/4 in length (electrically λ/2 in wire)

I've chosen 145.500 as my centre tuned frequency for UK SOTA. You can substitute your preferred frequency in this formulae, if needed.

When calculating wavelength for 145.500 MHz we can use
V=F x λ   thus λ = V/F where V is the velocity of light and F is our centre frequency in Mhz.

In air λ = 300,000 / 145.500 = 2.062m thus half wavelength (λ/2) is 1.031m

Inside a conductor or transmission line the velocity is reduced. The percentage reduction is known as the Velocity Factor (VF).

For the wire I am using the velocity factor (VF) is approximately 0.95.
Thus half wavelength using this wire is approx. 1.031m x 0.95 = 0.98m and this is what I have used for the wire measurement for λ/2.

The velocity factor for the 450 ohm ladder line / tuning stub is around 0.89.
Thus λ/4 in air is 2.062m /4 = 51.5cm. In the 450 ohm ladder line this becomes 51.5cm x 0.89 = 45.8cm
I've added on approximately 0.8 cm to this stub as it's easier to take off later, when tuning if needed, than it is to add it on. I have found that it is not over critical.

So in summary we'll be using the following measurements to make this PX3 antenna *[2]
λ/2 in wire = 98cm (x 5, one continuous length)
λ/4 in 450 ohm ladder line is around 46.6cm
*[2] when wrapping the wire around the PVC pipe, for the non-inductively wound phasing stub, we have probably reduced the velocity factor further. However this is to be a quick build and I've found very little difference in performance by tuning the antenna further than we do in section 6) and thus have ignored this reduction.
(If you have plenty of time then please feel free to experiment by maybe reducing the length of wire around each stub by say 1cm reductions and retest).

4) Bill of Materials (Component/Tool/Meter List)

- 4.9m (5 x 0.98m) x AWG 13 - AWG 15 (1.5mm2 to 2.5mm2) multistrand copper wire with PVC sheath
- 75cm x 450 Ohm Ladder line (we will cut to size). I have used multistrand.
- 1m x 50 Ohm low loss coax (5-7mm dia. for SOTA VHF) or a length you need
- 2 x 10cm PVC tube (34mm dia)
- 1 x 50 Ohm BNC Connector (You could use a PL259 if that's what you use)
- 1 x wrap around ferrite core for RF choke (or you could use extra coax and wrap 7 turns around the PVC tube while you tape it in place)
- 1 x PVC cable shroud (to help keep the rain out)
- 1 x reel of black insulation tape (we use very little in the construction)
- 1 x Liquid Insulation tape (either brush on or spray)
- 2 x small tie wraps (2 or 3mm width)
- 1 x self-amalgamating tape (only a little needed)

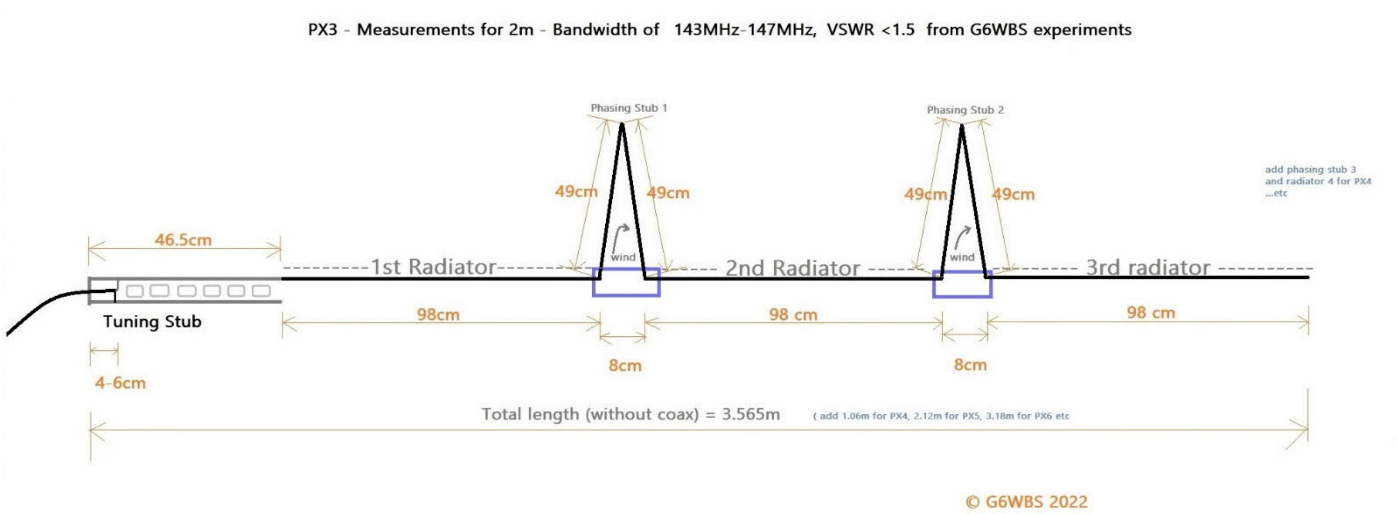
Tools

- Wire Strippers
- Wire snips/cutters
- Sharp knife (Stanley or similar brand)
- Soldering iron and solder
- Bradawl (or 4mm drill bit and drill)
- Cutting board - using your partner's dining table without a cutting board may result in serious injury ;)

Testers/Meters

- VSWR meter for the 2m band
  or a
- Graphical Antenna Analyser or Nano VNA (I prefer using an antenna analyser or NanoVNA vs a VSWR meter)

5) Construction & Tuning

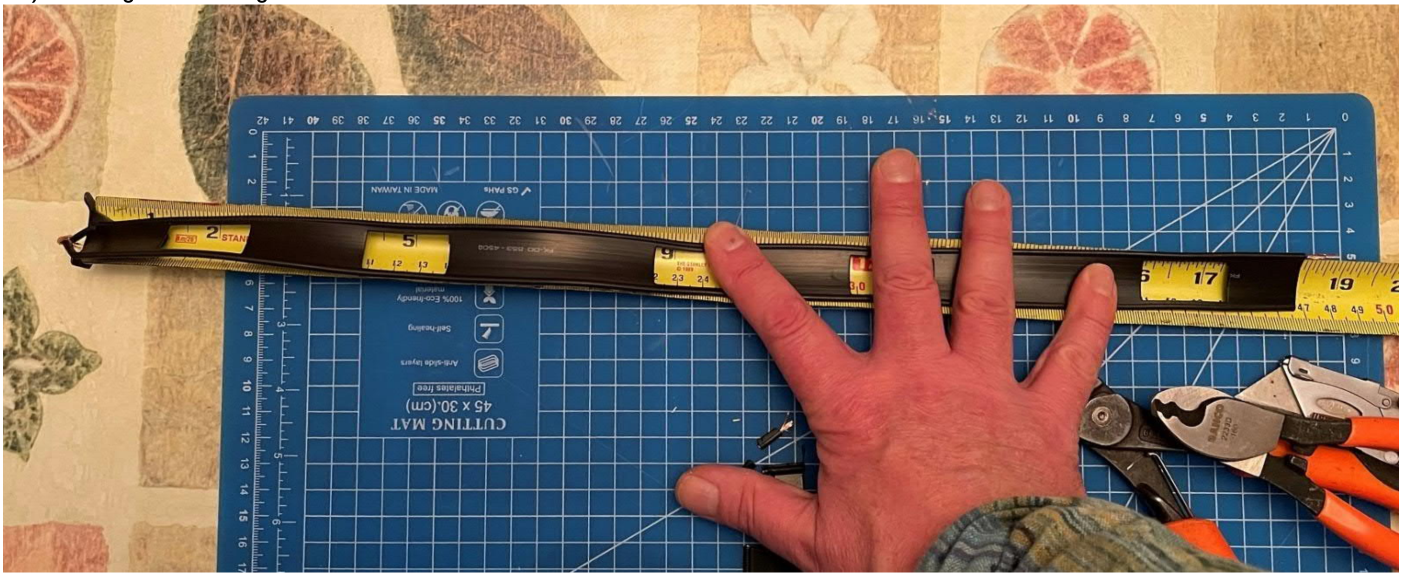


The above diagram shows the various components and their measurements for constructing a PX3 antenna and other PXn antennas.
The PX1 is a 'J Pole' – Use the Tuning stub plus 1 radiator.
The PX2 is a 'Super J Pole' – Use the Tuning Stub, followed by 1st radiator, then a phasing stub, then 2nd radiator.
The PX3 is what is shown in the diagram above and what we'll be making here.

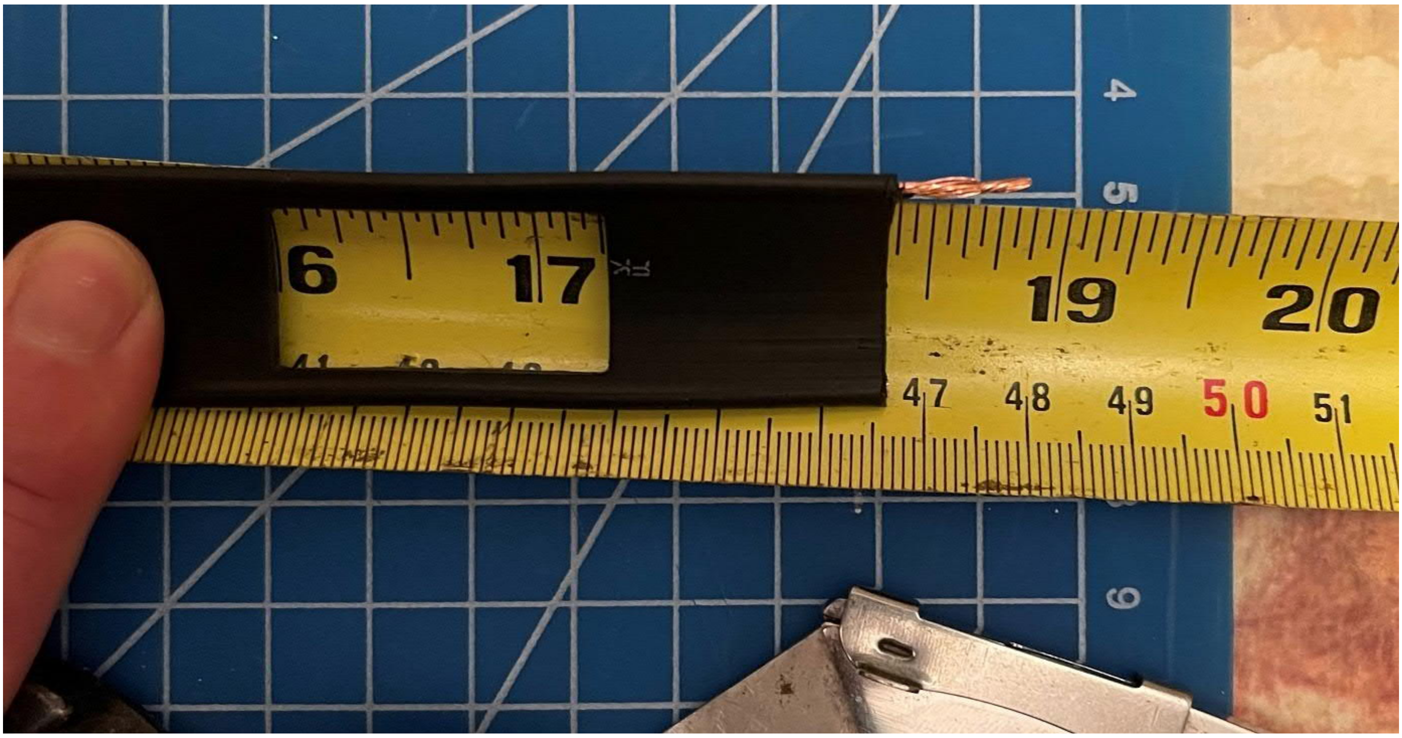
The following pages show the construction steps for making the PX3 antenna for SOTA use, including photos.

I'd recommend that you read this document in its entirety before starting any construction.

5a) Making the Tuning Stub

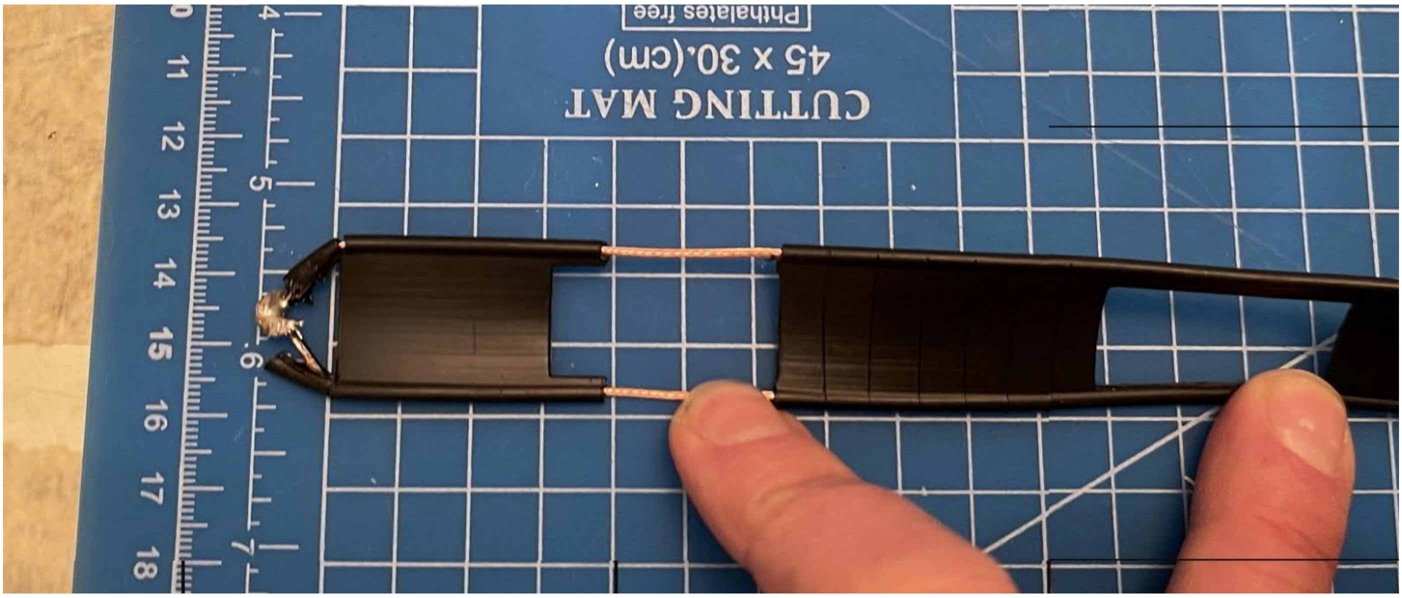


Measure and cut the 450 ohm ladder line to approx. 46.6cm. Allow an extra 15-20 mm at top right (as shown) and at the bottom (left, shown). Strip the tips to show the bare copper wire as shown. Twist the copper wire together at the left hand side.

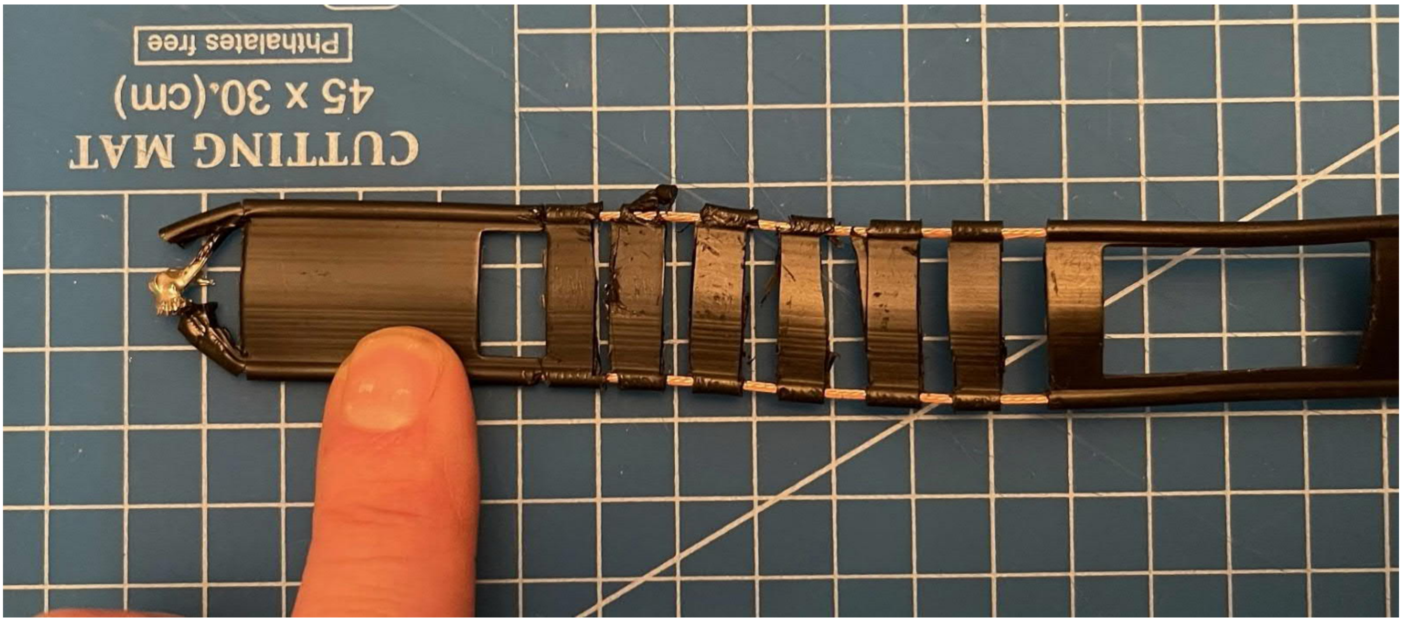


The extra 15mm or so shown above (exposed copper) will allow us to connect to the remainder of the antenna.

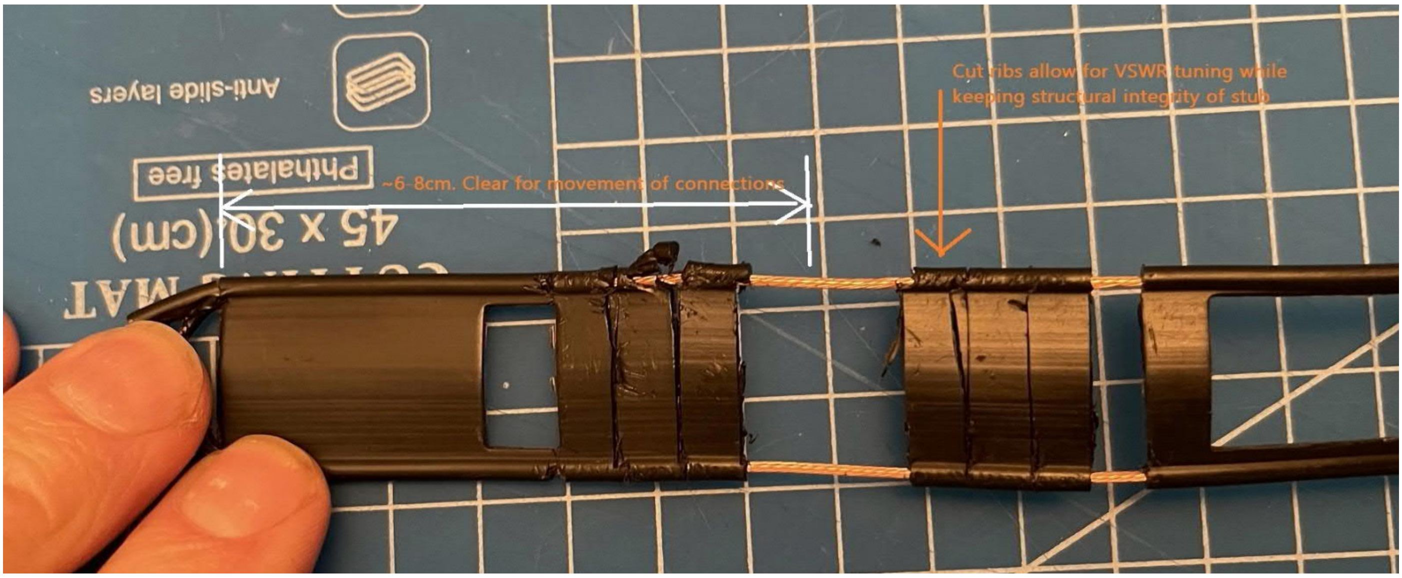
Solder the exposed copper wires together at the bottom of the tuning stub, as shown.



Carefully remove around 2-3 cm of the insulation as shown. DO NOT cut through the copper wire.
After this we want to make approximately 6 cuts, tangential to the copper conductors, for around 4-5 cm of the solid plastic, as shown. Again DO NOT cut through wires. The cutting board shows 1cm squares which should help you with sizing from the images shown.

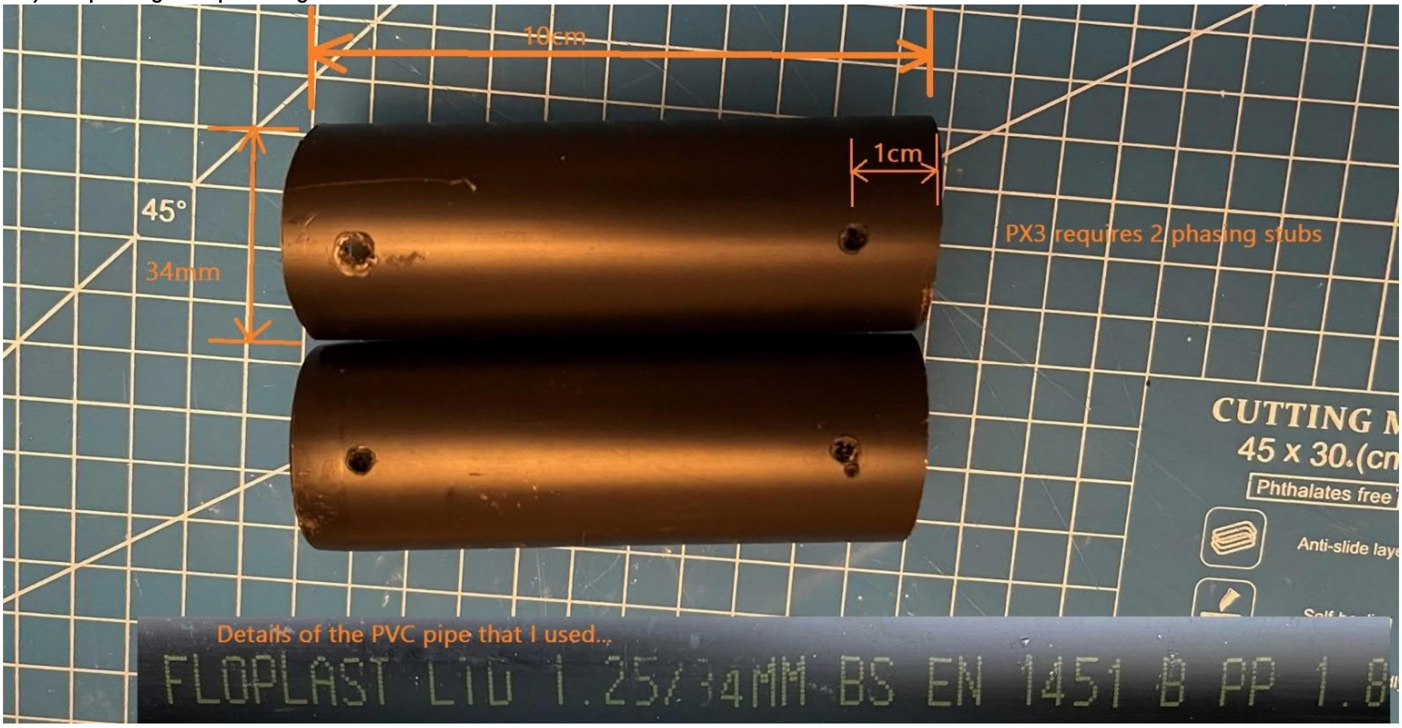


Carefully separate the insulators as shown in the diagram. These should be able slide along the conductor. We do this in order to allow tuning of the antenna (later) and to keep its structural integrity.



Slide the insulators and expose the bare copper wire for the distance of 6-8cm as shown in the diagram. We will use this to connect our coax later and adjust for best VSWR.

5b) Preparing the phasing stub formers

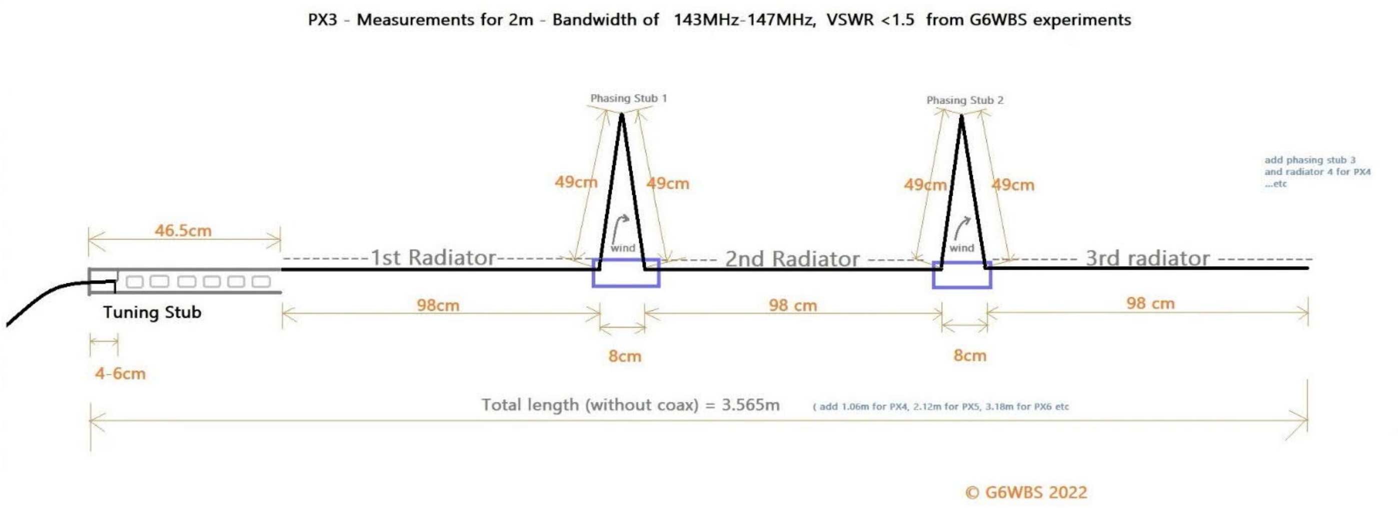


Cut 2 pieces of pipe to approx. 10cm length each. Then, using a bradawl, make a hole at each end approx. 1cm from the very end as shown in the diagram.

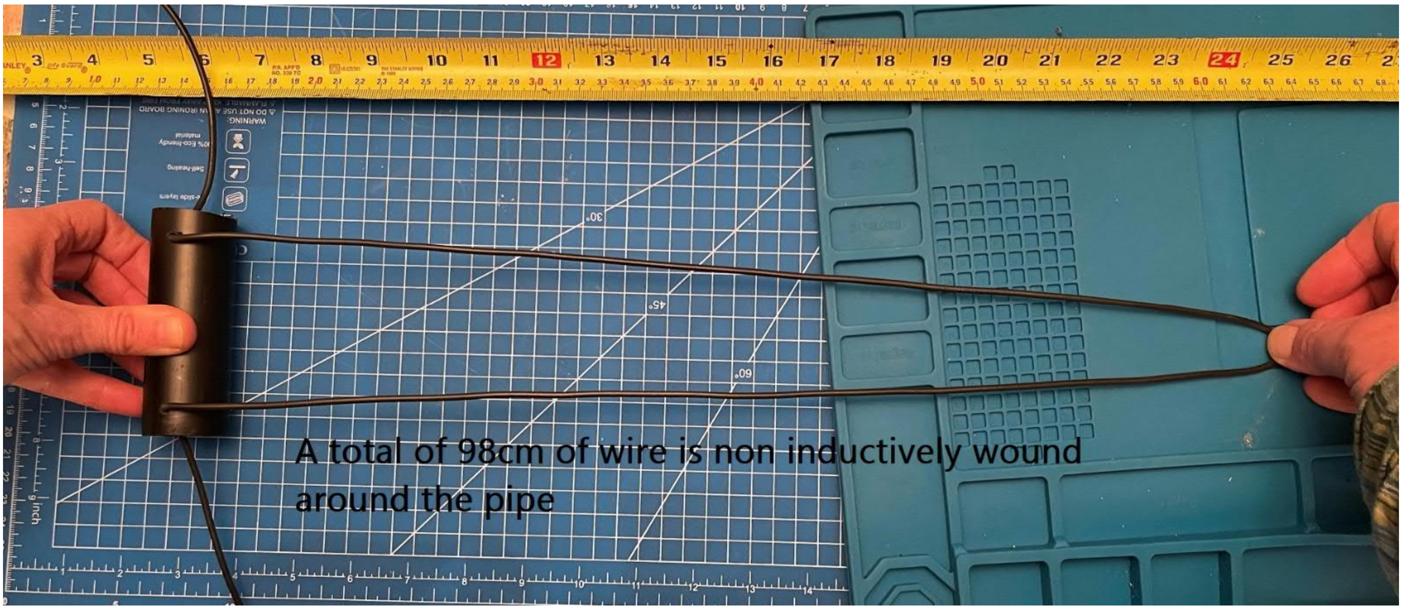
5c) Cutting and marking the antenna wire to length

Cut the PVC coated wire to make a 490cm length. We will use this to make the radiators and phasing coils/stubs Add a kink into the wire every 98cm. Alternatively you can mark the wire.

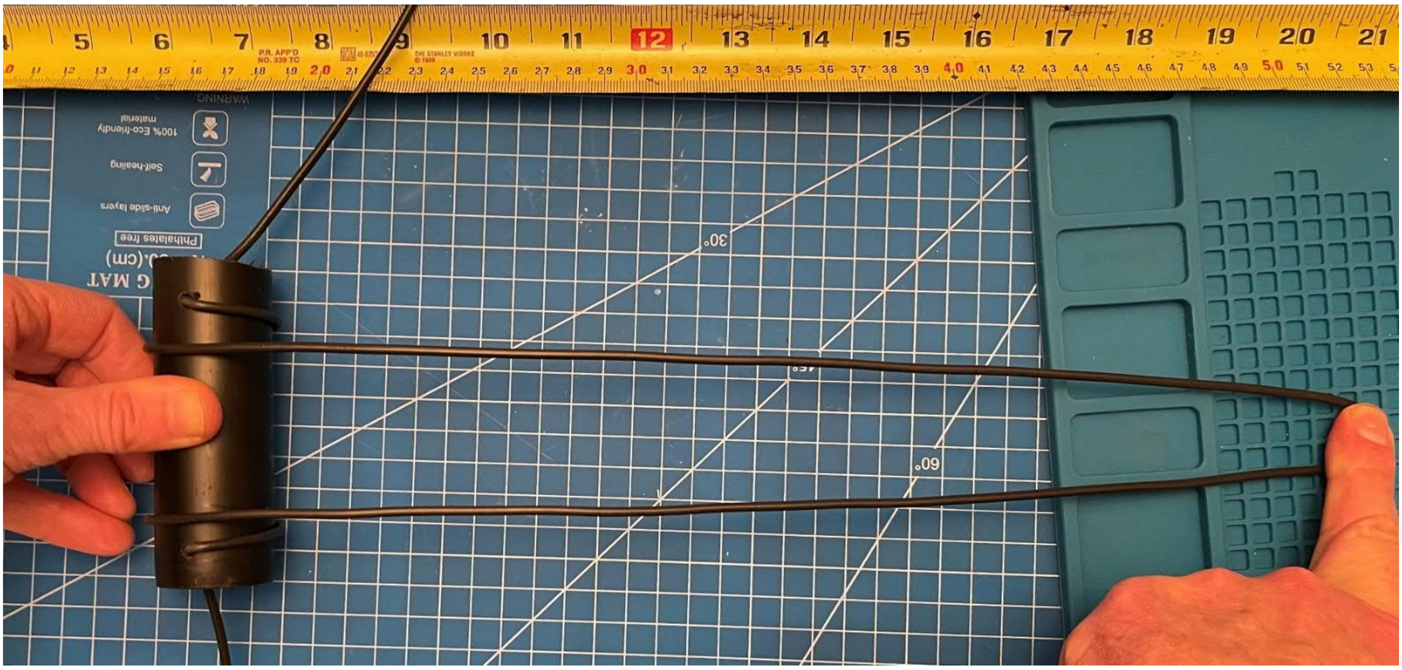
5d) Assembling and non-inductively winding the phasing stubs



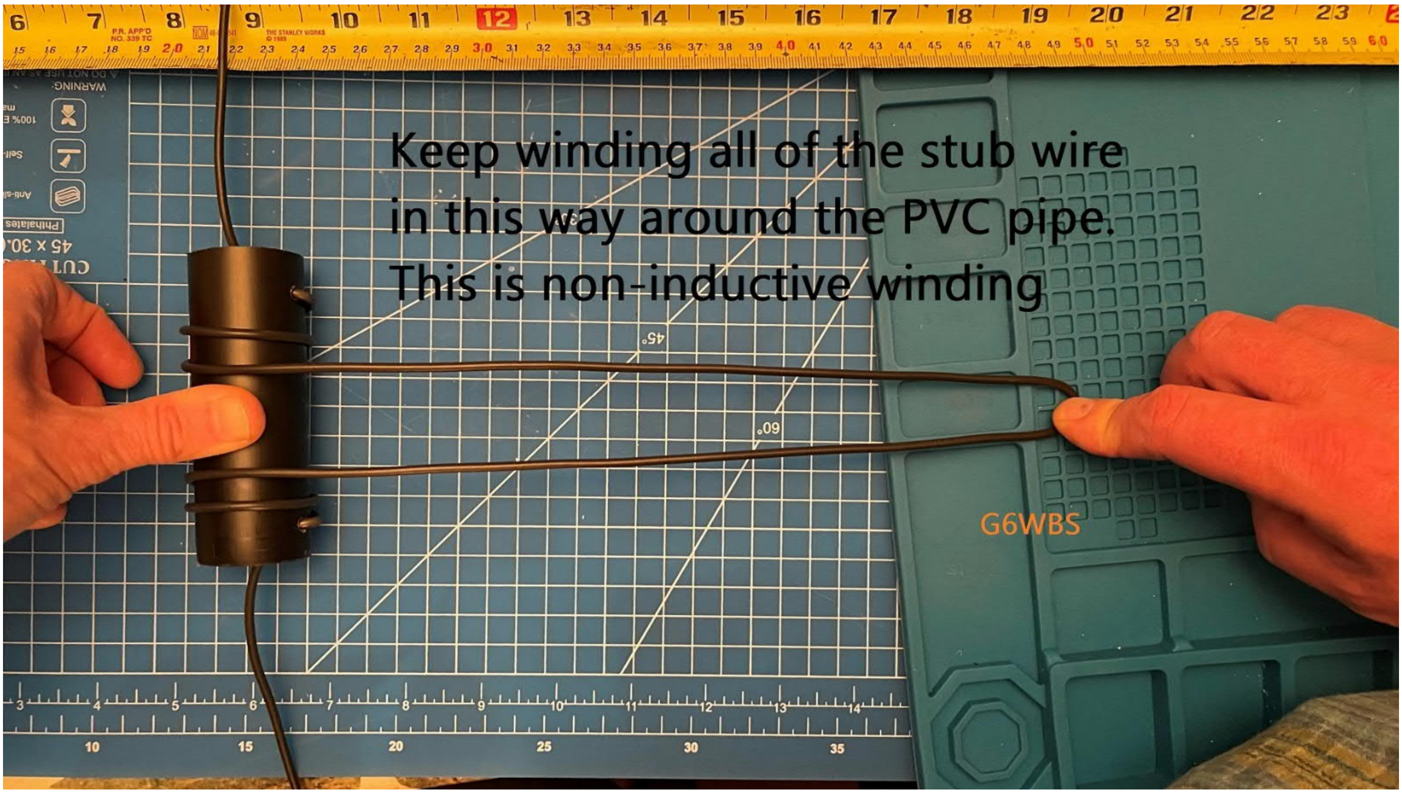
Take a look at the above diagram and use as a guide for the measurements.



Thread the wire through the phasing stub holes so that it looks like what is shown.
You'll have 98cm above phasing stub2, 98cm of wire between phasing stub 2 and 1, and 98 cm of wire below phasing stub 1.
Each phasing stub will also have 98cm of wire (which is going to be non-inductively wound on it)



Wrap the wire around as shown.



Keep winding until the wire is fully wound on the PVC pipe.

The above shows what it should look like when done.

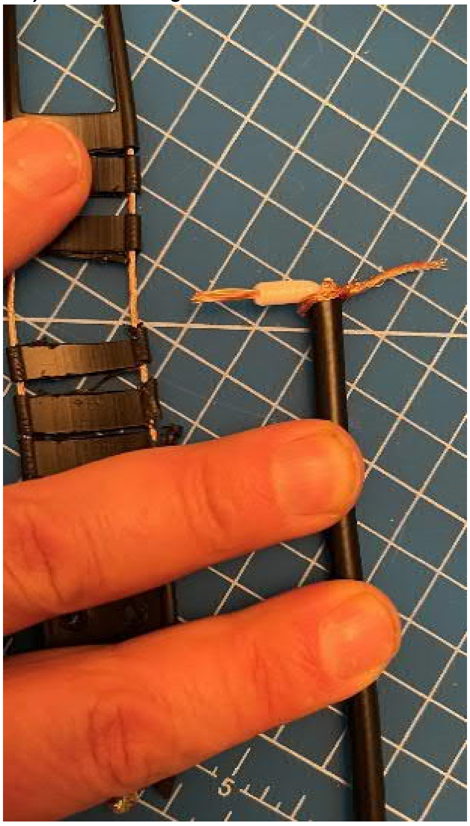
Secure the middle of the phasing stub wire with a piece of insulation tape.
Repeat for the second phasing stub.
(It's worth noting that the middle point on the wire (where the tape holds the wire to the pipe) is where the wire would be shortened, if needed, when tuning. Not expected on the PX3 but may be needed for PX4+ versions)

5d) Connecting the antenna to the tuning stub

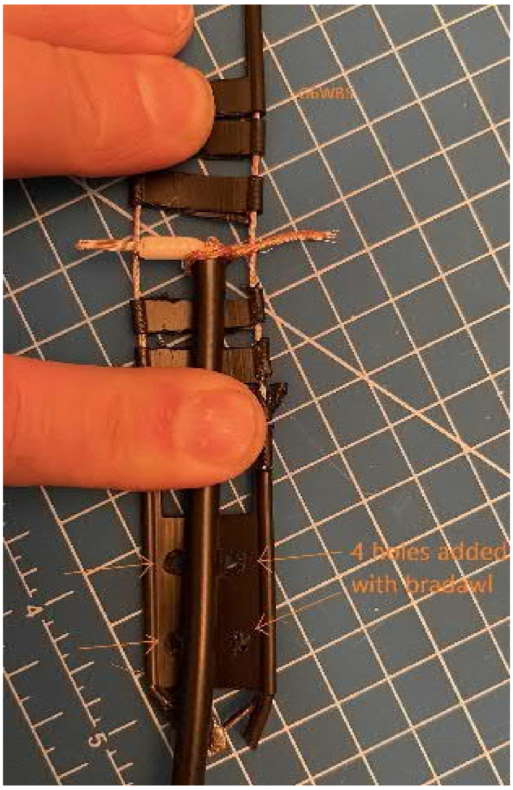
Strip approximately 1.5cm from the PVC coated wire end and solder to the phasing stub, as shown. The solder should be a good joint, nice and shiny.

I have tried using various connectors here but, in the end, decided that a permanent solder joint was best to avoid a bad connection.

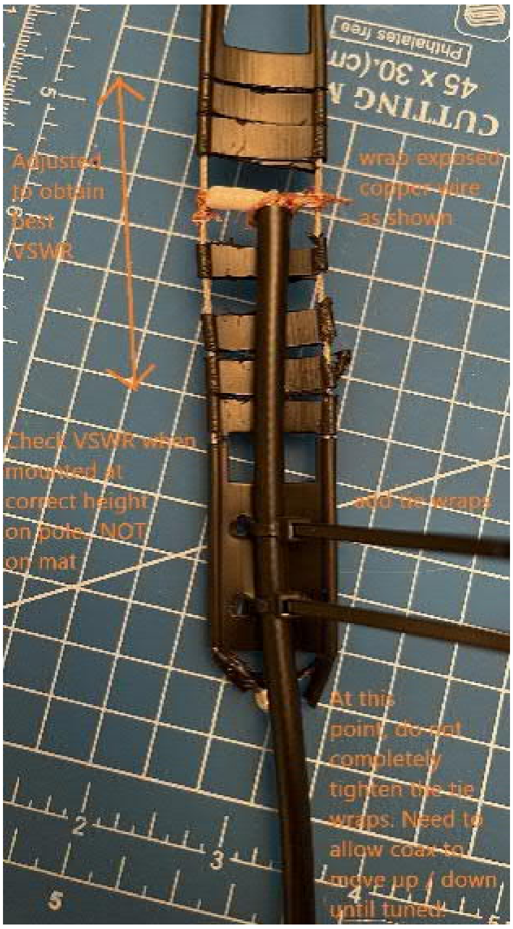
5e) Connecting the coax



Strip back the coax as per diagram. It's really important that you have no loose strands of wire which may short later.

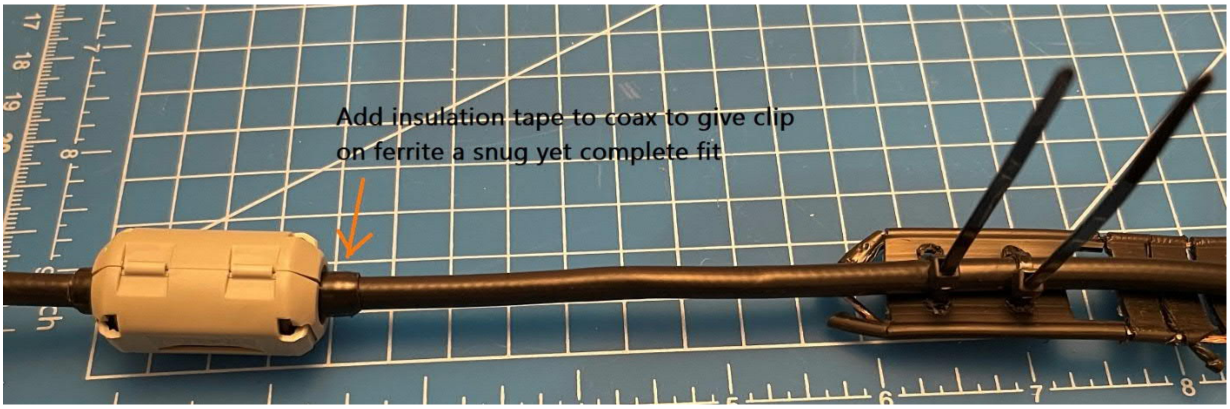


Align the coax over the stub, as shown, mark 4 holes and then use the bradawl to make 4 holes like in the picture.



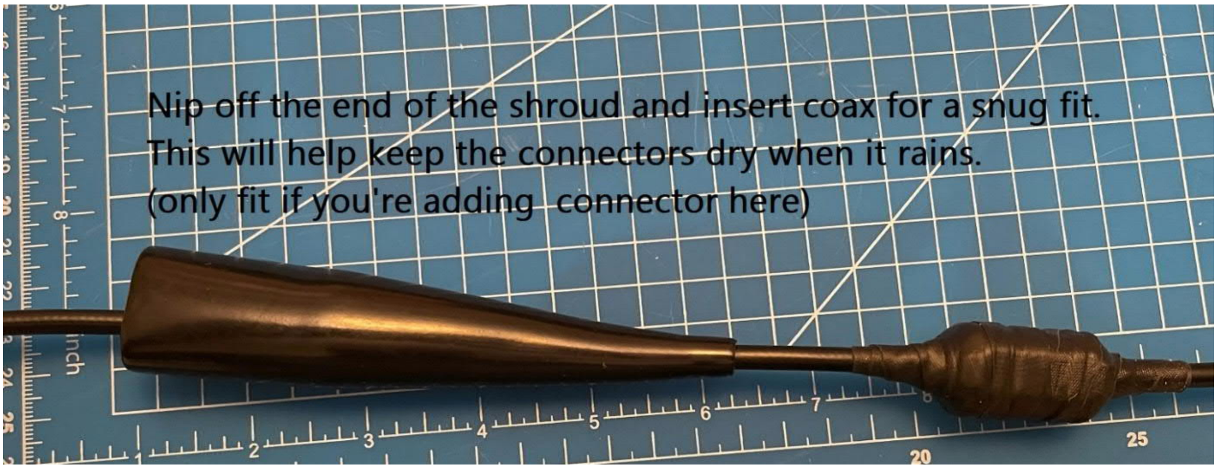
Add 2 tie wraps and allow them to gently pinch the coax. You should be able to still slide the coax up and down with a little effort (I.e. don’t tighten too much until after we’ve finished tuning it). We leave the tie wraps complete at this stage.

Wrap the inner and outer coax wires around the exposed conductors of the tuning stub (as shown in the diagram).



Add the wrap-around ferrite core to the coax as shown. If loose you can add some insulation tape in order to get a snug but complete fit.

Use self-amalgamating tape to wrap / protect the ferrite.



Cut the end off the shroud so that the coax only just fits through it. Thread through as shown in the diagram.
We use the shroud to protect the connector.
(if you're taking the coax back to the shack or car, then you may not need a connector or shroud here and thus you can ignore this step)

Add the connector to the end of the coax. I'd recommend a high quality connector, be it a BNC, 'N' Type or SO239. If this will be outside then wrap in self-amalgamating tape.

5f) Tuning the antenna

Connect the antenna to a fibreglass pole with some insulation tape.

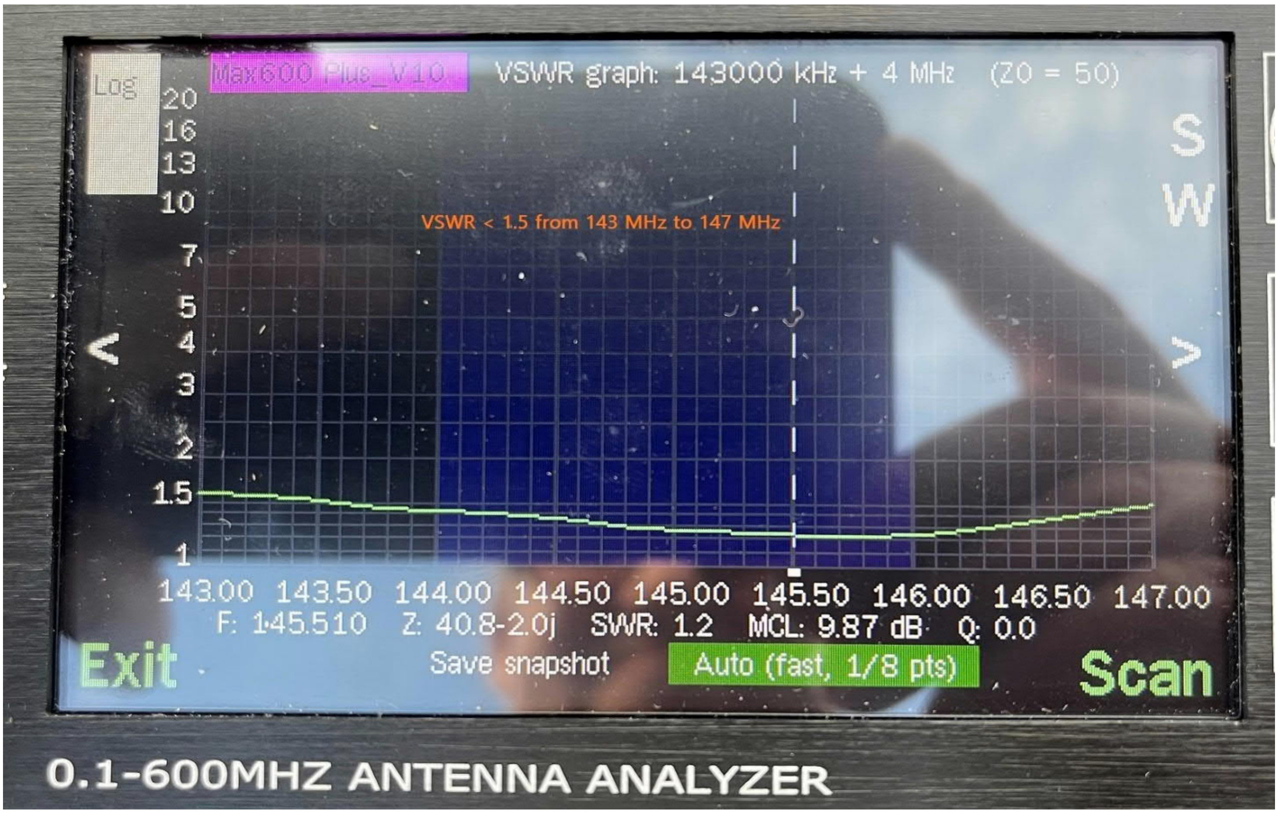
Raise the fibreglass pole so that the base of the antenna (bottom of tuning stub) is at least 3m off the ground (preferably at the height you'll be using it at).

Ensure the pole is supported and away from any metallic objects.

Test the VSWR with the antenna in situ. I test at the centre frequency of the band you'll be using.

If this needs adjusting, lower the antenna, adjust the coaxial feed point, place back in position and retest. Keep doing this until you get minimum VSWR.

If you have an antenna analyser or nanoVNA or similar then you can also find out where the centre of the tuned frequency is. I recommend that you tune for min VSWR before checking bandwidth.

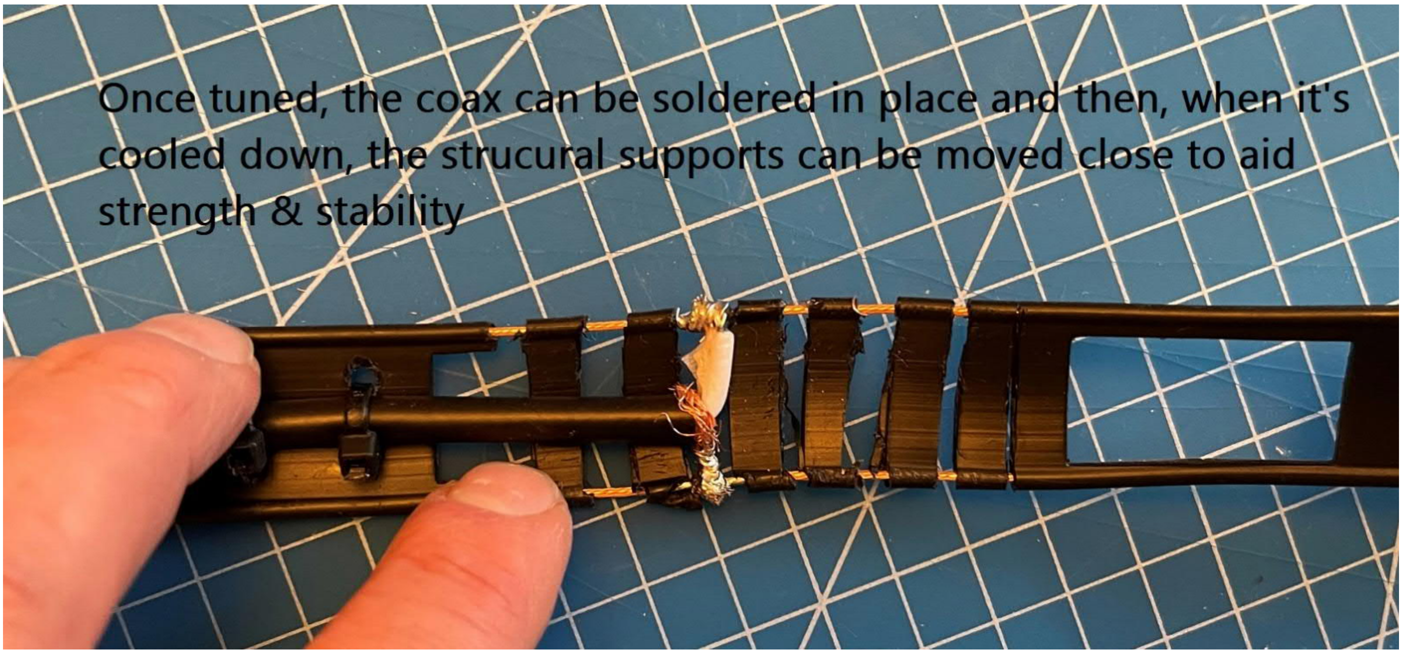


Having adjusted the coaxial feed point to get minimum VSWR I then attached my analyser.
The above analyser shows the centre frequency being at 145.510 MHz.
I was happy with this. I had a VSWR of less than 1:1.5 from 143MHz – 147MHz, which is fine for the majority of transceivers.
N.B. If you have made a PX4, PX5, PX6 etc then you may well find that the centre of band is too low. In this case I would shorten each phasing stub by 1cm and then repeat section 5f. This can take some considerable time.
If it was too high then you may need to add wire to each phasing stub (easier said than done, but I have never had to do this when using the measurements shown in this manual).

You may wish to double check tuning with a separate analyser if you have access to one. I had a slight difference between the two that I used but both gave acceptable results.

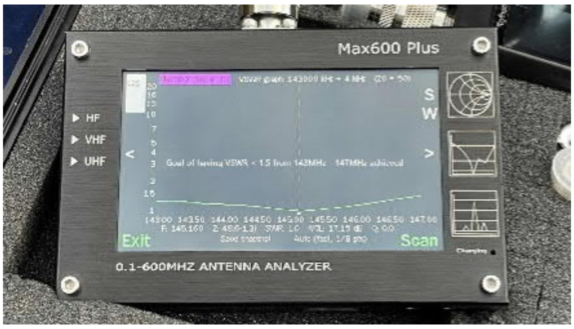
Once you've found the position for the best VSWR then you can fix the coax in place by moving the plastic supports snug to the coax.

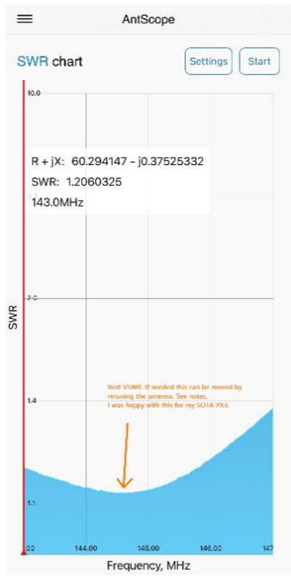
Then, once you're back in the workshop, you can move these away ready for soldering.



When the best VSWR / Tuning position is found and finalised move the PVC structural supports away from the joints to be soldered and solder the coax to the tuning stub as shown in the diagram. Then move the structural supports back to either side of the (now cooled) solder joins as shown. These reduce the movement of the coax around the joints and offers some protection against movement / vibration.
Tighten the tie wraps and remove any excess.

Any exposed wire should be sealed. I've used liquid insulation tape (comes in a bottle or spray can). This may require several coats (and hours) to dry properly.

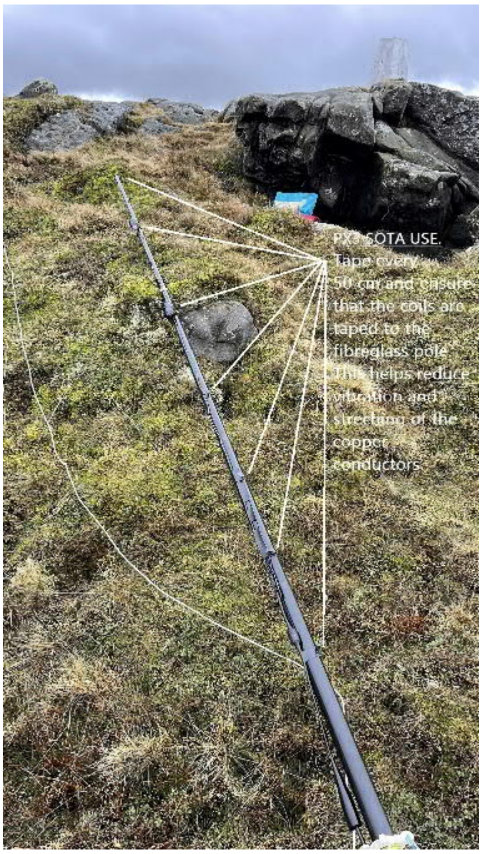




The above photos confirm the VSWR bandwidth (Tested with both the Mini 600 and Rig Expert Antenna Analysers). The bandwidth which yields a VSWR of 1.5 or less is 143MHz to 147 MHz, which should cover most 2m amateur bands around the world.


PX3
antenna
G6WBS

The above photos show the PX3 antenna extended and then rolled up.



For SOTA use
The PX3 should be connected to the pole (I use insulation tape) every 50cm or so in order to reduce the risk of stretching the copper wire.

If using a coax connector (like in the diagram) then use tape to support the connector both above and below where it joins the connecting coax.

I have found that the PX3 works well with its base 3m – 7m off the ground.

The higher it goes the better the gain (marginally) but also the more vulnerable to wind it becomes.

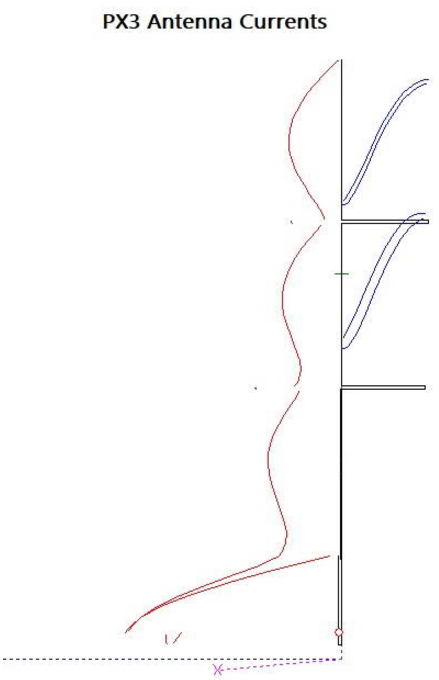
The PX3 measures approx. 3.5m in length. If this is too long then you may wish to construct a PX2 at 2.5m in length.

This photo shows the PX3 in strong winds, mounted at 3m above the ground.

6) MMANA design / far field plots

MMANA Modelling

The design was entered into some antenna modelling software called MMANA (See appendix for further details). Here are some handy pictures taken from that software



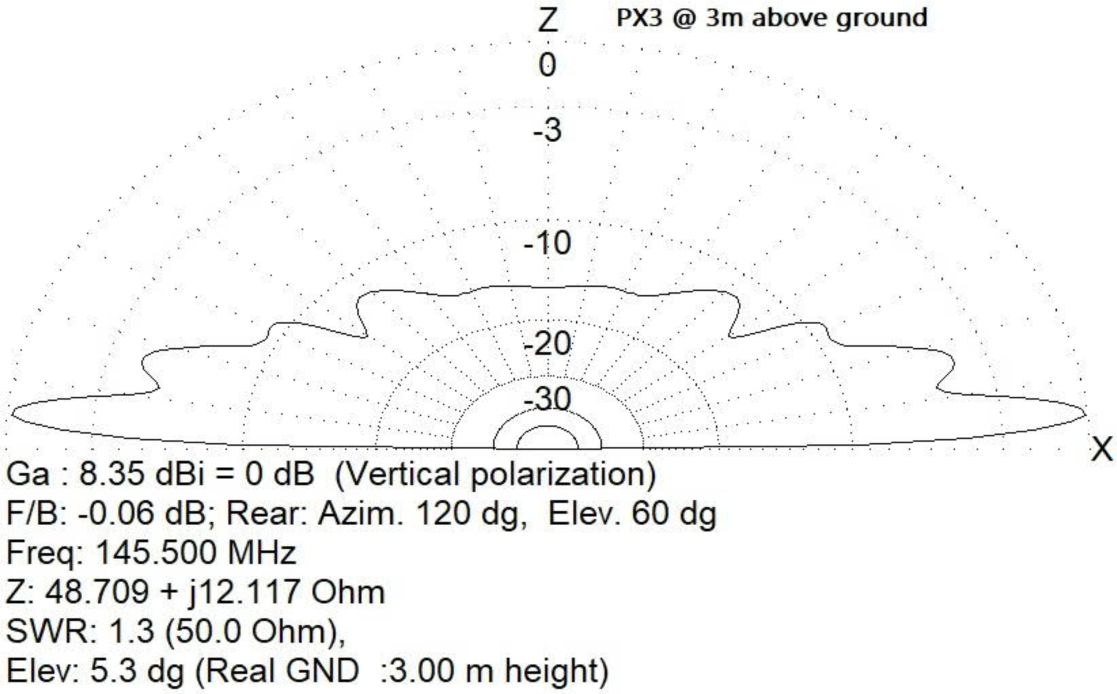
This diagram shows the expected current in the PX3.

The horizontal phasing stubs are hard to add in MMANA and thus are shown here to be horizontal and unwound.

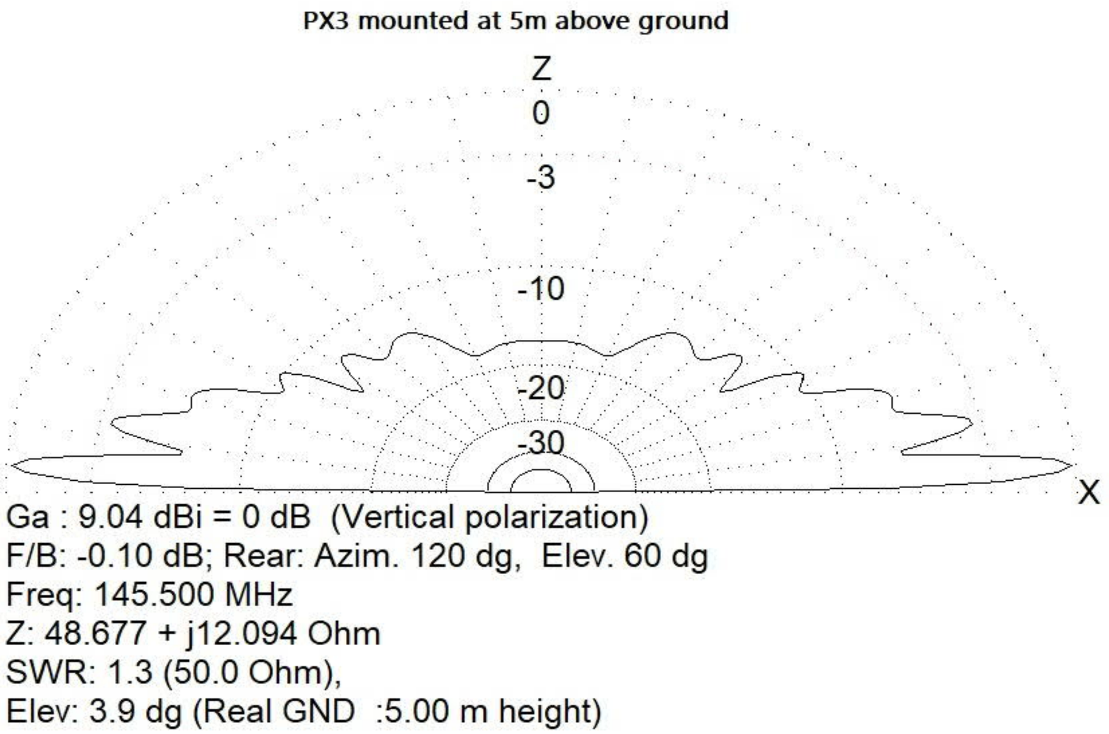
Using phasing stubs like this causes the antenna radiation pattern to go more horizontal than vertical, which is very handy for VHF operation as we want a low maximum antenna gain angle.

Of course no antenna can emit more power than it consumes (first law of thermodynamics) but your antenna can look to spread the pattern in different directions to suit your purpose, which is what we're doing here… removing the radiation which goes up and pushing more of it to the side.

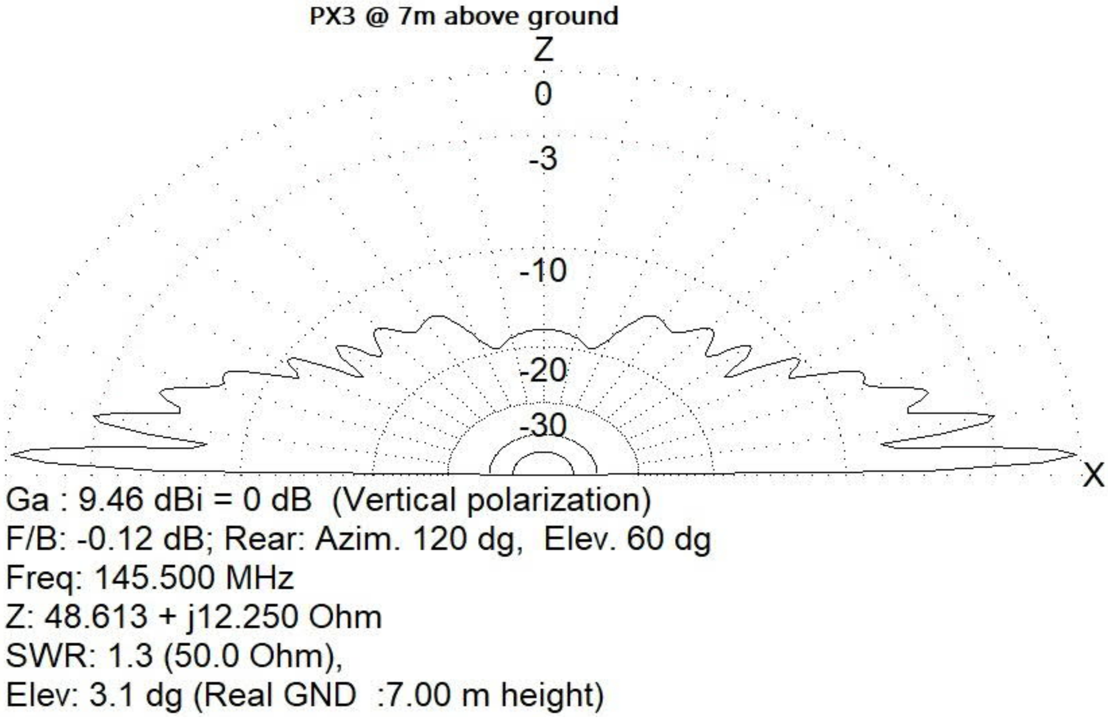
The following diagrams show how the radiation pattern varies with height off the ground.



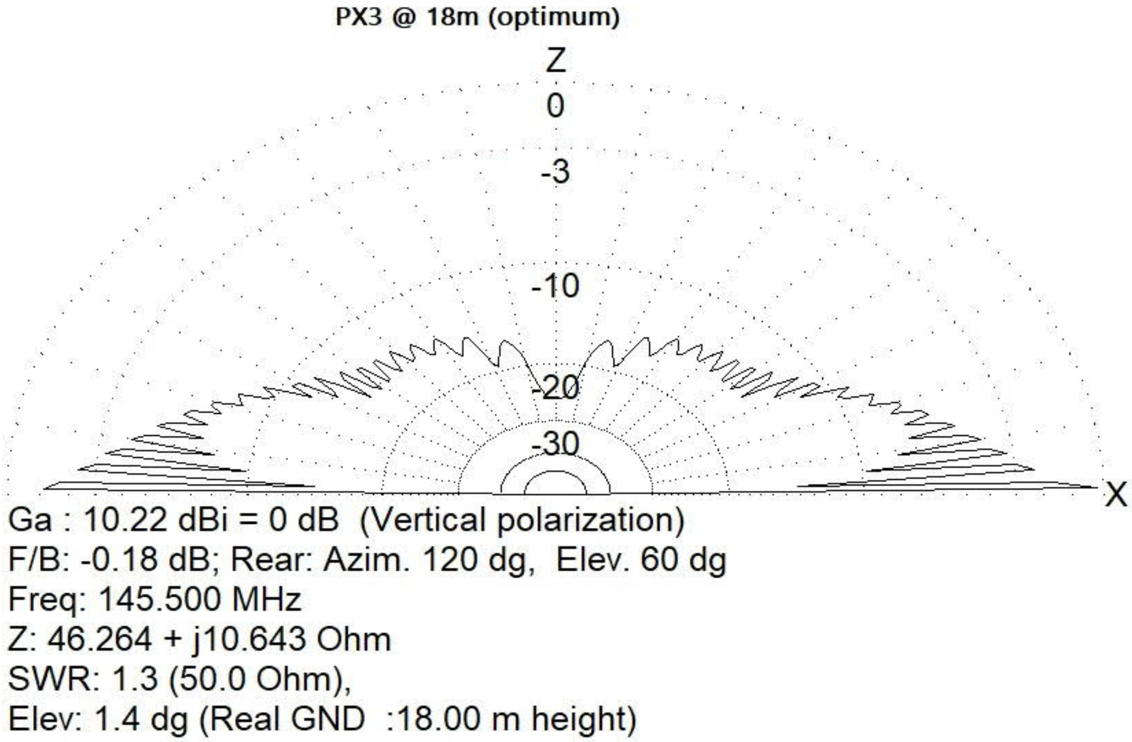
MMANA plot of the PX3 mounted at 3m above non-perfect ground



MMANA plot of the PX3 mounted at 5m above non-perfect ground



MMANA plot of the PX3 mounted at 7m above non-perfect ground



MMANA plot of the PX3 mounted at 18m above non-perfect ground

The maximum radiation angle lowers with increased height. The gain also increases.
However the radiation lobes become very sharp. In practice on a hill this means one moment you might be giving a distance station an S9 signal and the next you may be giving them an S3!
Thus going high in windy conditions is not recommended, even if your pole is strong enough!

7) Other Considerations

Using the PX3 in your shack
Depending upon what country you live in, and whether you get frost/snow or not, then you may wish to adapt the build of your PX3 to fit inside your fibreglass pole. If doing this then you may consider the following points:-

- I have used PVC covered copper wire here. You may wish to use enamelled covered copper wire. The velocity factor may be different to what I've shown here so you may need to experiment with lengths.

- I have used 34mm plastic (PVC) pipe for the phasing stub. You may wish to use a 20mm diameter pipe so that it will fit inside your fibreglass pole and wrap your enamelled wire around this instead (or even remove the pipe once the non-inductive wrap is done). Taking apart a commercially available collinear may give you some construction ideas.

If you decide to attach your PX3 to the outside of your fibreglass pole then snow / ice may affect its performance more so than if it were inside.

This picture was taken on a hill covered in mist.

I had just done 20+ QSO over 20 minutes including a QSO of 330Km using just 2.5 watts.

After those 20 QSOs signal reports started to drop even to local stations.

The fog together with a small amount of wind (5mph/ 8Kmph) had started to frost up the antenna including the phasing coils and tuning stub.

I had already activated the hill and so no big deal but it's worth mentioning if you intend to use one in your shack in cold countries.

Having done over 140 summits (at the time of writing this document) this was the only time it had happened but I felt that I should mention it.

This is a PX6 being tested in medium winds using a 12m Spiderbeam pole (not fully extended) and no guys.

It took much longer to tune than the PX3.

I found that it performs much better when 5m or more above the ground.

The PX3 being used at a SOTA summit

Good luck with your construction.

Have fun making it and using it.

Stay safe, and I hope its performance brings a smile to your face and it brings you joy knowing that you made it yourself.

8) Appendix

Design Origins
The design is loosely based upon Hans Beggerow's J pole antenna (1909) / The Slim Jim (Two-metre Antenna Handbook by F.C. Judd 1978, G2BEX) / the Franklin style of antenna and is a practical build and enhanced version of the Super J antenna with 3 or more radiators. The above pioneers inspired me to build the PX3 and share my findings.

I can high recommend "Two-metre Antenna Handbook" by F.C. Judd (G2BEX). This book inspired me to start experimenting with antennas some 30 years ago and I still refer to it today.

Ref. https://en.wikipedia.org/wiki/J-pole_antenna for more info on these early pioneers.

MMANA-GAL L is an antenna-analysing tool based on the moment method, which was introduced in MININEC version 3. The BASIC source code of the computation engine is published as a PDS in MININEC. The program uses the MININEC-3 engine modified by Alexandre Schewelew, DL1PBD, and are written in C++

(Original code by JE3HHT - Makoto Mori. MMANA-GAL basic & MMANA-GAL Pro by DL1PBD - Alex Schewelew & DL2KQ - Igor Gontcharenko. Multilingual MM Antenna Analyzer (MS Windows)

"MMANA-GAL basic is still free for Amateur Radio Use"

ref: http://gal-ana.de/basicmm/en/

MMANA can be downloaded at
https://mmana-gal.software.informer.com/3.0/

Other Credits
A big thank you to Kevin Hughes (MW0KXN) who modelled the PX3 leaning at various angles to see how the angle of maximum radiation changes with slant on the antenna. To our surprise changing the angle of the antenna from 90° to 88° to 85° to 80° degrees (from the horizon) has little effect of the antennas performance.
N.B. We still need to model the antenna bending in high winds.

This Document
This PX3 Construction document can be downloaded at
Https://G6WBS.com/