VK2JMJ 146.00 MHZ Yagi Antenna

Why not use the VNA instead of a tape measure?

- **Thanks given to http://dg7ybn.de/Symmetrising/Symmetrising.htm**
- **144.000 to 148.000 centre at 146.000 MHZ**
- **Wavelength = 300/ 146 = 2054 mm**
- **1/ 2wave = 1027 mm**
- **1/4 wave = 513 mm**
- **End effect 0.95 (shorter, it can vary)**
- **Reflector 1.2% (longer, it can be varied)**
- **Director(s) 0.95% (shorter, it can be varied)**

Build and mount the driven element first

Mount the driven element's water proofing box and the mechanical restraints to hold the two 1/4 wave elements securely in position on the boom. Reduce the gap in the centre between the rods as much as mechanically possible and separated enough for any voltages expected. This build held it at 3mm. Connect solder tabs as close as possible to the ends of the rods within the water proofing box. The driven element is the only element to be mount on the boom during the first stage of tuning.

Theory to tune the driven element with Velocity factor and end effect

The electrical length of the driven elements is different to the physical length calculated from the frequency wavelength and the calculated length varies with the following

- The velocity factor of the element, determined by conduction and outer surface
- The diameter or shape of the element
- The construction of the element, tubes or solid or angles
- The end effect of the element, influenced by the rod's diameter and shape
- The width of the boom structure
- The mounting mechanism's stray capacitance and inductance
- The length of the solder tabs that will lengthen the centre of the dipole
- The position of the solder tabs to the centre (must be close as possible)
- The length of the ends of the coax fly to the start of the balun

This means it does not matter how fancy-pants the calculations have been or which calculation software was used for the length of the driven elements because many other factors will alter that length electrically. Careful construction of the centre waterproofing box will reduce the unknown variables by controlling those variables mechanically and making them stable.

- Select a tube size for mechanical strength and stability and availability and cost
- Select a boom size for mechanical strength and availability
- Secure solder tabs firmly so that once set, the electrical length remains stable
- Lengths of coax connections to solder tabs being as short as possible
- Coax connections being mechanically stable
- Secure mounting of the rods so that the mechanical length does not change

Length tune the driven elements with the VNA

Complete the dipole tuning with only the driven element on the boom.

Connect a short fly lead to the VNA using a SMA connector at one end and open braid and centre conductor at the other end. The coax fly to the centre solder tabs needs to be as short as practical to operate the VNA. Do not use a long length of coax. Set the VNA for the centre frequency at 146.000 MHZ and a program a suitable span for the display. The calibration of the VNA is not important for this task. Search for the dip caused by the electrical length of the two rods that form the driven element dipole as they are physically mounted and restrained within the waterproofing box upon the boom.

A handy hint is to mark 5mm and 10mm divisions accurately at the far ends of the rods to assist with accurate shortening of the rods so that either side is exactly the same physical length.

Cut the ends of the rods at 10mm divisions to move the tuned dip closer to the band centre and then start cutting the rods at 5mm divisions (both ends must remain at the same length). Adjust the sweep points and sweep range on the VNA as the centre 146.000 MHZ resonance point is approached. The impedance of the dip not being at 50 OHMS is not important. The important issues are

- Dip at the centre frequency
- All other variables are controlled and stable mechanically
- Only the length of the rods vary the dip frequency

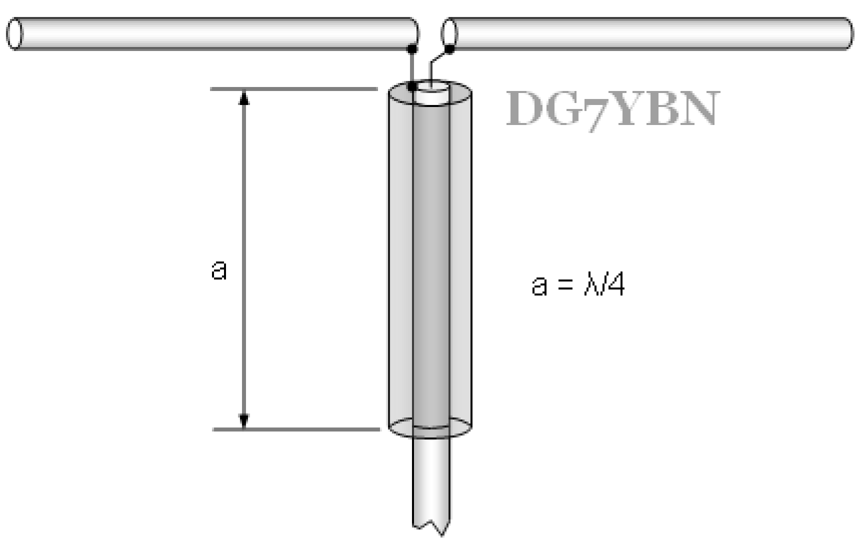
Discussion: It is not possible to calibrate the VNA on a coax fly. It is possible to get the perfect 50 OHM match at the centre frequency during this tuning, but this is not important. A handy hint if you think that the elements have been cut too short is to insert a threaded bolt in both ends as a test to extend the mechanical length.

Feed line matching devices

The un-balanced coax feed line is to be directly connected to the balanced structure of a centre fed dipole. Any RF energy placed on the driven element by the coax centre conductor will be induced to the other element. This induced energy will travel back to shack on the coax braid and cook the operator. It must be blocked so that the energy stays on the element to be radiated and not delivered back along the coax braid.

Visit DG7YDN and read about Symmetrising / Transformation lines and baluns

Classic Style Sleeve Choke or "Bazooka" Balun

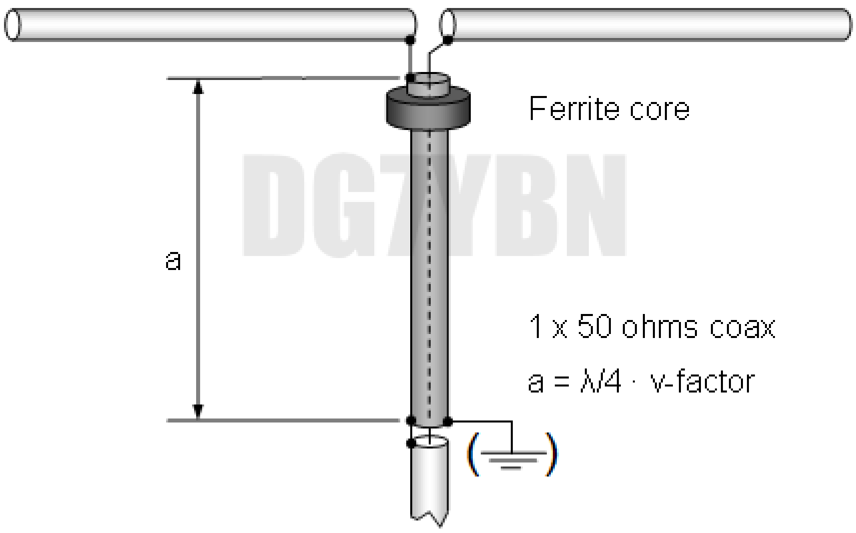


Discussion: The Classic Style Sleeve Choke (Bazooka) worked very well on a 70cm antenna build. VK2JMJ stripped the internals out of a larger coax leaving the shield and sheath intact and pushed the fed line coax inside it. The short electrical lengths of the feed line and the outer shield of the bigger coax were suitable for a 70cm build.

This structure requires that the boom coax connecter be insulated from the boom.

'Grounded' Coaxial Quarter Wave Line

DG7YBN Style Quarter Wave Lines



Discussion: This design works the same as the Bazooka Balun by creating the 1/4 wave trap by grounding the coax to the boom. The 1/4 wave trap is then improved at a high impedance by adding a very good ferrite core.

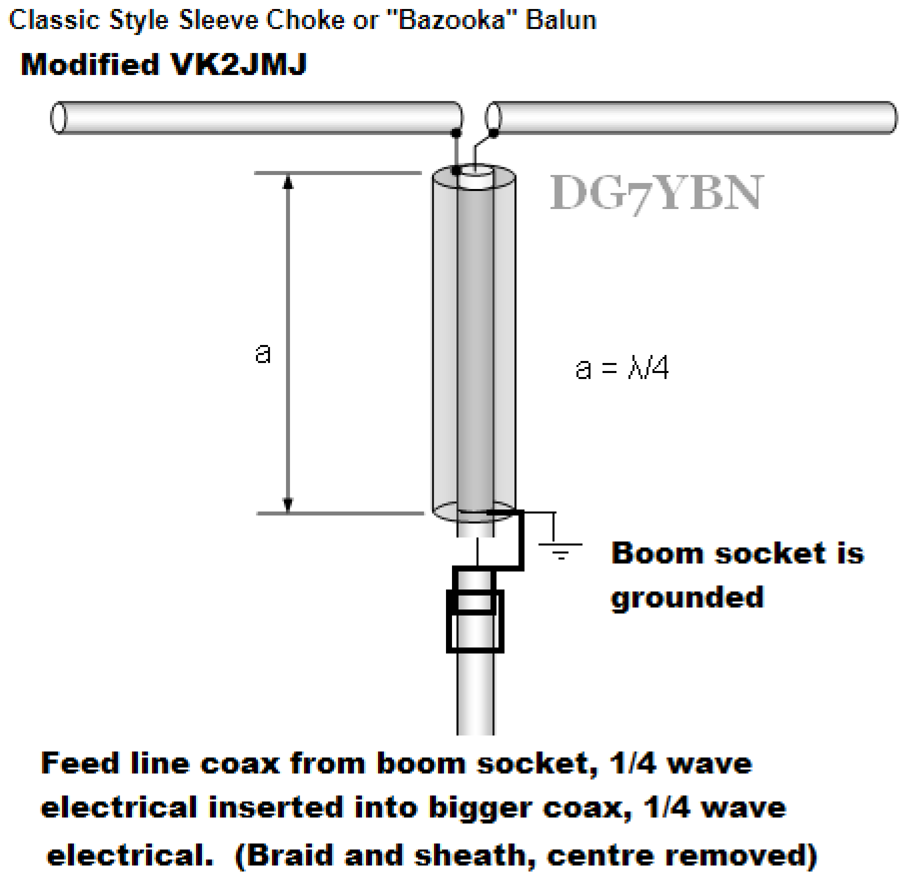
Manufacture a right angle bracket for the coax connector that will be mounted to back of the boom and mount the socket to accept the coax feed line. The bracket is to mount to the metal boom at the rear of the driven element and the coax end is to enter the waterproofing housing of the driven element.

Use the VNA to determine a 1/4 wave electrical length of feed line coax, leaving just enough at both ends for solder connections. Solder that electrical length to the connector and solder to the driven elements with the ferrite core in place.

Experiment with the influence of adding and removing a ferrite choke to the length.

Experiments with this type of balun has failed.

RF was still getting back onto the braid of the coax feed line.



How the 1/4 trap works using electrical lengths

The outer braid is close to a 1/4 wavelength at the centre frequency and has formed a 1/4 wave electrical length trap from the connection at the socket where the two coax braids are connected together and also connected to the boom ground via the socket mounting bracket.

The feed line braid is also close to a 1/4 wavelength and is forced to be at a high impedance at the driven element by this 1/4 wavelength and also by the outer shield's 1/4 wavelength.

The centre core of the coax feed line supplies energy to one of the driven elements. This energises the opposite driven element. This induced energy will try to leave by entering the coax feed line braid, but the energy is challenged by a high impedance created by the 1/4 wave lengths of braid in the inner coax and the outer braid. The energy is forced to stay on the element to be radiated.

Manufacture the 1/4 wave symmetrising traps

Required RG59U and RG213 and N-Type female panel solder connector.

Take a length of RG59U coax, being slightly longer than the calculated 1/4 wave length.

300/146/4 = 513mm. Cut a length at 550mm. Strip 5mm of the outer sheath to expose the shield and prepare the shield to connect directly to the output of the VNA socket. Take care not to damage the socket. A hint may be to solder a very short component lead to the braid. You may now realise the importance to select a coax that has a braid that will accept soldering. The VNA will show a dip at a frequency lower than 146 MHZ. Trim the far end to slowly bring the dip closer to the centre frequency.

Prepare the second shield and sheath from the RG213 larger coax. Cut a length at 550mm. Draw out the centre and the shield braid. Insert the RG59U into the braid and twist and solder the two shields together at one end leaving a very short solder pig-tail to connect to the socket ground. Insert the dual assembly into the sheath of the larger coax. At the other end, trim back the outer braid and sheath to expose the inner RG59U coax and strip it back 10mm to make pig-tails to connect to the solder tabs inside the waterproofing box for the driven elements. The outer second shield is trimmed back and is not connected to the inner coax shield, but remains very close to the end of the inner coax. Two 1/4 wave electrical length traps are created. Mount a coax connecter and bracket to the boom. Solder the coax assembly inner core to the centre pin and solder the inner and outer shields to the coax socket ground. Solder the other end inner coax to the driven elements, braid to one side, the inner conductor to the other element. The outer braid is not connected.

Tune the sleeve choke with the driven elements

Progress so far:

- The driven elements have been trimmed to an electrical length using the VNA
- The boom does not have any directors or reflectors
- The balun has been tuned to an electrical length using the VNA
- The balun and the grounded feed line socket and driven elements have been mounted and ready for testing

Set up the VNA for a frequency range larger than expected. View the dip. It is expected to be very close the centre frequency as determined by the electrical length of the 1/4 wave traps and the 1/4 wave lengths of the two driven elements.

Setup the VNA to cover the working band frequency. 144.000 -> 148.000. Complete a calibration using the O/C, S/C and LOAD at the coax connector that will connect to the boom socket. The length of coax to the VNA must be short as possible as a long length will disrupt the results. The sweep impedance will be lower or higher than 50 OHMS and may be inductive or capacitive . This is not important. The resonant dip needs to be somewhere within the working range. Do not adjust the lengths of the driven elements.

Manufacture boom sliders

Rather than drilling into the boom at a fixed location for the elements that limits in field tuning, manufacture a boom sliding element mount. VK2JMJ used plastic conduit saddles and also a 3D printed sliding mount. At the centre of each director and reflector mount the sliding bracket. This allows the element to be slid easily along the boom. When the tuning has concluded the element will be secured onto the boom.

- No evidence was found for any reason to insulate the directors or the reflector from the boom.
- No evidence was found that the mounting mechanism should be limited to a single bolt through the absolute centre of the element and the boom. However, with the sliding bracket in place, a centred single screw would be ideal.

Insert a reflector

The reflector element is longer than the driven element so it will present inductance to the driven element. Move the reflector along the boom to best match. You will notice that the impedance point is moving. Experiments with a longer reflector seemed to have less impact on the trace. Using a reflector that was only slightly longer than the driven element had the most impact on the trace on the Smith chart of the VNA. Leave the reflector in the sweet spot.

Insert the first director

Experiments with the first director's length showed a length shortened by a small percentage less than the driven element had the most impact on the trace. Move the director along the boom. The director is capacitive and will move the impedance trace against the actions of the inductive reflector. Find the sweet spots to shorten the range swing of the impedance. You may also see a phase shift. Leave the director and reflector in the sweet spots.

Insert the second director

The next director is shorter than the first. When it has been shortened by the suggested percentage, it seems to have the greatest impact on the trace. Move both directors and verify the sweet spots and move the reflector. The wild range of the impedance should be getting shorter and the VSWR should be getting lower. Leave the elements at the sweet spots.

Insert the third director

This is also shortened by the text book percentage. It is surprising how much impact the position this director has on the trace on the VNA when it so far away down the boom. Locate the sweet spot. Re-locate the other directors and verify the reflector position. The range of impedance swing should be getting smaller. The element positions are controlling the impedance at the centre of the driven element.

Insert the more director (s)

This is also shortened by the text book percentage. It is surprising how must impact the extra director (s) has on the trace on the VNA when it so far away down the boom. Locate the sweet spots. Re-locate the other directors and verify the reflector position. The range of impedance swing should be getting smaller. The aim is limit the impedance swing to a circular trace around 50 OHM resistive. The SWR dip can be controlled to the centre of the frequency range.

Discussion:

It was surprising during the build how much the third and a fourth director can impact the performance of the driven element when it is at the other end of a long boom. The reflector continues to have impact but not as much once the boom is loaded with directors. Continue to reposition each of the elements to reduce the impedance swing and dip the VSWR to the centre working frequency.

It was found the director final placement was completely dependent upon the director length reduction compared the previous director. VK2JMJ did not follow a fixed percentage reduction formula (because he is a random in nature sort of fellow) and this has resulted in the directors being unevenly spaced. It could be concluded that if one wishes to construct a narrow band Yagi, then a small percentage and constant reduction for each director would be used.

No common mode RF was getting back out to the shield. This can be detected by moving the coax connections at the VNA or by extra hand capacitance not effecting a change in the trace.

As more directors were added, my body capacitance was impacting less to the trace suggesting that the radiation pattern of the structure is being more forward rather than sideways.

During experiments and boom assembly and tunning, the Yagie was clamped to a large steel work bench located just behind the reflector and was conducted inside the garage. Being a very large steel work bench, it seemed to have no impact as the bench would not be resonate.

Once moved outside to open air the setup improved. Final tuning needs to be completed in a space simular to how the Yagi will be used.

Mechanical boom support structure

VK2JMJ used a vertical strut at the centre of gravity of the boom to hold it aloft for the final tuning with horizontal polarisation.

Build Conclusion Comments

All the numbers, all the calculators and all the different designers, the WEB sites, the fancy pants dudes and fancy pants calculators have made this learning process very difficult to fully understand and follow. Hats off to them for the dedication and efforts.

For a home brew the secret tool is the VNA Smith chart. A firm understanding of the Smith chart is required to comprehend how inductance from the reflector and capacitance from the directors are impacting on the centre impedance and resonance of the driven element. Moving the directors and reflectors allows direct control of the impedance at the centre of the dipole and force a correction on the odd lengths in the 1/4 wave traps and coax connections and lengths of the solder tabs.

Special thanks to DG7YBN for the designs of the 1/4 wave choke balun designs. The efforts of others has produced many different balun designs and a lot of software calculators.

This design is to use low power over the full 4mhz bandwidth. The balun design using one coax inside the braid and sheath of a large coax has worked very well for this 2 metre build. The same Balun design worked very well for a 70cm build. However it would not be suitable for lower HF frequency ranges due to the long length of a 1/4 wave.

The lengths for the directors need only follow a simple rule to be a percentage smaller for each one so that they become capacitive to the previous director and the reflector be a percentage larger so that it becomes inductive. The exact lengths is not important enough to calculate a boom correction factor because the differences in director lengths and reflector length just means the VNA will set them it at a different boom position.

But what IF ?

If it is desired to construct a Yagi that has a very tight bandwidth and more directors, then the percentage reduction of the directors becomes more important and will have a smaller percentage reduction for each one maintaining the capacitive impact on the driven element. Many more directors would have no reduction in the physical length.

Once the lengths of the directors and reflector has been set, the VNA will determine the locations on the boom.

Once the final tunning was completed, experiments with extra reflectors above and below the existing reflector proved to be of very little value.

Field test, Fight with the pool

The method to determine a radiation pattern is still in the thought stage.

Yagie under test, located at Albury, heading 295 degree, 3 metre elevation and pointing into suburban houses and hills with horizontal polarisation and 2 watts of transmission power.

Receiving station, Howlong. Path 25 km, high tower mounted rotatable horizontal, pointing 115 degree.

(1) The receiver station was rotated until a peak in signal strength.

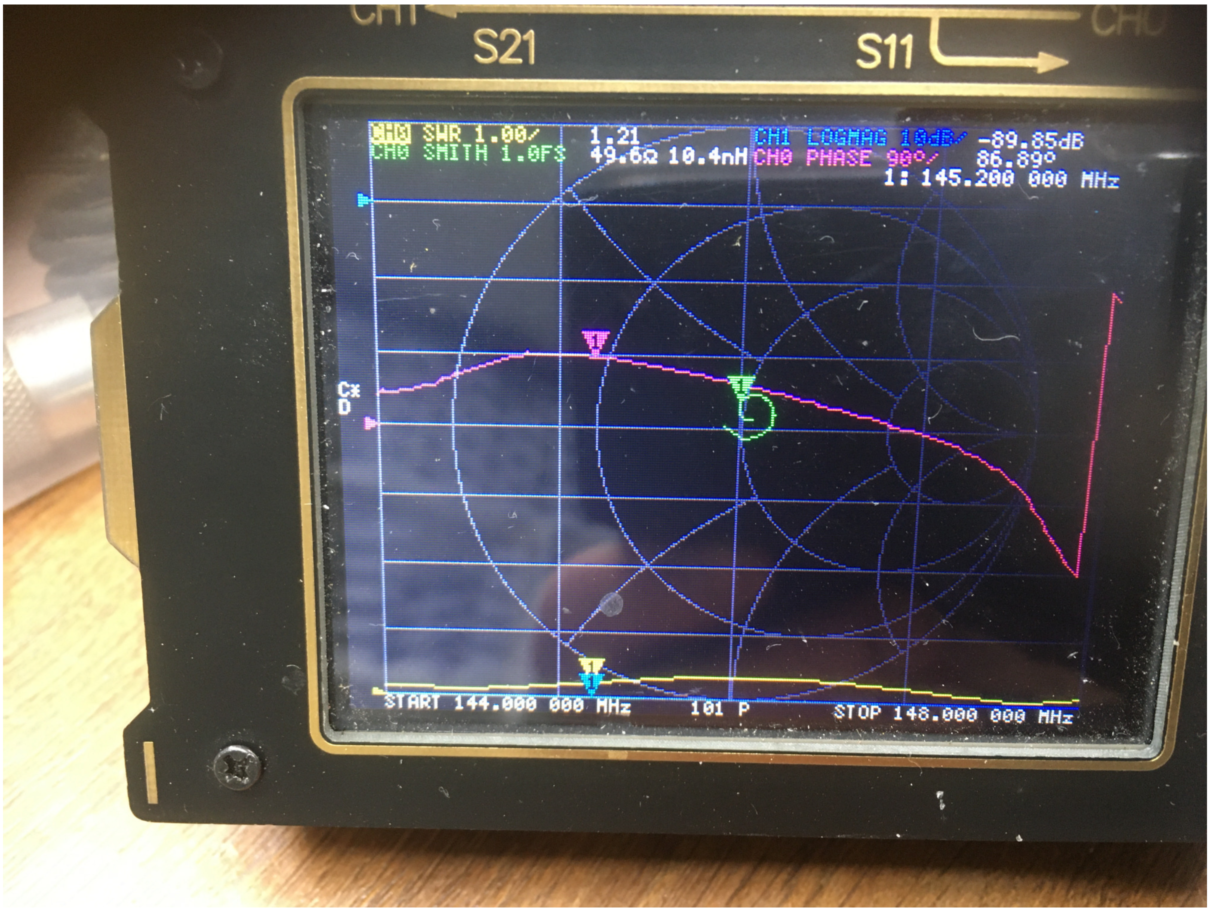
(2) The transmitter was rotated until a peak in reception strength.

(3) The transmitting station used 25 degree increments of rotation to form a signal strength plot. Too cold and too wet to get serious.

Conclusion:

Low power from my old FT290R FM only just made the hop. The forward power needle does not budge, however at full power setting the forward power indicates 2 watts and gave a full signal strength reception. Some off the back and some off the sides, but forward pointing is best and a small forward pointing window is even better.

"That will do Pig", for a home build.



It is far too cold and wet outside to bother doing a final tune. That can wait for summer. This photo is the VNA on the end of the coax in the shack after the set up in the garage. Things can only get better.

(END) VK2JMJ, July 2023.