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Concepts for compact, lightweight and fast deployable VHF YAGI (group) antennas

Introduction

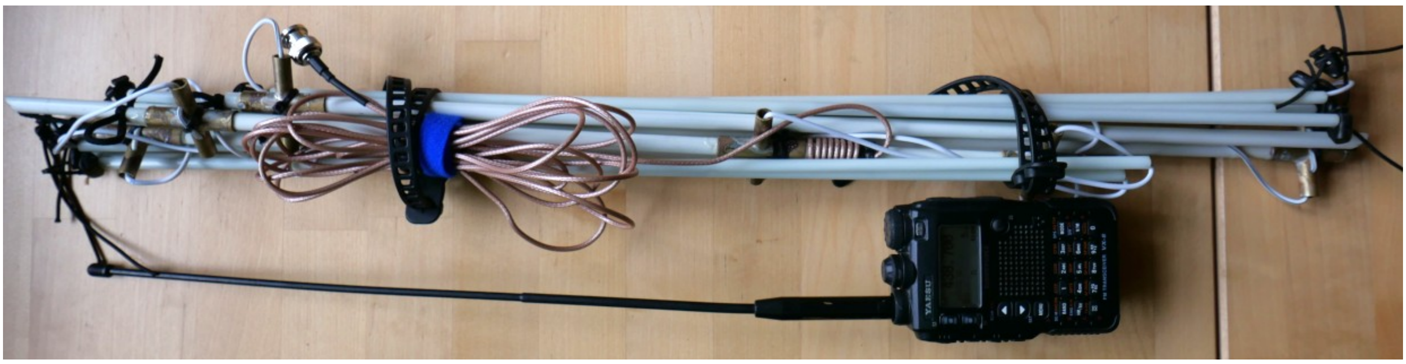
Portable Yagi antenna designs are quite popular in the amateur radio community. Lots of great ideas and detailed plans exists on how to build lightweight Yagi antennas for SOTA and other portable use.
A very popular approach is to use PVC pipes (electrical installation material) to build the boom and to use aluminum welding rods for the elements. But this means a collapsed length of 1 meter minimum for a VHF Yagi and to use a fitting to build longer booms. This will not only make your backpack look a bit strange but also will get interesting with strong winds on a mountain top.
Some ideas for an alternative approach using a segmented fiberglass (or: glass reinforced plastics, gpr, in German: "Glasfaserverstärkter Kunststoff, GFK) construction came into my mind and I developed this idea for over two years now building several prototypes. I tested these prototypes on many mountain trips, some with really hard conditions for the antenna and I improved the design step by step.
Besides the low weight and compactness, another advantage of the presented design principle is the low time required for assembly and disassembly. Nobody wants to use a portable antenna when erection is a mess and takes too much time. This especially becomes important when talking about arrays.
In the first part of this document I describe the design principles by a 6-Element Yagi with 2m boomlength. This antenna is really small, lightweight, very fast to erect and intended for versatile portable use. This was the first design I worked on and on which I tried to get the design mechanically and electrically stable.
In the second part of the document I describe a 2 x 2 x 7 Element array configuration using the same design techniques. This array can still be carried with a backpack and can be erected by 1 person alone in less than 1 hour. I started the work on this array after I finished the work on the 6-Element single Yagi antenna. I wanted to see if the design principle also works for bigger structures.
Please note: I published the first version of this document (Version 0.4) in June 2019 and I updated it from time to time with new details and improvements. Most probably there will also be new releases in the future!
Feedback is highly appreciated and I look forward to hear from you!

Inhaltsverzeichnis

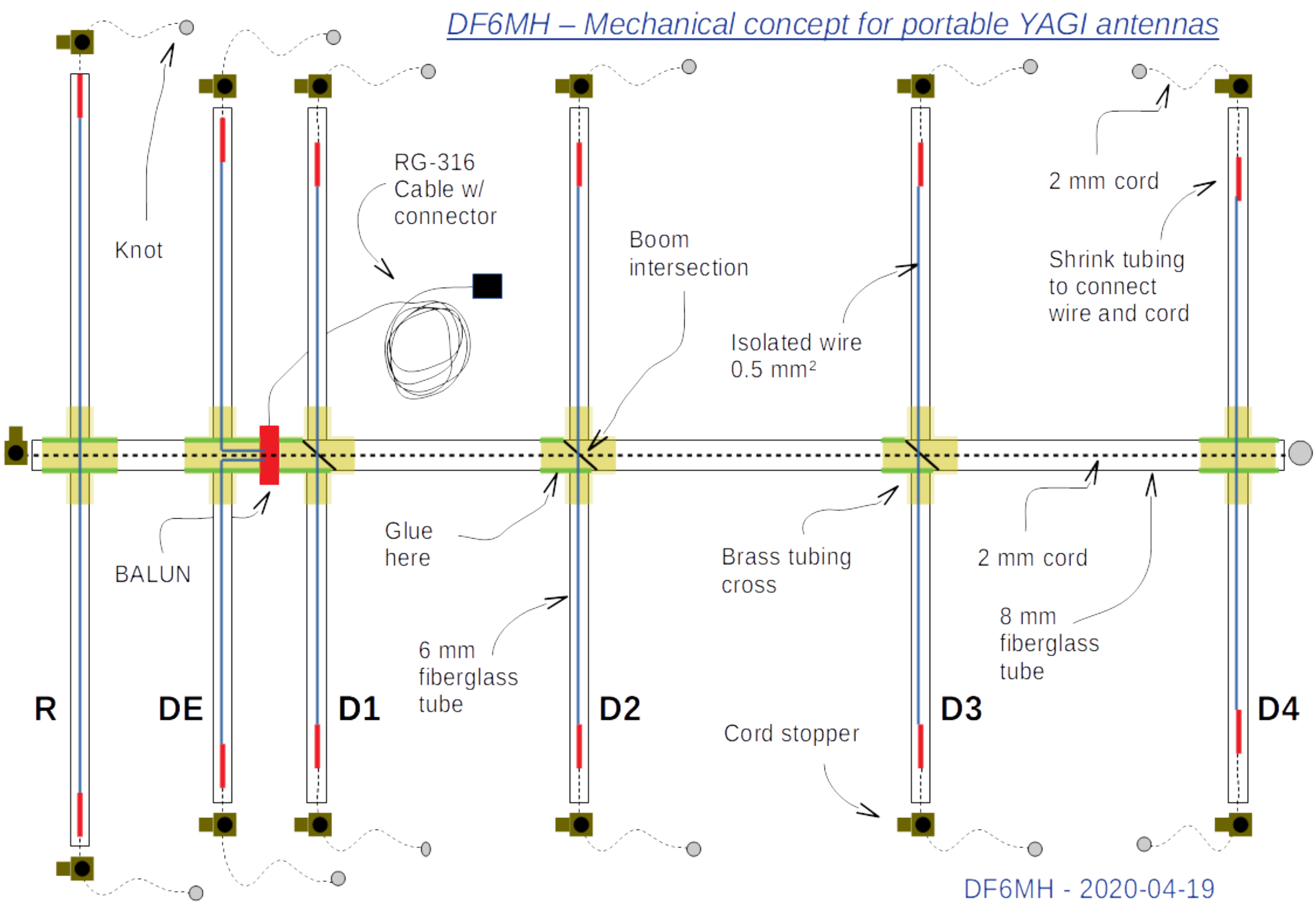
6-Element Yagi design

Key facts

- Electrical design after DK7ZB, 2m boomlength, 6-Element, 9 dBd gain, 2 m VHF band.
- Lightweight due to fiberglass construction. Total weight is 500 grams including 4 m of RG-316 coax cable.
- Fast deployable due to “tent pole” design. Elements are tighten together by rubber cords. No elements can be lost, no element sorting required. Assembly and disassembly requires 2 minutes, even with heavy gloves. No tools are required to set up the antenna.
- Very compact, collapsed length is less than 65 cm.
- Low wind load which improves stability and reduces requirements on the supporting pole.
- Quite robust due to durable fiberglass construction.
- Perfect for SOTA and other portable use.
- No low-cost solution, material cost per antenna is around 40 Euros.
- Manufacturing the antenna requires no special tools but some patience and takes 4 – 6 hours.



Overview



The antenna is realized by a skeleton using fiberglass segments pluggable connected by intersection elements made out of brass tubes. The boom is divided into 4 segments using 8 mm fiberglass tubes. 45 ° cuts at the end of the boom segments prevent the boom from axial winding. Driven element, reflector and directors use 6 mm fiberglass tubes guiding the wires for the electrical function of the antenna. These elements are divided into two sections and fit into the brass intersections which also connect the boom segments.
The elements are secured and locked by (rubber) cords. A 2 mm cord is used inside the boom and pieces of 2 mm rubber cords are used to lock the radiating elements. The 2 mm cord is attached to the element wires by shrink tubing and cord stoppers are used to tighten and loose the elements to and from the boom.
A current BALUN is realized by some turns of the RG-316 cable directly on the boom and close to the driven element. This avoids the need for a box carrying the BALUN and connector.

Electrical design

My main inspiration for the electrical design was the page of John – M0UKD
http://m0ukd.com/homebrew/antennas/144mhz-2m-portable-yagi-vhf-beam-antenna/
which is based on the well known design of Martin - DK7ZB
https://www.qsl.net/dk7zb/PVC-Yagis/6-Ele-2m.htm

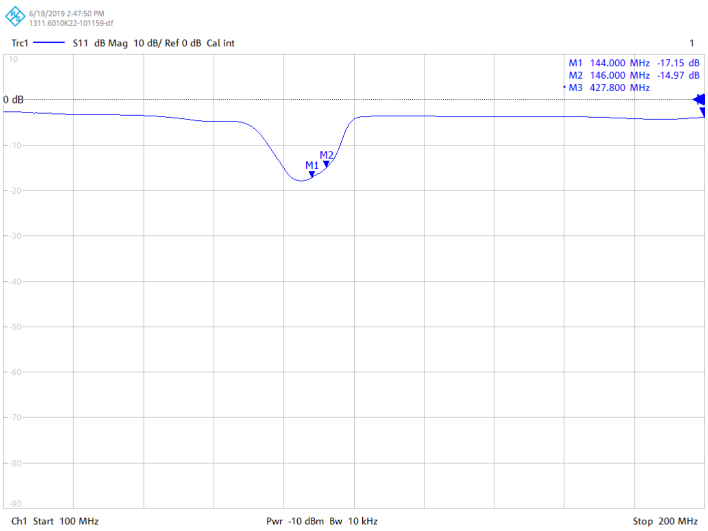
With the element lengths proposed by DK7ZB, the resonance of the antenna is much too deep for the VHF amateur radio band because the isolated wires and the fiberglass tubes cause a capacitive loading. I ran a new simulation using CST, a professional 3D EM simulation tool covering also the capacitive loading and determined the elements to the following length:

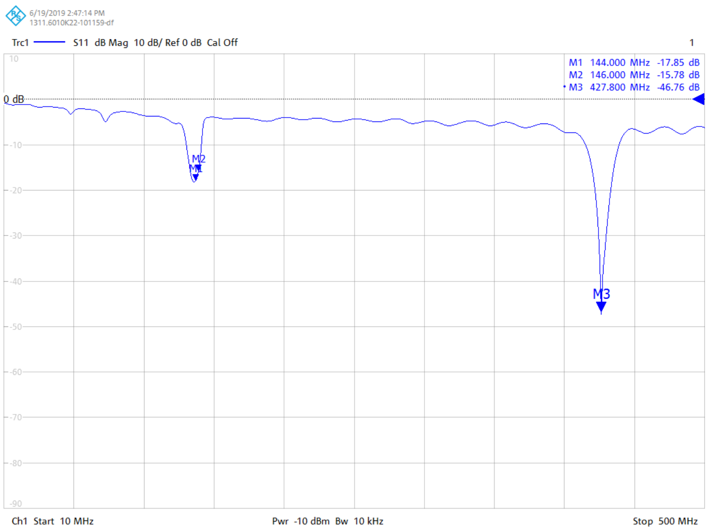
Element	Element length	EL/2	Boom Position
Reflector	948 mm	474 mm	30 mm
Driven Element	914 mm	457 mm	290 mm
Director 1	860 mm	430 mm	425 mm
Director 2	844 mm	422 mm	875 mm
Director 3	844 mm	422 mm	1500 mm
Director 4	814 mm	407 mm	2010 mm

The table also shows the element boom positions which are required to glue the brass tube crosses in the right position onto the fiberglass boom sections.

Note: There is a risk when you try to build this antenna that the stated wire length won't result in the correct resonance frequency and / or antenna pattern. This is because the fiberglass material and the isolated wire you buy may differ from the material I used in terms of their dielectric constant ε_r. Also see the part **"**Discussion on electrical design" further down this document.

Return loss of my second prototype





The two plots show the return loss of my second prototype antenna. I built this antenna with the element length shown in the table above which are based on simulation. Resonance is appx. 2 MHz too low but this not a real problem as the electrical design is of quite wide bandwidth.

Building practice

Brass crosses

Manufacturing the 6 crosses out of brass tubes is the most time consuming part of building this antenna. The trick is to hard-solder the two pipes more or less orthogonally together.
I highly recommend to hard-solder the brass crosses with silver-solder and the appropriate solder-flux. I used soft-soldered brass crosses in my early tries with this Yagi design and I broke several of them during use. A soft-solder connection is not strong enough to withstand a permanent use. Silver hard-solder and the flux can be found as set at ebay. I bought 3 rods of 1 mm x 500 mm L-Ag55Sn hard-solder and Felder "CuFe Nr.1" flux for appx. 20 Euro.

Please check the safety datasheet[1] for the recommended flux "Felder CuFe Nr. 1"!
The soldering fumes are quite toxic and you should avoid to directly inhale them!
Only solder on well vented location and keep distance!

OK, here are some hints on how to build the brass crosses:

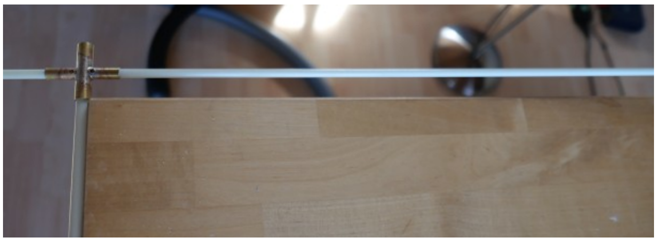
Cut 6 pieces of 40 mm length from the 10 mm brass tube and 12 pieces of 20 mm length from the 8 mm brass tube. I can recommend to use a small pipe cutter as shown on the left.
The 8 mm pieces are shaped with the 10 mm round file in order to fit better onto the 10 mm pieces.
Drill a 3 mm hole close to the concave filed end in each of the 8 mm brass tubes. That is where the wire will feed through in order to do not interfere with the boom element inside the 10 mm brass tube. Drill these holes before soldering.

A small vise assists to clamp the three brass tubes together. But do not use too much pressure as the brass softens during soldering and will then deform! Check the orthogonality by visual estimate or use the corner of an old plastic card to check. Use the file again if necessary to make an orthogonal fit possible. Do not be to hard to yourself with the alignment, corrections can also be made afterwards.

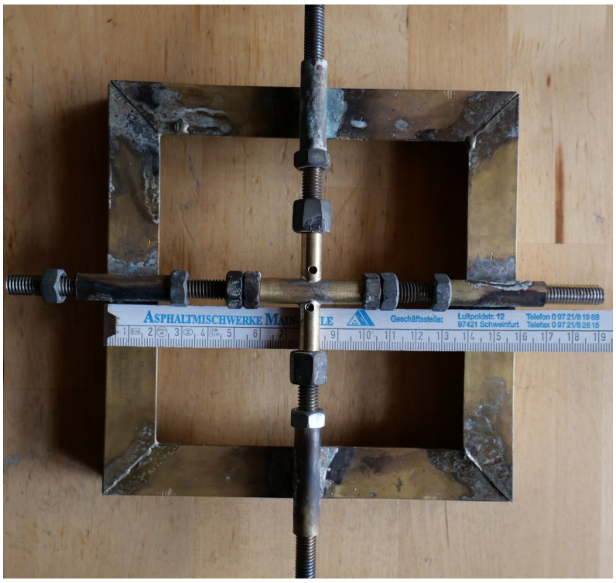
If everything looks OK, hard-solder the three pipes together. The mechanical strength of this hard solder joint will be more than sufficient for our purpose.
After soldering, you can remove the solder flux residues with the aid of vinegar and steel wool.
Check that there are no burrs on the brass crosses. Use a file to remove them if necessary.

As already mentioned, the soldered brass crossed can be fine tuned for orthogonality and alignment after soldering. For this, insert two 6 mm gpr pipes and one 8 mm gpr pipe into the brass cross.

1 https://torchmaster.com.au/new/wp-content/uploads/Silver-flux-1.pdf



It is possible to lay it on the floor, use the edge of a table and to check the axial alignment with your eyes.
You can correct the cross by putting two M6 screws into the two cross arms as shown in the picture and hitting the cross carefully with a hammer. The second method I use is to use a M6 and one M8 threaded rod as levers to adjust the cross.
The solder connection will not break when slightly correcting the brass cross as the brass gets softer and the solder connection is stronger than the soft brass.



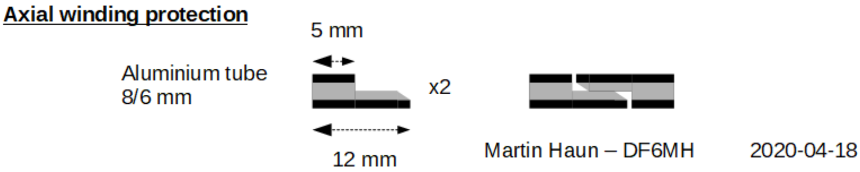
If you want to build more brass crosses than required for one antenna, think about building a jig for alignment and soldering!
Here you can see my jig for aligning and soldering the brass crosses. It is made out of brass profiles and pipes.
I used adapters from M8 to M6 to reduce the threaded rod diameter fitting into the brass cross arms. This also has the advantage that I can also use 10 mm brass pipes as arms for the cross. This becomes important for the antenna array described later in this document.

Boom and elements cutting and preparation

Fiberglass pipes are really a robust material, but some care has to be taken when cutting them. The ends tend to fan out. Use a hacksaw with fine teeth and a cutting jig as shown if possible. The cutting jig also helps to make the accurate 45 ° cuts in order to secure the boom against winding. Before cutting, wind one layer of masking tape on the gpr tube to reduce the fan out during cutting.
The director, driven and director elements are easy to cut. Just cut 2 tubes to 60 cm length and 10 tubes to 50 cm length from the 6 mm fiberglass material.
The boom sections out of the 8 mm material need 45 ° cuts in order to prevent the boom from axial winding.
No big math skills are required to determine the exact length from table showing the electrical length of the elements. I do not pre-cut the boom segments but cut them during the mounting process which is described in the next passage of this document. This helps to keep a high accuracy for the boom position.
As final step use some 2k glue in order to "close" the cut ends of the fiberglass tubes. This prevents the ends from fraying.

Optional: Improved axial winding protection

The 45 ° cuts at the boom intersections are not a perfect axial winding protection. Sometimes it needs some manual alignment by hand after setting up the antenna to make the elements being perfectly parallel.
This can be improved by small inserts made of 6 mm aluminum tubes.
Cut 12 mm pieces of the aluminum tube and make a cutout with the hacksaw or better use a “dremel” (small angle grinder) tool as shown on the picture. Use a file to make small flattenings at the end of the cutouts. This allows an easier alignment of the boom segments when slotting them together.
These inserts have to be glued into the cut boom ends. Be careful, fiberglass tubes do not like too much pressure from inside, they tend to crack. This is also why the brass crosses cover the fiberglass tubes from outside and not the other way round.
Make the boom fiberglass pipes inner diameter a bit larger at their ends with a round file if the pressure tends to be too high.



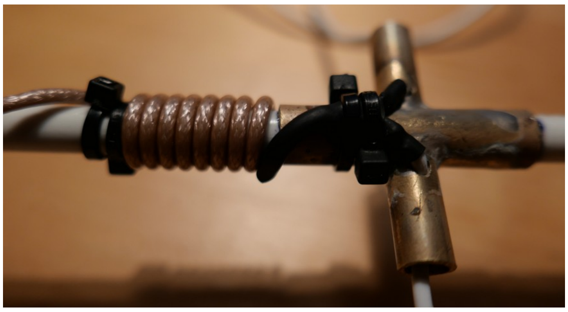
Gluing the brass crosses onto the boom segments

The brass crosses have to be glued (use 2-part epoxy) radially aligned onto the boom segments. The best way to do this is to let your antenna “grow on the floor”. That means that you first glue the brass cross for the reflector onto the first boom segment. Let the glue dry. Put two 6 mm fiberglass elements into the reflector brass cross and strong card board beneath their ends in order to align them parallel to the floor. Put the fiberglass elements into the driven element brass cross and place some card board beneath them in order to align the driven element parallel to the floor. Then you can glue the driven element brass cross to the right position. Finally glue the first director brass cross the same way and wait for the glue to dry. Then you can put the second boom section into the first director brass cross. Do not glue here! :-) The rest should be clear.
The overview drawing on the second page of this document also shows where to glue the brass crosses onto the boom segments. These positions are marked green.
If you want to use the boom inserts for axial winding protection – which I highly recommend – glue them into the boom segments before mounting the brass crosses. Be sure that the two boom segments fit well on their intersection before continuing with gluing the next brass cross.
I want to give some additional hints:
I often experience that the gpr pipes do not fit well into the brass crosses. They are a bit too thick. I then take 60-grit sand paper in order to reduce the gpr pipe diameter. It is a good idea to treat all gpr surfaces with sandpaper anyhow as the roughness is better for the glue connection. I also clean the surfaces with denaturated alcohol before gluing.

Threading the cord into to Boom

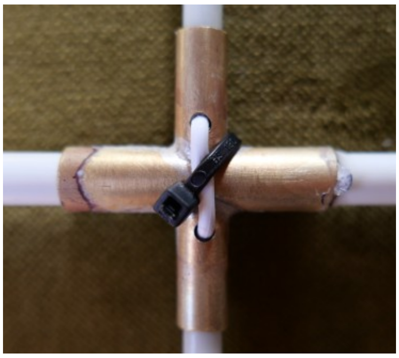
Thread a strong cord through the whole boom in order to keep the boom segments and thus the whole antenna together. I use 2 mm keflar rope which is of very low strain.
It is not so easy to thread the rope trough the boom segments, especially when you use the inserts against axial winding. I first thread a stiff wire trough all segments and with this I pull the keflar rope through them.
Finally, fixate one end of the rope with a knot on one brass cross, the other end of the rope can be loosen and tighten with a cord stopper.

Driven Element and current BALUN



The two wires coming from the driven element have to be fed through the 3 mm holes in the brass cross as shown in the picture. Use shrink tubings to connect the wires to the RG-316 coax cable. The current BALUN is formed by placing 8-10 turns of the coax cable directly on the boom. Use cable ties to fix everything to the boom.
I recommend to cut the two wires to final length after finishing the BALUN connection.

Reflector and directing elements



Cut wires of appx. 1 m. Feed one end through the left hole, one end through the right hole. Repeat this for all elements left. Fixate the wires with a cable tie as shown in the picture.
Finally you have to cut all elements according to the table on page 3 of this document.

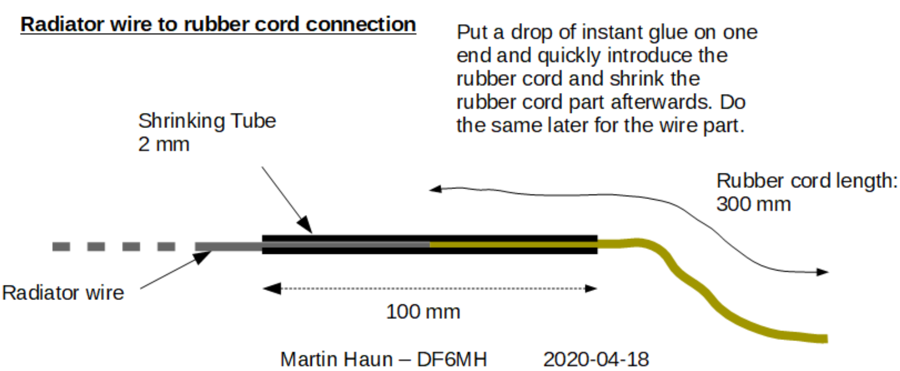
First measure the resonance before attaching the rubber cord!

I highly recommend to first measure the antenna impedance with an antenna analyzer in order to be sure that the design is resonant at the right frequency! You can use tape to temporarily fix the 6 mm fiberglass tubes to the brass crosses.

What to do when the resonance frequency does not fit?

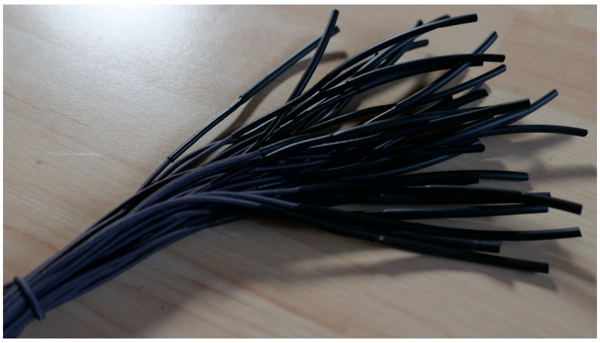
Required wire length may vary to the variance of ε_r of the fiberglass tubes and the wire isolation. Also see the part "Discussion on electrical design" further down this document. If the resonance frequency is not more away than some few MHz, you can try to scale the element length by the factor of measured to target frequency.

Element fixation by rubber cord and stoppers



After the element wires are cut to the right length and have been fed into the brass crosses, they are connected with the 2 mm rubber cords.
I originally used two small knots in the rubber cord to prevent the shrinking tube slipping off the cord. The knots had to be very tight in order to fit into the 6 mm gpr pipe and sometimes they made problems at this point. The shrinking tubes also slipped from the wire from time to time so I changed the connection slightly:

I now use instant glue before shrinking instead of knots. This resolves both described problems and eases the manufacturing process a lot!

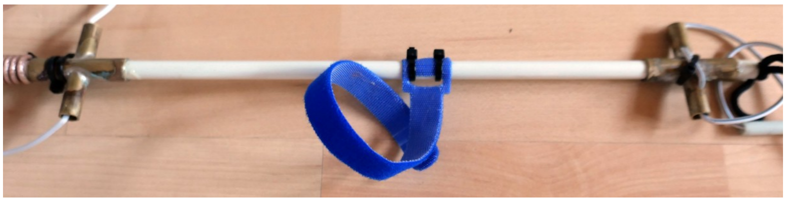


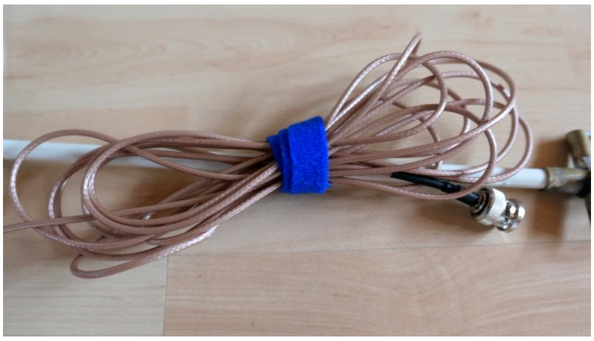
Final assembly

One of the last steps is to feed the element rubber cord and wires through the fiberglass tubes. Put the cord stoppers on the rubber cords in order to lock the elements onto the boom.
Place knots after the cord stoppers in order to protect the cord stoppers from getting lost as soon as you think that the antenna works as expected.

Storage for the RG-316 cable

I used a velcro cable tie and permanently fixed it to the boom with small cable ties. This eases fixation of the RG-316 cable.





AND NOW: Have fun and many DX with your brand new Yagi antenna!

Required materials and tools

Material required for building the antenna

- 2.5 m of fiberglass tube 8 mm, 1 mm wall thickness
- 7 m of fiberglass tube 6 mm, 1 mm wall thickness
- 50 cm of brass tube 10 mm, 1 mm wall thickness
- 50 cm of brass tube 8 mm, 1 mm wall thickness
- Optional: 20 cm of aluminum tube 6 mm
- 10 m of isolated wire, 0,5 mm²
- 3 m of rubber cord 3 mm
- 3 m of rubber cord 2 mm
- 12 cord stoppers for 2 mm rubber cord
- 2 mm shrink tubing
- 4 m of RG-316 cable
- 2-part epoxy glue
- Some cable ties

Tools required for building the antenna

- Hacksaw
- Round file 10 mm
- Gas jet + silver hard-soldering wire (e.g. L-Ag55Sn) + appropriate solder-flux (e.g. Felder CuFe Nr.1)
- Small (machine) vise
- Soldering iron + soft-soldering wire

Discussion on electrical design

The electrical design follows a very popular proposal of Martin - DK7ZB:
https://www.qsl.net/dk7zb/PVC-Yagis/6-Ele-2m.htm
There you will also find a NEC based simulation of the design. NEC based simulation tools deal quite well with simple metal wire or pipe structures but do not offer the possibility to simulate dielectric materials.
When starting with the first design of my fiberglass antenna, I knew that the capacitive loading of the wire insulation and the fiberglass tubes around them will have a big impact on resonance frequency. As NEC based simulation tools can't deal with dielectric materials, I tried to manually shorten the wire length by trial and error. This was not really successful and I ended up with an VSWR round about 2 and I also was not really sure about the resulting beam pattern. Nevertheless the antenna worked quite well and I made a lot of nice contacts with it.
After two to three antenna deployments under very cold and windy conditions, I noticed that the soft solder connection of the brass tubing is too weak and gets broken from time to time. I decided to build a second prototype of my yagi antenna with hard-soldered brass crosses to improve durability. With the unstable electrical design in my mind I decided also to improve this point.
I have access to a professional antenna simulation tool at work which also can simulate dielectrical materials. I modeled the antenna with wire insulation and fiberglass tubes. Meshing was a bit tricky but in the end I was able to get reasonable results. I simulated DK7ZB's original design and was able to reproduce the simulation results of his NEC based tool.
Simulation showed that a simple cut down of the wires by a fixed factor will change the beam pattern drastically. This is not a real surprise when you are familiar with Yagi design (which I was not really when I started with this project...). Have a look in the Rothammel[2] book in chapter 24. There you will find graph 24.1.4 showing optimum length l/λ per director for different element diameters d/λ. This graph shows that the thicker the elements (equals

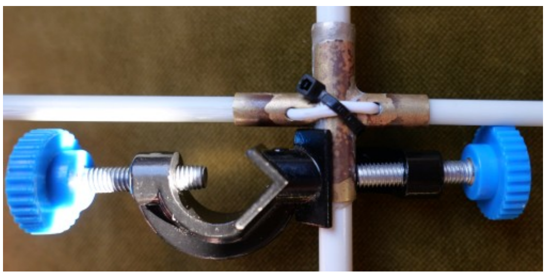
2 Kirschke A. (2013) *Rothammels Antennenbuch* (13. Auflage). Baunatal, DARC Verlag GmbH

capacitive loading) the more you have to shorten the outer directors. By the way: Like most of the Yagi designs you find in the literature, the DK7ZB design is in terms of director element length also very close to graph 24.1.4 in the Rothammel book.
With the Rothammel table in my mind, I scaled down the original DK7ZB director lengths by a declining factor. I ended up using a factor 0.93 for the reflector going down to 0.91 for the outermost directing element.
Element boom positions remain the same. The scaling produced nearly the same beam pattern as it is stated from DK7ZB and return loss is around 13 dB from 144 to 146 MHz. The simulated wire length are stated in the table at the beginning of this document.
I tested the simulated element lengths in my second prototype design and immediately got a nearly perfect resonance at the 2m band without having to manually adjust the wire length. So simulation did a good job and I assume that the beam pattern is also in a reasonable fashion.
The question arises which influence a varying ε_r of the fiberglass or the wire insulation has on the resonance frequency. That is also a matter of reproducibility when you want to rebuild the Yagi. It is not said that you will get the same fiberglass tubes and the same insulated wire as I used for my design. In literature, you most often find a value of 5 for fiberglass as well as for PTFE which is most often used for the wire insulator. My simulation was based on an ε_r value of 5 for both. I performed a parameter sweep varying the ε_r of the fiberglass from 4 to 6. That sweep showed a resonance frequency shift of appx. 0.7 MHz per 1 change in ε_r. In most cases this is tolerable as the matching of our design is not very narrowband.
If you rebuild the Yagi and you find a resonance frequency slightly out of the 2 m amateur band then you can try to adjust wire length by a constant scaling factor.

How to attach the antenna to an improvised hiking pole mast

I want to show an easy and lightweight way on how to build a mast out of your hiking poles. I myself always use hiking poles when going to the mountains with a bigger backpack. This saves energy and also rests your knees!
So why not using the hiking poles as mast for the antenna? I did this several times in kind a makeshift manner using a lot of cable ties. This is not very satisfactory as disassembly is not very comfortable and also produces a lot of garbage.

I did several tries with reusable cable ties but these were not robust enough. So I ended up with this solution:
The two hiking poles are attached to each other at their handles by 2 hose clamps. I use hose clamps with a butterfly nut which allows for easy tightening and loosening by hand.
The antenna is attached to the hiking pole tip by a cross connector as it is shown in the picture. This also allows for easy changing the antenna polarisation.
I built a simple upper bearing out of a square plastic pipe. This bearing is attached to 3 guyropes out of 2 mm accessory cord which are fastened at ground by tent pegs or big stones. The bearing shown works for hiking poles divided into two parts for length adjustment where you can slip out the lower segment completely. If you have other types of hiking poles you surely will find an appropriate solution.



Rotating the antenna is still possible with this construction but you need to fixate the lower end of the mast construction against unwanted rotation in case of wind. This can be done by a second cross connector and a short stick which is blocked by a stone or similar.
An advice for setting up the hiking pole mast: Do not slip out the length adjustment of the lower hiking pole completely. After fixing the

guyropes to ground and stretching them, slip out the lower segment to give additional tension and stability to the construction.

This picture shows the complete hiking pole mounting kit. Total weight of the material shown in the picture is 275 gr.

Electrical influence of the hiking poles mast

It is not very surprising that the mast will have an electrical influence on the antenna. Especially when the antenna is mounted vertically. I experience a slightly worse VSWR for vertical mounting. There will be definitely a negative influence on the antenna pattern.
I use aluminum hiking poles with 2 segments at the moment. The segment lengths are 90 cm and 60 cm. The segments are galvanically isolated but at the intersection there will be some capacitive coupling between them.
I also have other hiking poles out of carbon fibre reinforced plastic which have much shorter segments. This may improve the situation.

Packing

The antenna as well as the hiking pole mounting kit fits quite well in a 65 mm diameter poster tube. I found them of 60 cm and 80 cm length. 60 cm is too short so I cut down a 80 cm type and used tape to seal the seam. Total weight of this kit is 950 gr. It is perfect for attaching it sideways to a backpack.

Possible design improvements

Here I want to share some thoughts about possible improvements of the introduced antenna design.

Boom made of carbon fibre reinforced plastic (CFK)

I temporarily thought about using a CFK pipe to build the boom. I ordered a square 8 mm pipe for testing purposes. A cfk pipe would result in lower total antenna weight and less boom deflection.
After dealing some hours with the CFK material I scraped the idea of using cfk for the boom. The material is much brittle and you easily end up with a lot of splinters of CFK in your fingers.
I think it would be possible but requires some special treatment of the material which makes it more difficult to rebuild the antenna. CFK may be an option if you are used to work with this material.

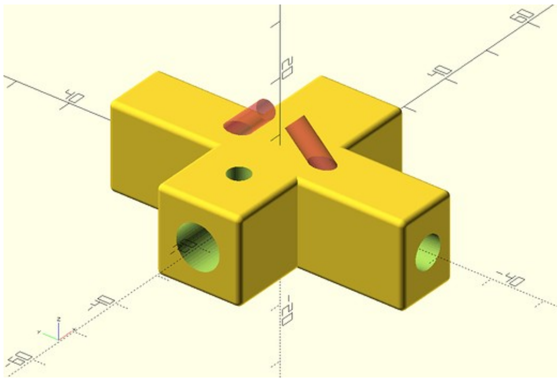
Replacement for brass crosses

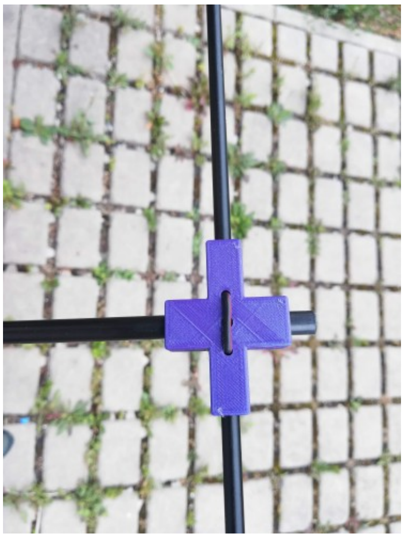
As it is very time consuming to manufacture the brass crosses, it would be nice to have an alternative. Material of choice would be aluminum as this would also reduce antenna weight even further. Best would be a milled and drilled cross. But usually you don't have these machines at home.
It is also possible to solder aluminum but this is very tricky. I made some tries "Reibelot" and results were not to bad but I do not trust this solder connection to a full extent.

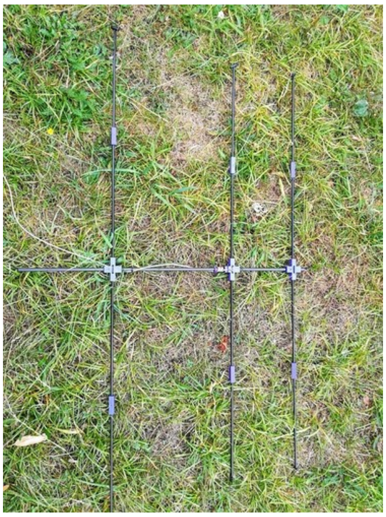
Design adoption by Ondra – OK1CDJ

- added with beginning of version 0.5 of this document

I published version 0p4 of this document in the SOTA reflector board[3] and Ondra – OK1CDJ picked up my both ideas to use carbon fiber reinforced plastic (cfrp) for the boom and to replace the brass crosses. He used a 3D printer to print the crosses out of PET-G filament. Ondra published the files for the 3D printed parts on Thingiverse.com[4].
He also used an alternative way to lock the boom against axial winding: The printed crosses have a cut-out for a short and small second pipe glued to the boom end.
Boom deflection is very low in Ondra's design because the used cfrp pipes are quite stiff. That is definitely an advantage.
Ondra also built a very small 3-element YAGI and divided the elements by four to make the collapsed antenna even smaller. He used the same factors of 0.93 (reflector) to 0.91 (outermost director) to downscale DK7ZB's original design and got a good match.
Here are some pictures of his antennas and the 3D printed parts:







Great work, Ondra! Congratulations!

3 https://reflector.sota.org.uk/t/fiberglass-vhf-yagi-antenna/20650
4 https://www.thingiverse.com/thing:3794227

2 H x 2 V x 7 Element lightweight group YAGI

Key facts

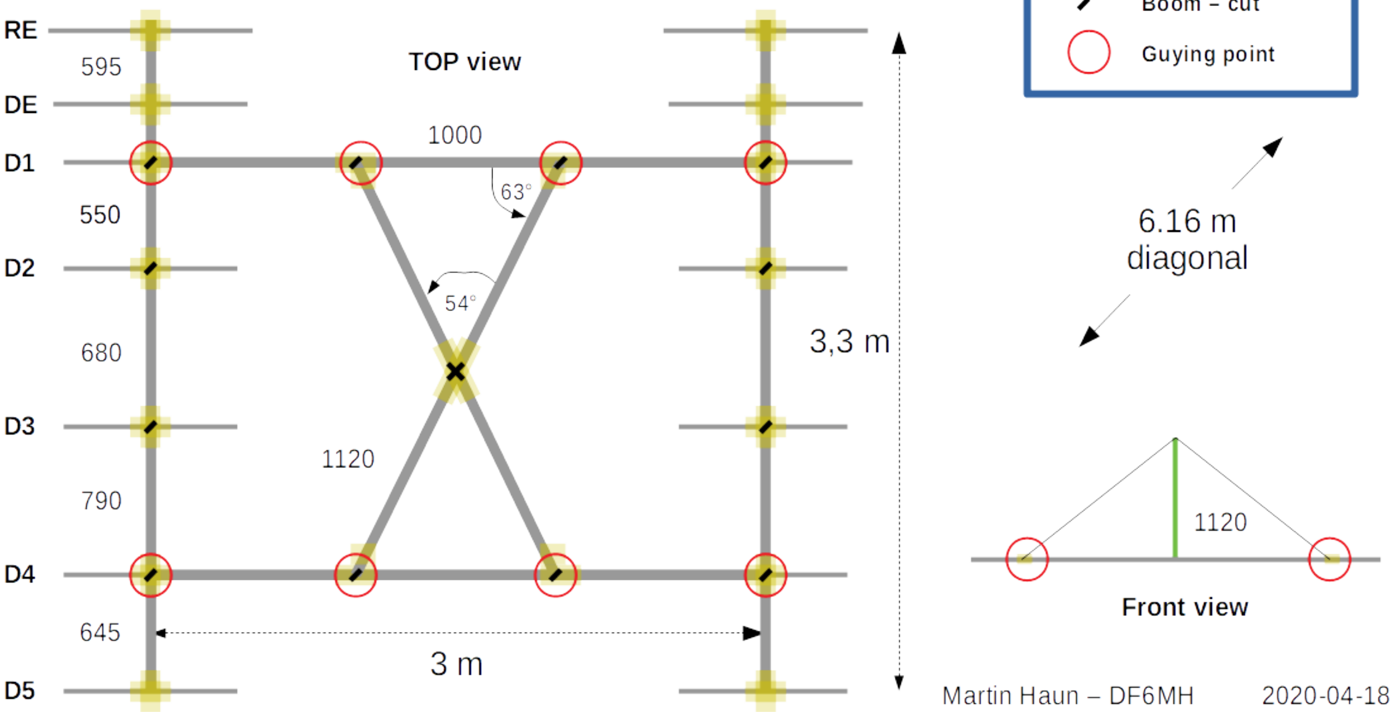
- Single Yagi: modified DK7ZB 7-Element design[5] (28 Ohm, 11 dBd gain). Also can be used stand alone.
- 2 Yagis form a horizontal layer by introducing a spacing structure also made out of fiberglass segments.
- This layer is supported by guying ropes attached to a small ancillary pole.
- Theoretical overall gain: 17 dBd
- Collapsed length is less than 120 cm
- Antenna structure weight: 3.3 kg
- Can be supported by fiberglass mast (I use lower 8 segments of a Spiderbeam 12 m HD fiberglass mast, weight is then appx. 3 kg)
- Still lightweight and small enough to pack and to carry the whole structure on a mountain top.

Overview

DF6MH - Fiberglass VHF YAGI group antenna 2 x 7 element horizontal layer

	RE	DE	D1	D2	D3	D4	D5
Position	0	320	595	1145	1825	2615	3260
Length	938	887	871	844	823	824	807
Length/2	469	443	436	422	412	413	404

Wire length Unit: mm Modified DK7ZB 28 Ohm design



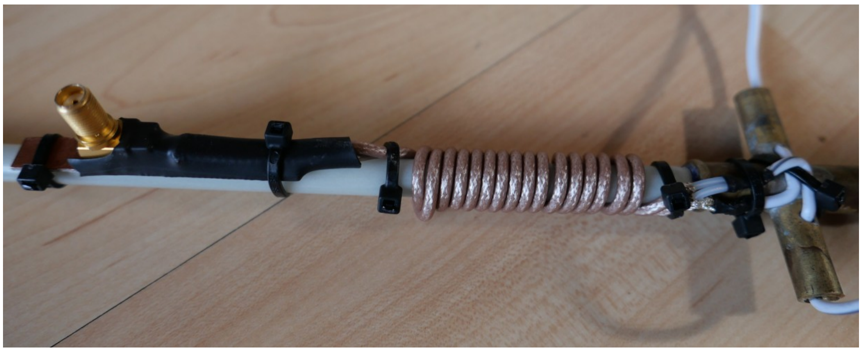
5 https://www.qsl.net/dk7zb/4x7ele/7-El-stacked.htm

Building practice

I first want to describe the horizontal layer structure. It consists of 2 single Yagi antennas and an inner support structure.

Single Yagi Antenna

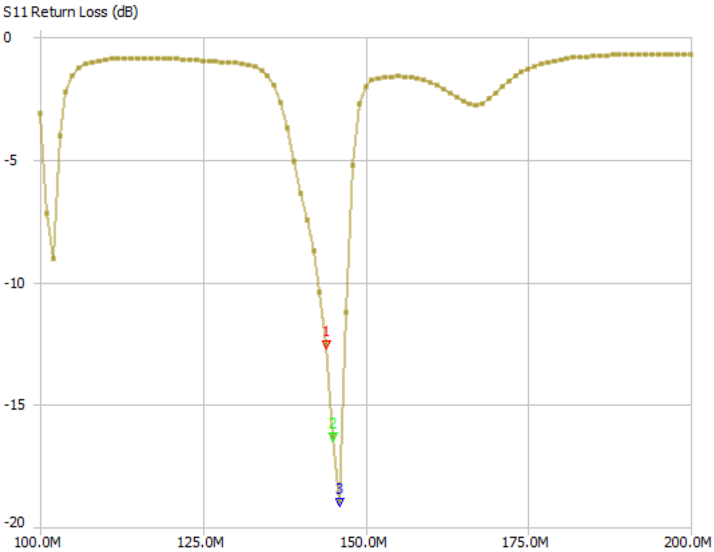
Most building practice is reused from my 6-Element design. I only want to go deeper into the differences.
Building the single 7-Element Yagi is straight forward. The only difference is, that the crosses for D1 and D4 have to be built with one arm for an 8 mm diameter gpr tube (use 25 mm of 10 mm brass tube), not two times for the 6 mm diameter gpr tubes. This is because these crosses are connected to the inner support structure which is completely built out of 8 mm grp tubes.
Wire length and element positions can be found in the table. Wire length was determined by CST simulation again and previously found scaling factors worked again. I had to use 0.925 for the radiator and 0.901 for the outermost director.



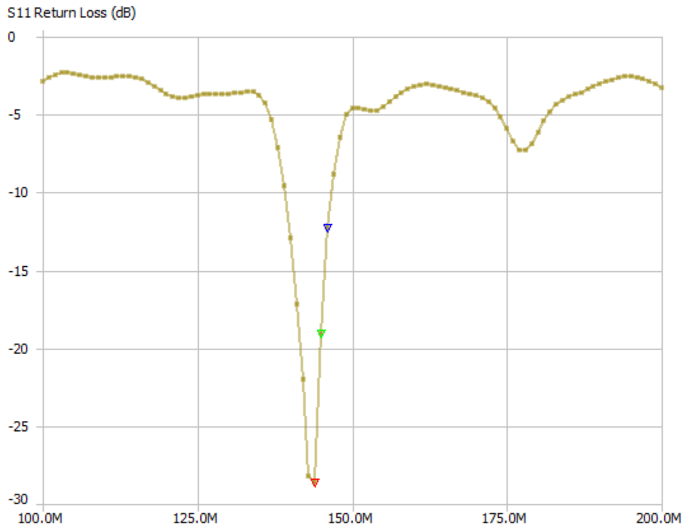
The single Yagi feed requires some special treatment. An additional impedance transformation to 50 Ohms is required as feedpoint impedance is designed to 28 Ohms.
A common practice is to use 2 x 75 Ohms of length Lambda/4 in parallel in order to do the transformation.
I used two RG-179 cables of 370 mm length. This is slightly longer than Lambda/4 according to my measurements but resulted in best match. It is not clear to me yet why, because I got perfect antenna match without transformation on a NWA normalized to 28 Ohms.
The transforming RG-179 cables are wound onto the boom and again also form the current BALUN. I soldered a 90 ° THT PCB mount SMA jack onto a small piece of PCB and soldered the RG-179 cables to it. Everything can be fastened to the boom with cable ties. There may be better ways to do all the connections. If you have an idea, please let me know!

Return loss plots

Single YAGI antenna



Group YAGI antenna

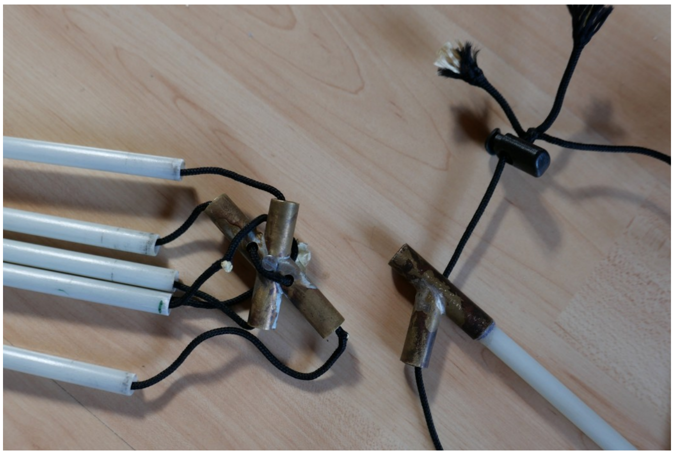


M1 = 144 MHz, M2 = 145 MHz, M3 = 146 MHZ

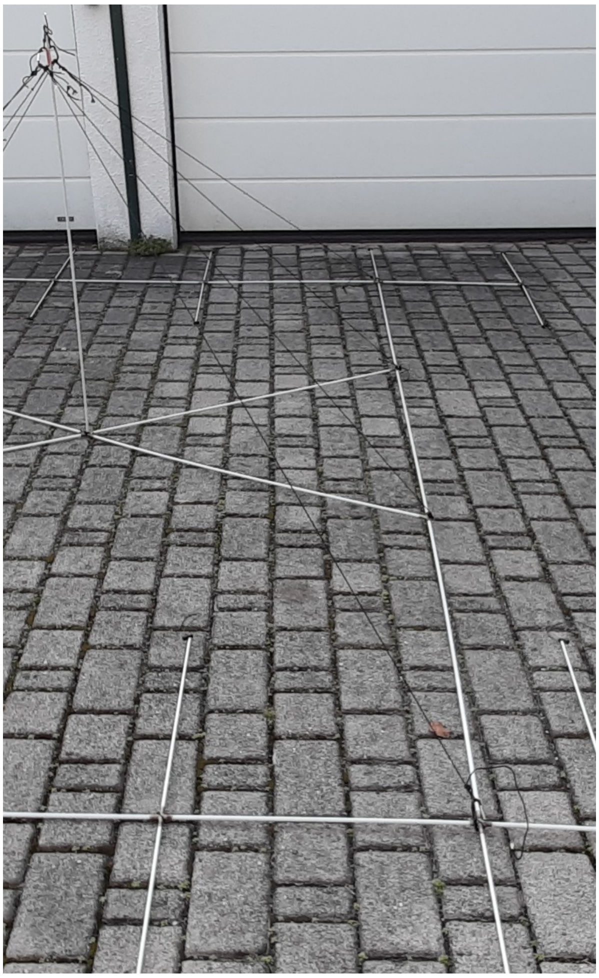
The left plot shows the return loss of a single Yagi antenna, the right picture the look into 5m of M&P airborne 5 cable, the 1:4 divider and all 4 antennas. Single yagi return loss differs slightly from antenna to antenna. The plots were taken with nanoVNA.

Inner support structure

The inner support structure requires some special brass connectors. Details can be seen in the following picture:



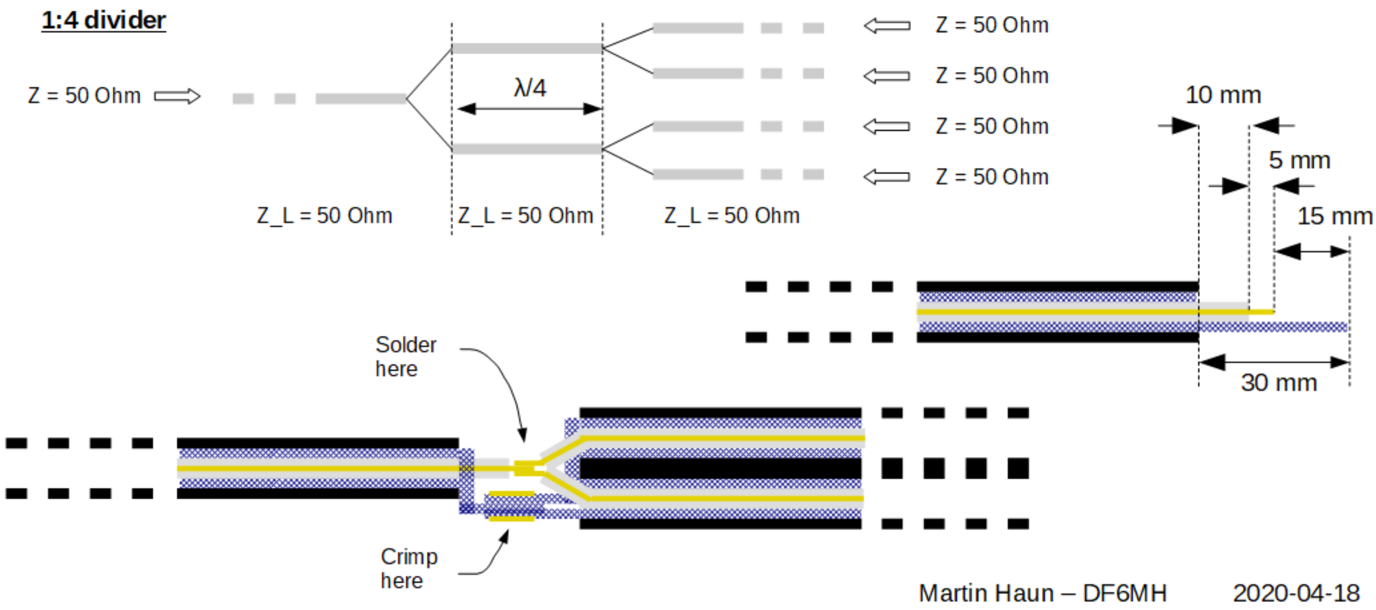
You can see the inner brass cross on the left side of the picture. The through part is of 45 mm length. A M3 screw builds a stop for the two gpr pipes fitting into it. The rope for fixation also goes through this tube. The two arms of the cross are of length 30 mm. The rope is bypassed by two 3 mm holes.
On the right side of the picture you see one of the outer 4 brass connectors of the inner support structure. These are also the only 4 glue points for the inner support structure.
A hole is drilled through this brass connector in order to feed the rope for tightening the structure through it.
Glue a ring out of 10 mm brass tube onto both support pole ends. This will avoid splicing of the pole ends by the ropes.



This picture shows details on the single antenna layer guying. You see the pole which supports 8 guy ropes made out of 2 mm keflar rope (from Spiderbeam shop). There is no special fixation of the pole to the antenna layer. I just fed the rope two times through the gpr pipe encompassing the central brass cross and attached two carabiners at the upper end of the pole. The guy ropes are connected to the antenna structure with small and cheap carabiners (you find them e.g. at amazon or ebay for little money).
I added rope fasteners (just made easy 3-hole rope fasteners out of pieces from an old folding meter stick) to the guy lines in order to make length adjustments possible. This helps to align the antenna layer parallel to the floor more easy and makes your antenna looking better when it is up in the air!

1:4, 50 Ohm coaxial splitter for the 2 x 2 array

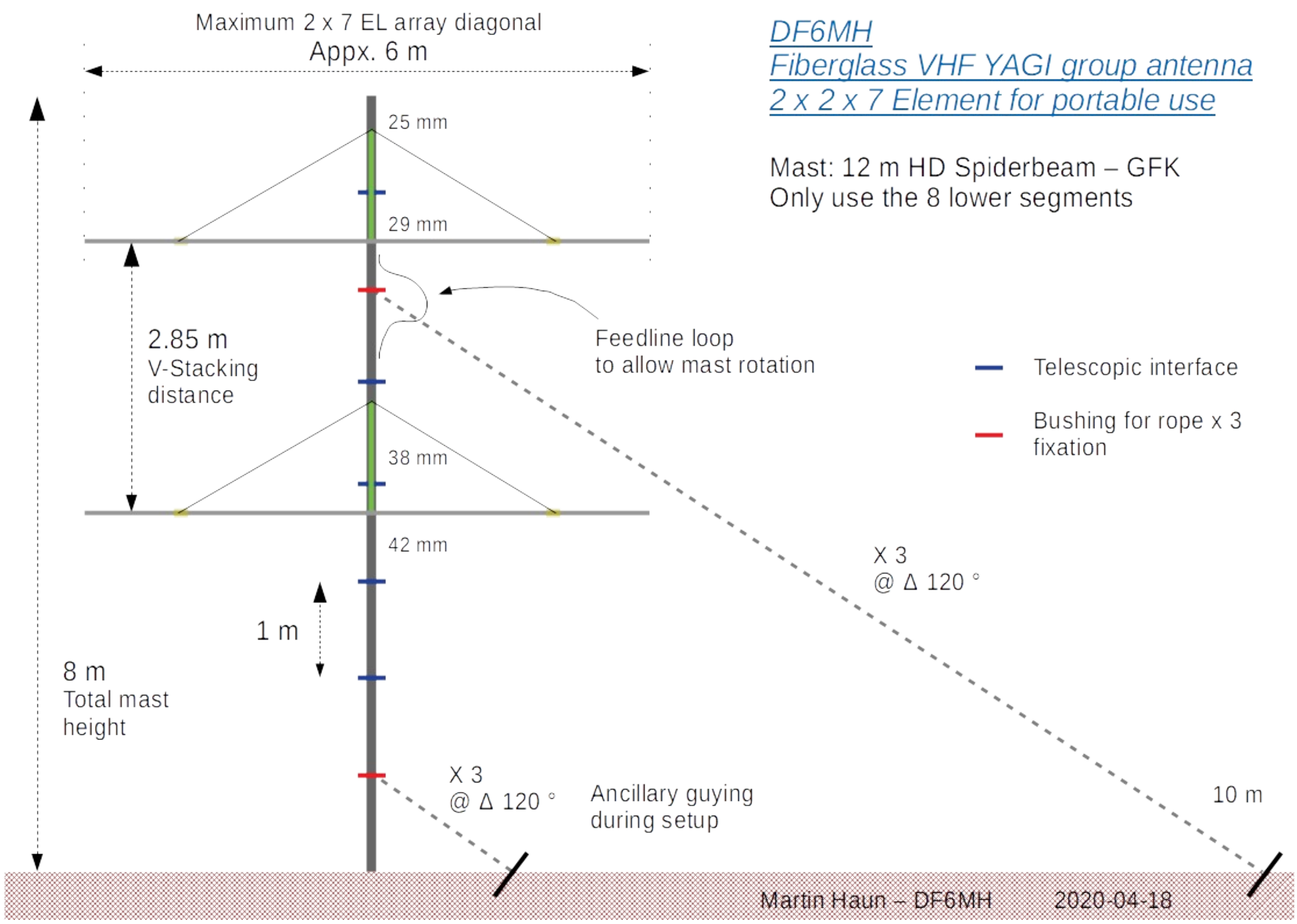
I recommend to use 1:4 coaxial cable divider which is the cheapest way to go. You also can use a professional tapper but this quite costly, heavy and requires more connectors.
The working principle of this divider is explained quite quickly: Two feedlines going to the single Yagis are connected in parallel. The resulting impedance is then 25 Ohms. This impedance is shifted to 100 Ohms by a Lambda/4 transformer. The Lambda/4 transformer is simply a piece of 50 Ohm cable of Lambda/4 length (apply cable velocity factor). Two of these structures are again connected in parallel and we are back to 50 Ohms.
I recommend to use low loss coax cable. I use Airborne 5 cable from Messi & Paoloni which is also very lightweight. The problem with this cable is that the coax shield is not solder able. I soldered the inner conductors and crimped the shield with ferrules from old SMA connectors.
I recommend to mechanically support the solder and crimp connection with some pieces of wood or plastics and to shrink everything together in two or three layers of shrinking tube.



Here you see the soldered and crimped connection. On the picture you see two 75 Ohm sat cables used for an 1:2 divider for another project.

On this picture you can see the complete 1:4 antenna feedline. Total length is 4.5 m.

Mounting on 12 m HD Spiderbeam mast



It was obvious for me to use the 12 m HD Spiderbeam mast as I already own one for several years. Test proofed that it is stiff and stable enough to support the 2 x 2 x 7 Element group. I only use the lower 8 segments which result in a total mast height of about 8 meters.

It is sufficient to guy the mast once. I did this directly below the upper antenna layer on top of the 6th mast section. I used a ferrule like part from an old party tent as bushing which fits quite well over the 7th mast segment but does not slip over the 6th segment and has holes to attach the guy-ropes. You find a picture of my upper bearing down below.

I recommend to mount the first antenna layer about 10 – 20 cm above the bushing as some space is required for a loop in the feedline which allows for a 360 ° mast rotation.

The second antenna layer follows 2.85 m below the first layer which is the recommended stacking distance by DK7ZB. Needless to say that it is important to mount the layers in the same azimuth direction.

I mount the antenna layers with two clamps. The antenna layers just sit on them and are fixated with flexible and reusable cable ties.

It is required to fixate the first mast segment so that you have a solid base for the whole mounting process. I recommend to build an ancillary guying for the fist mast segment if you are one a plain field. You can keep this support also during operation which also prevents the mast from slipping out of place on the ground, but then you again have to use a bushing for this fixation. I use a 50 mm pipe coupling from plumbing equipment which nicely fits over the second segment of the Spiderbeam mast. You can see details on the picture below. On the second picture you can see my upper bearing.

Packing

Everything fits quite nicely in a 120 cm ski bag for children skies. You can see the following equipment:

- 4 x single Yagi antennas
- 2 x inner support structure
- 8 x short ropes with rope fastener and carabiner to support the antenna layers
- 8 x long ropes with rope fastener and carabiner to support the antenna layers
- Upper bearing with cords
- 3 steel tent pigs for upper bearing
- Lower bearing with cords
- 3 aluminum tent pigs for lower bearing
- 1:4 coaxial divider + 5 m of additional 5mm M&P Airborne cable
- 2 clamps to support the antenna layers on the mast
- Reusable cable ties to fixate the layers to the mast

Some impressions from my test deployments

Nice sunrise at the first use of the first prototype of my new Yagi antenna on top of mount “Sonnjoch” (OE/TI-615) in the bavarian “Karwendel” mountains on 2018-11-11.

This picture was taken during a test of my first prototype on mount “Großer Traithen” (DL/MF-080) *in the bavarian alps on 2019-03-20.*
You can see the broken first director brass cross which had been soft soldered.
I used my backcountry skis to support the pole. I will not use this kind of support any more as rotating the mast is not so easy with this method.
In the future I will use my bearing with the attached cords also in snowy conditions. The skis will be used as snow anchors to fasten the cords to ground.

Testing of my second prototype on mount Sonneck – JN67DN in the “Wilder Kaiser” mountains in Tirol / OE on 2019-06-29.
I used my setup as described here in this document and was completely happy with it.
I made a lot of nice contacts in 2 m SSB during this mountain overnight stay.

… and now the vertical setup. Here you can see the vertical boom deflection.

First test of my 2 x 2 x 7 Element group antenna on mount "Karkopf" on 2020-04-15. (Chiemgau Mountains, JN67CR, 1500 m a.s.l.)

Document history

Document version	Date	Changelog
0.1	2018-11-20	Initial draft version
0.2	2018-12-10	Typo corrected – Thanks to Andreas - DH9AT
0.3	2019-06-30	+ Switch from soft-soldered to hard-soldered brass crosses + New element length determined by simulation + Discussion on electrical design added + Improved axial winding protection introduced + Hiking pole mast proposal added + Some new pictures added
0.4	2019-07-03	+ New picture added on first page + Again many thanks to Andreas – DH9AT for his critical review of this document and all the helpful discussions on this antenna design
0.41	2019-07-11	+ 2 typos corrected – Thanks to Andrew - VK1DA/VK2UH
0.42	2019-07-14	+ Some more typos corrected – Thanks again Andrew!
0.5	2019-09-10	+ Details about design adoption by Ondra – OK1CDJ added + 3D printed crosses + Boom out of carbon reinforced plastic
0.6	2020-06-02	+ Document title changed + Some changes on document structure + List of contents added + Update on brass cross manufacturing process + Update on wire to rubber cord connection + Update on axial winding protection + 2H x 2V + 7 Element stack on fiberglass pole introduced