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Mechanical concept for a compact, lightweight and fast deployable VHF Yagi antenna

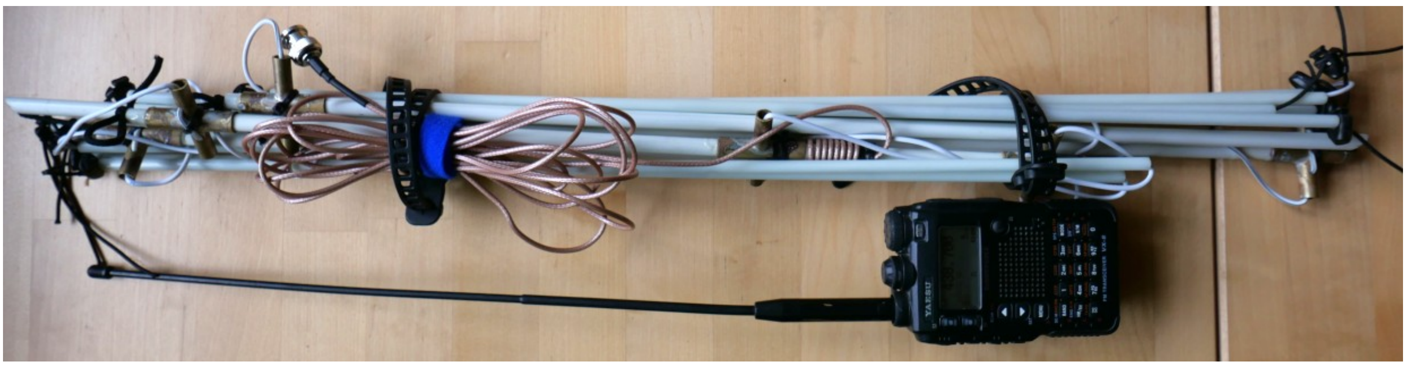
Key facts

- 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.

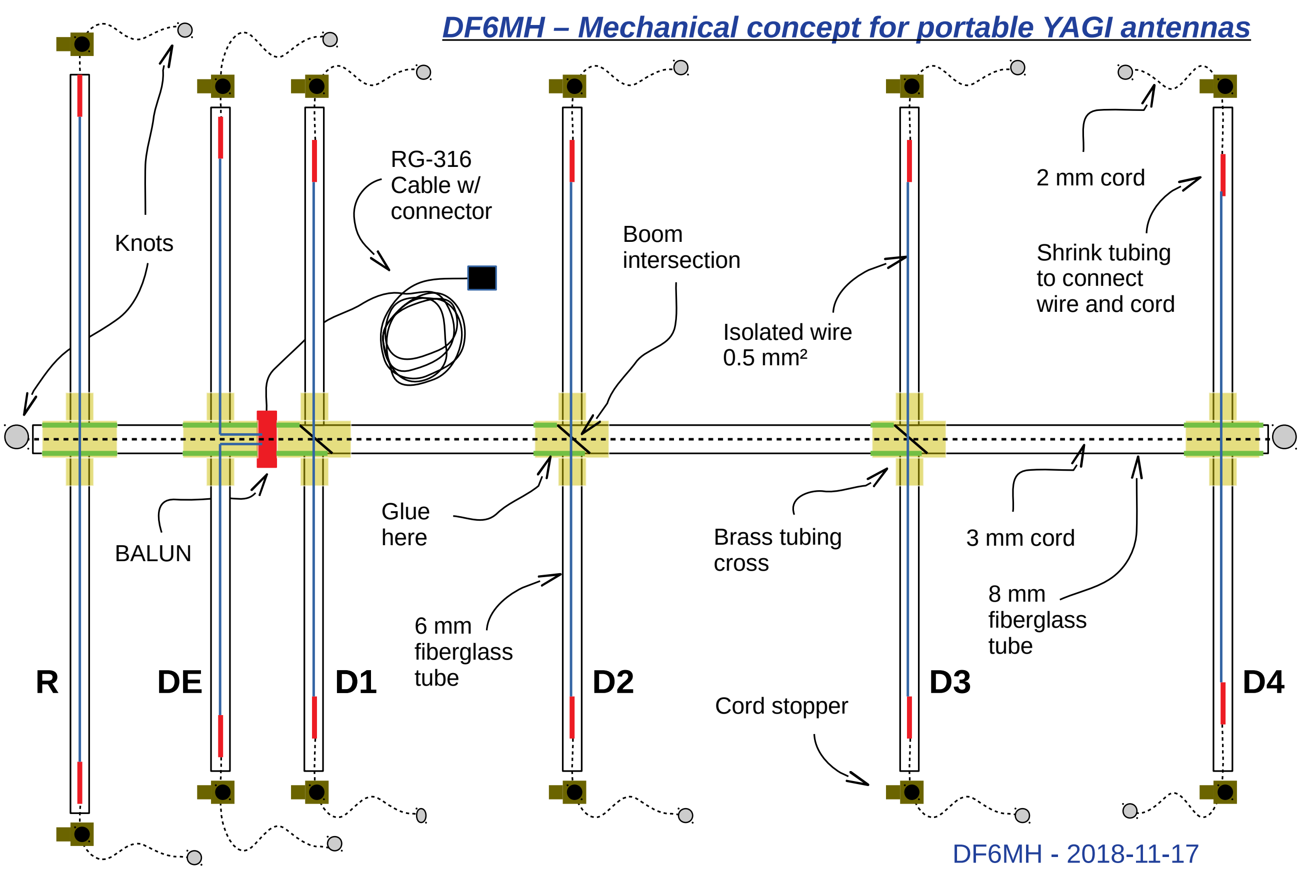
Introduction

Portable 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 construction came into my mind and I developed this idea for over one year building several prototypes. I tested these prototypes on many mountain trips, also on two overnight backcountry skiing bivouacs with really hard conditions for the antenna.
I now think the design got quite stable and I want to share my concepts on how to build a compact, lightweight and easy to deploy Yagi antenna. The shown practice does not only work for Yagi designs but is also deployable for all other kinds of portable antennas.
Feedback is highly appreciated and I look forward to hear from you!



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 3 mm cord is used inside the boom and pieces of 2 mm 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

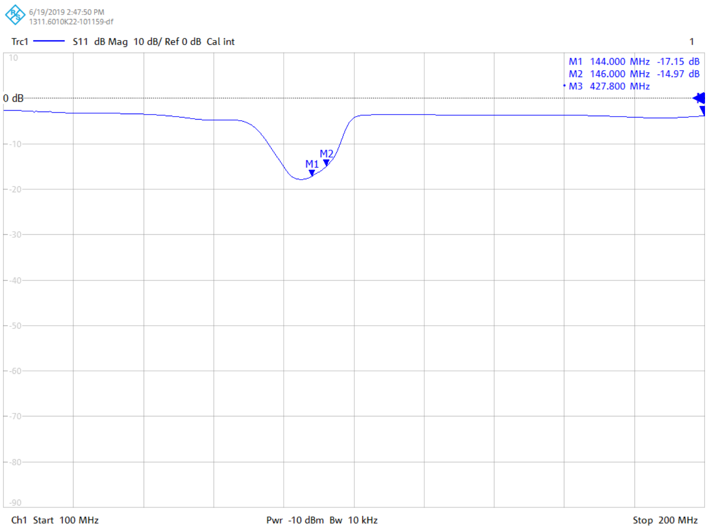
With the element lengths proposed by DK7ZB, the resonance of the antenna is much too deep for the VHF amateur radio band because the isolated wires and the fiberglass tubes cause a capacitive loading. I ran a new simulation using CST, a professional 3D EM simulation tool covering also the capacitive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

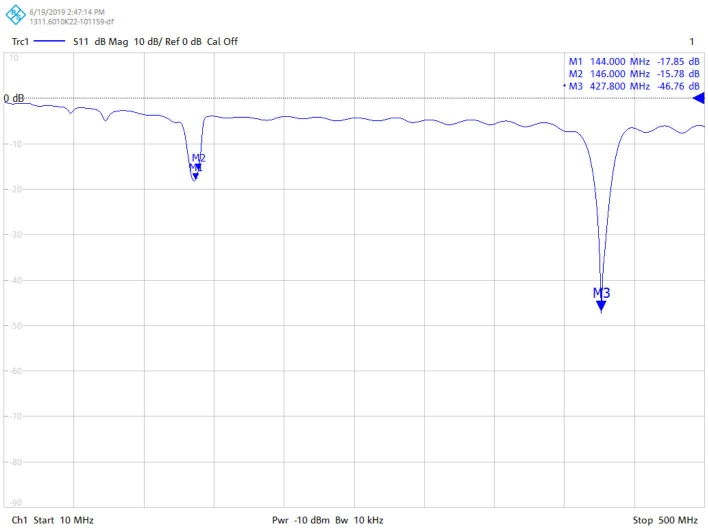
Element	Element length	EL/2	Boom Position
Reflector	948 mm	474 mm	30 mm
Driven Element	914 mm	457 mm	290 mm
Director 1	860 mm	430 mm	425 mm
Director 2	844 mm	422 mm	875 mm
Director 3	844 mm	422 mm	1500 mm
Director 4	814 mm	407 mm	2010 mm

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 and will challenge your patience. The trick is to hard-solder the two pipes orthogonally together. Otherwise your Yagi antenna will look strange!
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.

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. 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. Check the orthogonality with a small triangle before soldering. I used a piece of an old credit card for this purpose. Use the file again if necessary to make an orthogonal fit possible. 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.

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.
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.
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 13 mm pieces of the aluminum tube and make a cutout with the hacksaw 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 pressed 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. This is a matter of judgment and needs some patience.

It may also be necessary to glue the inserts into the boom ends if diameter of the material you use differs from the material I used.
I did not test these inserts on my prototype antenna up to now. I only tested it on a small test intersection with a piece of 10 mm brass tube. But this test looked really promising and I am convinced that it also works for the whole antenna. I will use this technique in the next antenna I will build. I'm a bit afraid of updating my existing antenna with the inserts because boom alignment could be wrong and I also risk to crack my already glued fiberglass pipes. This is also why I strongly recommend to first test the inserts and the slotting mechanism before gluing them into the brass crosses.

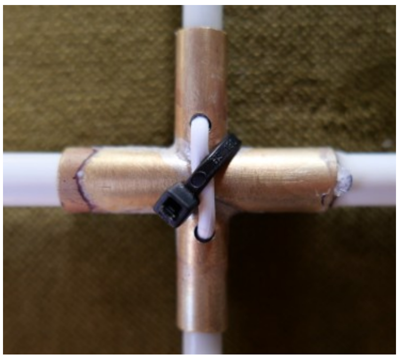
Gluing the brass crosses onto the boom segments

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.

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.

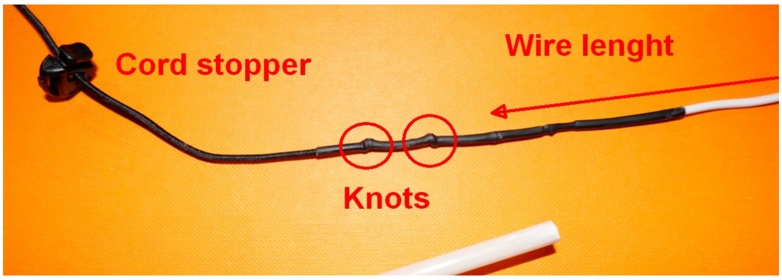
First measure the resonance before attaching the rubber cord!

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. This is done by placing 2 small and very tight knots in the rubber cord and shrinking a 10 cm piece of 2 mm shrink tubing onto the wire and the rubber cord with the knots. The knots prevent the cord from slipping out of the shrink tubing. Rubber cord length should be around 30 cm for the driven element and 20 cm for all other elements.
The distance from the end of the wire to the end of the shrinking tube on the rubber cord should not be too big. Otherwise you can't stretch the rubber cord enough to fixate the fiberglass tube. That means to place the two knots in a distance of appx. 10 to 15 mm and to cut the rubber cord some mm after the last knot.

Final assembly

The last step is to feed the element rubber cord and wires through the fiberglass tubes. As final step, 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.

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

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[1] 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 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.

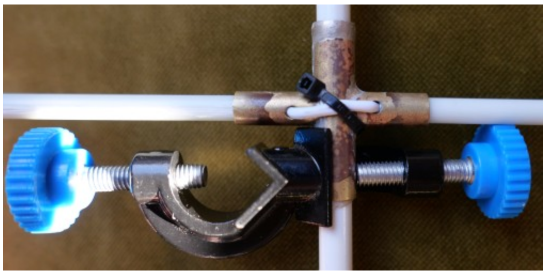
1 Kirschke A. (2013) *Rothammels Antennenbuch* (13. Auflage). Baunatal, DARC Verlag GmbH

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.

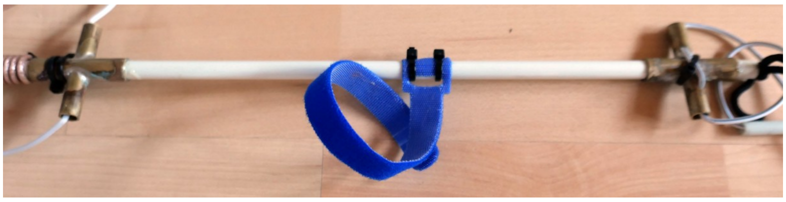
This picture shows the complete hiking pole mounting kit. Total weight of the material shown in the picture is 275 gr.

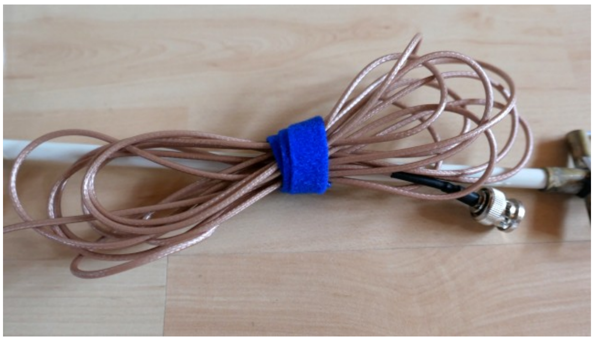
Electrical influence of the hiking poles mast

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.

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.





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.

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.

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!