

Dipole and Yagi Antenna

Table des matières

1. Dipole for 433 MHz.....	2
1.1. Presentation.....	2
1.2. Polarization warning.....	3
1.3. Theoretical length.....	3
1.4. Building.....	4
1.4.1. Coaxial.....	4
1.4.2. Pole material.....	4
1.4.3. Solder.....	4
1.4.4. Mechanical reinforcement.....	6
1.5. Tuning with VNA.....	8
1.6. Common error.....	9
2. Yagi 5 poles for 433 MHz.....	11
2.1. Presentation.....	11
2.2. Yagi Calculation.....	11
2.3. Adapting calculation.....	12
2.4. Building.....	13
2.5. Common error.....	16

1. Dipole for 433 MHz

The dipole antenna is an operating antenna by itself and also the base for a Yagi antenna.

1.1. Presentation

As the name suggests, the antenna is built with two poles. The poles are in the opposite direction with the feed point (electrical connection) right in the center.

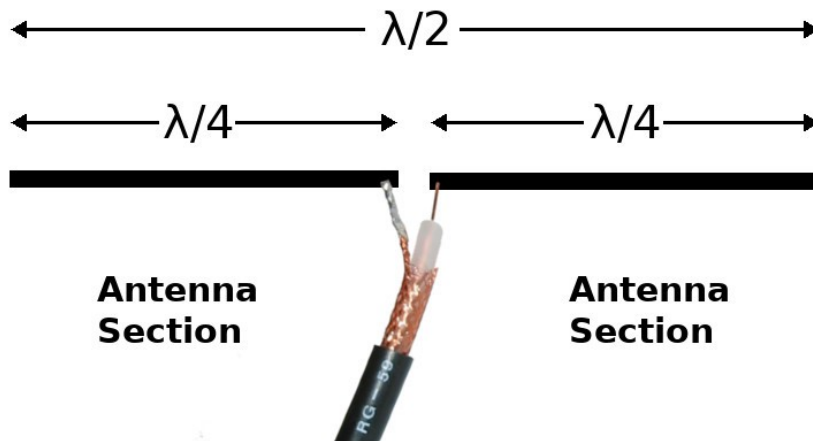


Fig 1 : Structure of Dipole antenna

The poles have **exactly** the same length. Each one having a $\lambda/4$ length (as a single pole antenna). The total length of a dipole antenna is $\lambda/2$ (half wavelength).

One of the pole act as an active element while the other act as ground plane (and vice-versa due to the alternative nature of the signal).

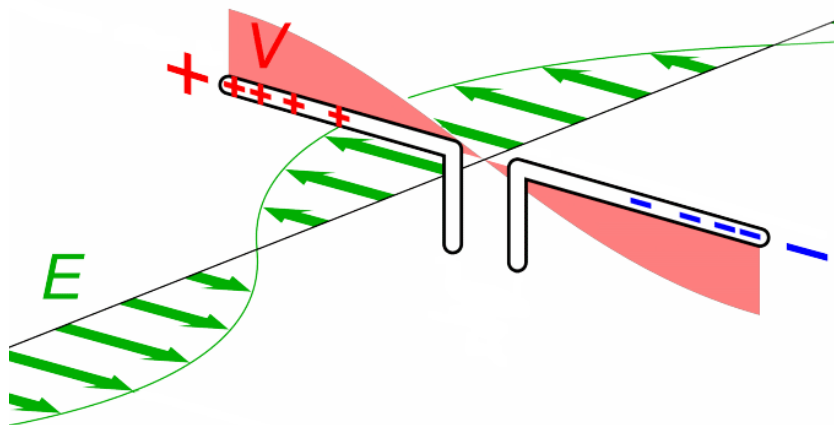


Fig 2: Distribution of voltage across the antenna

In reception mode, the signal electric field do create a voltage gradient across the elements wich, in turn, induce a current.

From the emitter perspective, the current is maximum at the antenna feed point (the antenna center point). At that point the length of the antenna pole is zero resulting in a zero Ohms resistor. The voltage is zero volt at the feed point (due to Ohm law).

At the end of the pole, the current has no way to escape. So the current is zero at that location.

To resume, the current maximum at the feed point and zero at the end of pole. In the same time, the pole resistance increase from zero at the feed point up to a maximum at the end of the pole. This result in a voltage distribution from 0 Volts to a maximum voltage at the end. Never touch the end of the dipole antenna on an emitter, the voltage can reach up to 2000 volts!

1.2.Polarization warning

The dipole antenna is very sensitive to the polarization. Using it on the wrong orientation/rotation and no signal will be received.

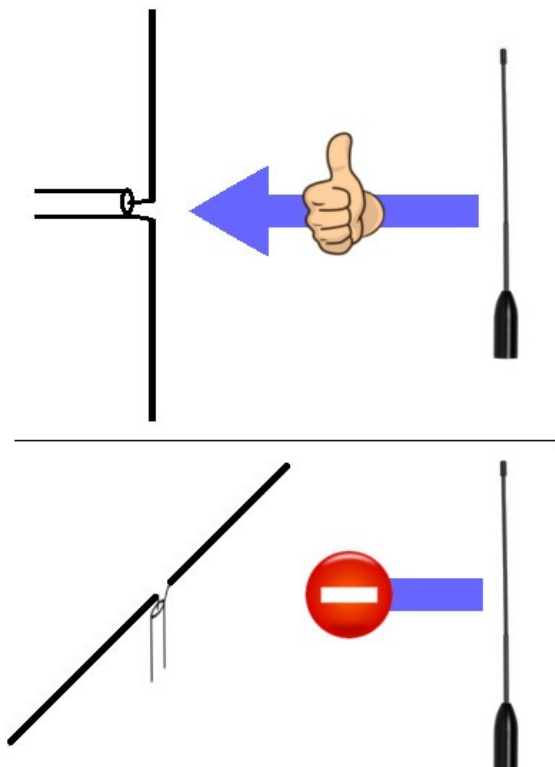


Fig 3: transmission and polarization

1.3.Theoretical length

The dipole is made of twice quarter wavelength antenna. So we can rely on the quarter pole antenna calculation.

The $\lambda/4$ antenna formula is:

$$L = C / (4 * \text{freq})$$

where:

- L is the length in meters
- C is the speed of light (in meter/sec).
- Freq is the frequency in hertz

For a 433 MHz antenna, the length is calculated like the following:

$$L = 300 * 10^6 / (4 * 433 * 10^6)$$

$$L = 0,1732\text{m}$$

$$L = 17,32\text{cm}$$

The full length of the dipole at 433 MHz made 34,64cm (two poles of 17,32 cm each).

1.4.Building

1.4.1.Coaxial

The antenna is connected to SMA connector of the receiver (SMA female). The first par of this antenna is the coaxial cable.

One meter of RG-58 coaxial cable (copper based) is fitted with the appropriate SMA male connector (ref: https://shop.mchobby.be/product.php?id_product=2095).

A **crimp SMA connector** is used to avoids any kind of interference injection or impedance mismatching on the receiver board.

The opposite side of the cable remain unpopulated.

1.4.2.Pole material

Hexagonal **brass bar** 2,5mm wide is selected for the pole. Brass can be soldered with stain solder, is a good electrical conductor and is **sturdy**.

The final antenna must have **poles aligned in a perfect straight line!**



Fig 4: hexagonal brass bar

The poles are cut at 17,32 cm (as close as possible).

The material, composition, surface condition, section will impact the antenna performances.

1.4.3.Solder

Due to high frequency in use:

- 1.The connection pole-to-coaxial must be as small as possible.
- 2.The spacing between the two poles must be as small as possible
- 3.Any air gap must be avoided a much as possible (it modifies the impedance).
- 4.The coaxial braid (the ground) must stay as close as possible of the coaxial core (avoids signal injection and impedance issue).

Coaxial cutting

A precise cutting of the coaxial cable can meet the expectation exposing the core on one side and the braid on the other side.



Fig 5 : Coaxial cut-out

Tin the coaxial

Once the cut-out made, use some flux then tin the core and the braid. Take care to not overheat and melt the dielectric !

Once done, the end of the coaxial should look like the following.

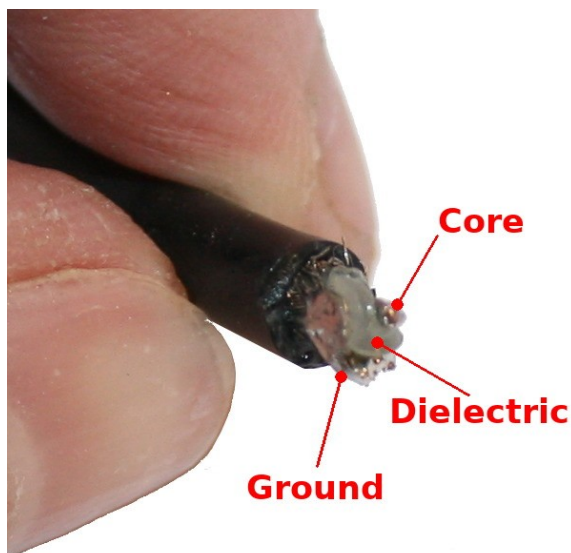


Fig 6: Tinned coaxial

Tin the poles

Tap some flux at the connection point of each pole.

Tin the connection point make sure that have some extra solder on the connection point.

Remark: If you have difficulties to melt solder on the pole then it means that your iron is not powerful enough (the pole cool down the solder point quicker that the iron can heat it). Using a 80W iron would be welcome to quickly communicate enough heat to the metal.

Reflow soldering

Trace a straight line on a paper with a perpendicular line in the middle.

Use adhesive roll to maintain the coaxial right in place on the perpendicular line.

The straight line will help you position the poles at 90° from the coaxial. Use the tip of the iron to reflow the tinned pole (with its extra solder) on the tinned coaxial.

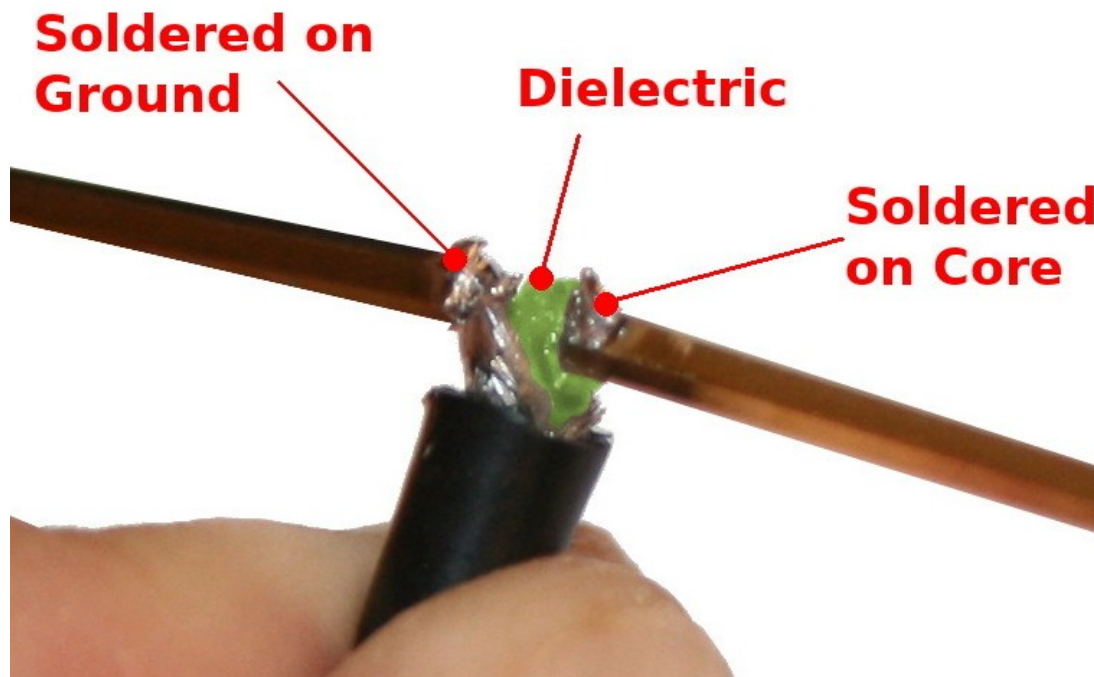


Fig 7: Poles soldered on coaxial (dielectric highlight in green)

This should be done as quickly as possible to preserve the dielectric from melting. 3 to 5 seconds should be enough to solder a pole on the coaxial.

Useful tips:

- Use a higher power iron would shorten the heat time
- Using higher temperature (eg : 350) would keep the pole melting point at a higher temperature for longer time. Note: It will also “burn” the flux... work quickly
- Flux will help solder fluidity while soldering.
- Pre-heat/melting the tin on the pole will definitely shorten the soldering time.

Check conductivity

Take a multimeter and check the conductivity between the two poles.

No short-circuit should be detected between the poles. The coaxial core should never be in direct contact with the ground braid.

Cleaning

Use a toothbrush and isopropyl alcohol to gently clean the solder joints.

1.4.4. Mechanical reinforcement

The antenna poles must be straight! A mechanical reinforcement is required to preserve the solder joints and keep the element straight.

The part used must be:

- no conductive

- as small as possible to avoids/limits the inductive or capacitive effect on the antenna poles.

Here the technical drawing of an pole holder made with **2mm thick PVC**.

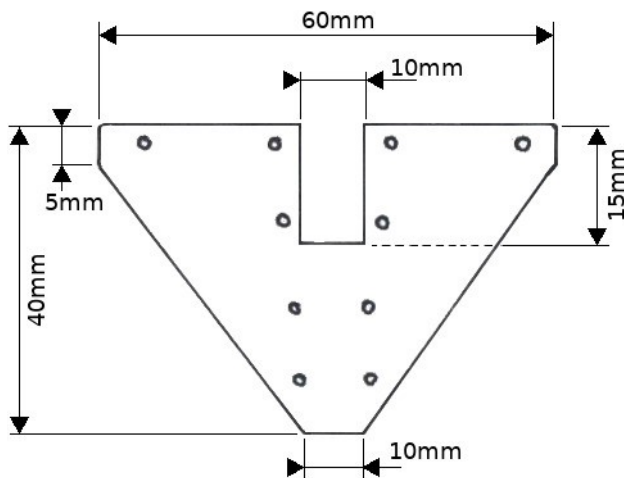


Fig 8 : pole holder

The holes (2mm diameter) are used to zip ties the poles first. **Keeps the poles on a straight line is crucial !**

Once the poles properly aligned, zip ties the coaxial cable to secure the solder joins.

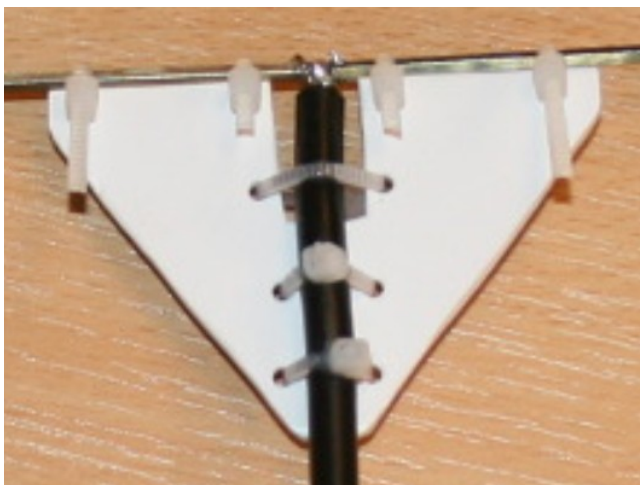


Fig 9: mechanical reinforcement of the dipole

At this stage, the dipole should look like the following picture

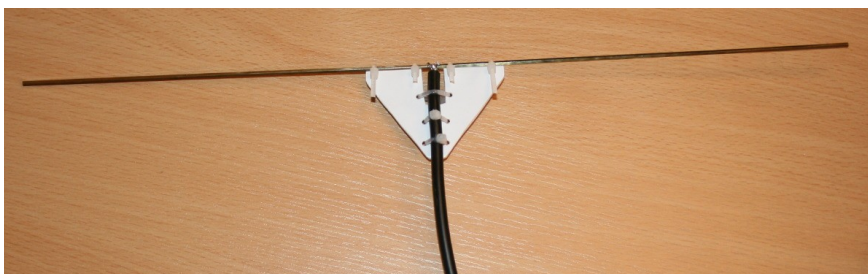


Fig 10 : general view of the dipole

1.5.Tuning with VNA

As for any antenna, a tuning stage is strongly recommended. Grab your VNA and configure it for SWR graph display.

The first SWR analysis around the expected emitting frequency (from 350 to 450 MHz) shows a resonance at 393 MHz with a SWR of 1,26.

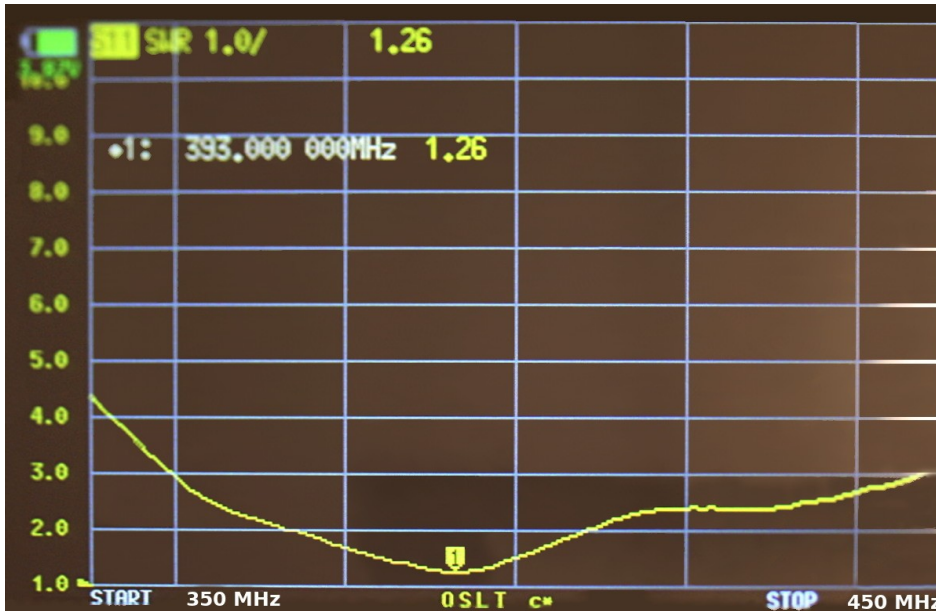


Fig 11: Initial 433 MHz dipole SWR analysis

Remember the past explanation about the resonance frequency and antenna length.

Lower resonance frequency means that we can shorten the antenna!

Takes appropriate grinding tool and gently remove some material from the both antenna poles. Secure the pole to avoid solder joint breakage due to vibration.

Remember: the two poles must have the same length.



Fig 12: shorten the antenna

With successive attempt of shorten + measurement, the resonance frequency will move toward the expected 433 MHz.

The figure 13 below shows the final measurement where SWR is below 1,5 for 433,2 MHz (really great SWR value).

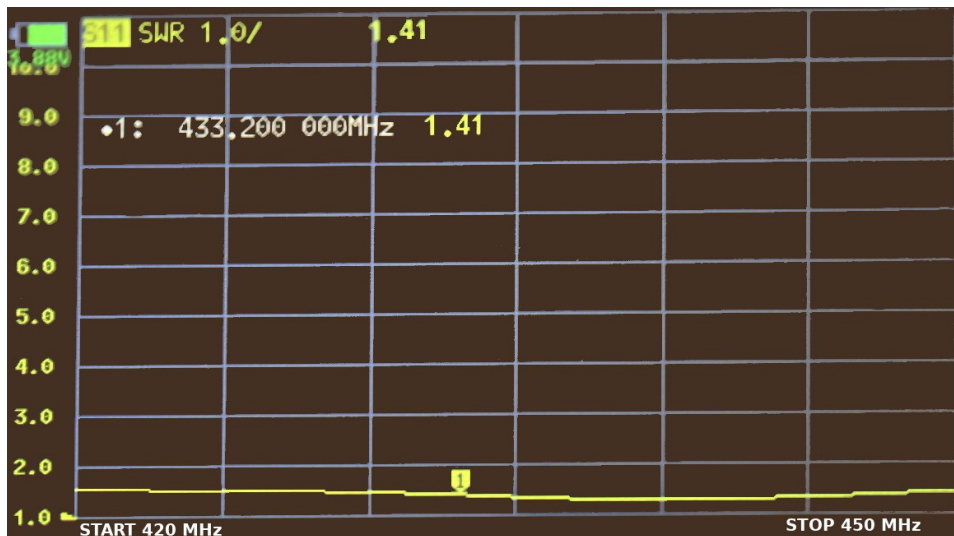


Fig 13: final tuning of the antenna

Attentive reader will notice that SWR is even lower at a higher frequency (440 MHz) meaning that antenna was over-shorten (just a bit too much).

Nonetheless, this dipole was used to create a 433 MHz Yagi Antenna transmitting data over 4 Km.

1.6.Common error

At such high frequency, it is quite easy to mess with the Dipole antenna. An simple air layer in antenna connection may deeply impact its behavior.

The figure 14 here below shows an acceptable design that cannot be applied at higher frequency. The reasons are detailed on the picture.

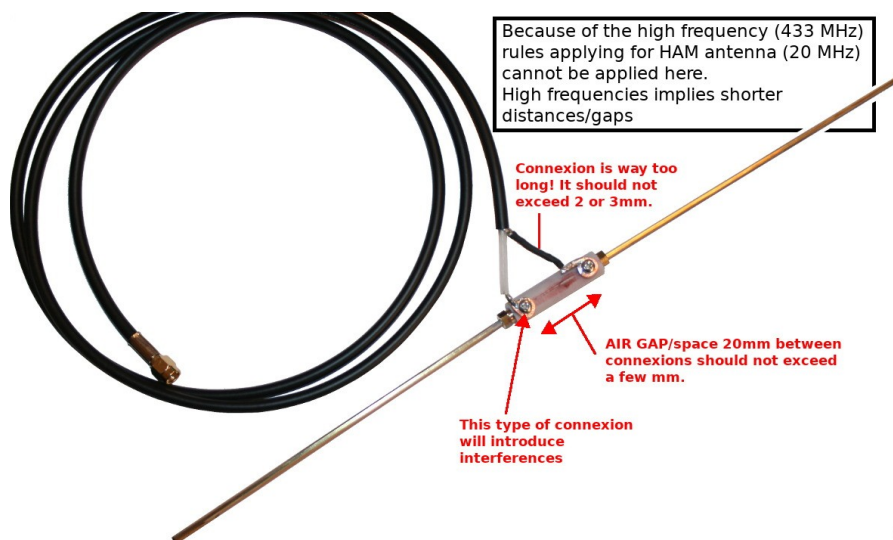


Fig 14: Wong Dipole assembly for high frequency

The figure 15 shows an incorrect design for the mechanical reinforcement. Indeed, the PVC piece connects the high voltage/low current section of the poles and will act as a capacitor disturbing the radio wave.



Fig 15: Parasitic mechanical reinforcement

2.Yagi 5 poles for 433 MHz

2.1.Presentation

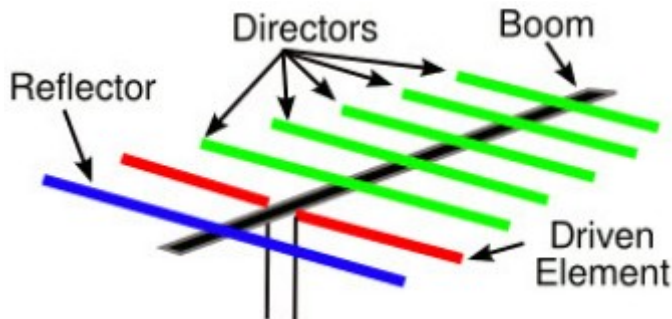


Fig 16: Yagi antenna

The driven element is designed to receive or send the radio wave. There is only one driven element on the Yagi.

The driven element can be any type of pole (dipole, folded pole, Jpole and other type). In this scenatrio the tuned 433 MHz dipole will be used as driven element.

The directors must be positionned at the proper distance to capture the radio wave and re-inforce the signal by re-emitting to the next director/driven-element.

The reflector capture the radio wave passing next to driven element and reflect it back to the driven element.

The position and dimension of each element must be calculated carefully to obtain the expected signal reinforcement

2.2.Yagi Calculation

Here are the calculation and rules for building a Yagi antenna.

Driven Element:

$$\lambda = C / f = 300.10E6 / 433.10E6 = 300 / 433 = 0.6928 \text{ m}$$

$$\lambda/2 = 0.3464 = 34.64\text{cm}$$

Reflector Element:

$$\text{Length} = 34.64\text{cm} + 5\% = 36.37\text{cm}$$

Director 1 Element:

$$\text{Length} = 34.64\text{cm} - 5\% = 32.90\text{cm}$$

Director 2 Element:

$$\text{Length} = 32.90\text{cm} - 3\% = 31.92\text{cm}$$

Director 3 Element:

$$\text{Length} = 31.92\text{cm} - 2\% = 31.28\text{cm}$$

Distance Reflector --> Driven Elements

Dist = 20% WaveLength = 20% of 69.28cm = 13.85cm

Distance Driven --> Director 1 Elements

Dist = 15% WaveLength = 15% of 69.28cm = 10.39cm

Distance Director 1 --> Director 2 Elements

Dist = 12% Wavelength = 12% of 69.28cm = 8.31cm

Distance Director 2 --> Director 3 Elements

Dist = 10% Wavelength = 10% of 69.28cm = 6.93cm

2.3.Adapting calculation

Once build, we know that the dipole (for the Yagi) is pre-tuned for a frequency close of 433 MHz.

After tuning with the VNA, the total length of the dipole (from left to right) is effectively of 33.1cm.

Now, based on this new information, we should update the size and position of the other Yagi elements.

Driven Element (tuned):

33.1 cm

Reflector Element:

Length = 33.1cm + 5% = 34.75cm

Director 1 Element:

Length = 33.1cm - 5% = 31.44cm

Director 2 Element:

Length = 31.44cm - 3% = 30.50cm

Director 3 Element:

Length = 30.50cm - 2% = 29.89cm

Distance Reflector --> Driven Elements

Dist = 20% WaveLength = 20% of 69.28cm = 13.85cm

Distance Driven --> Director 1 Elements

Dist = 15% WaveLength = 15% of 69.28cm = 10.39cm

Distance Director 1 --> Director 2 Elements

Dist = 12% Wavelength = 12% of 69.28cm = 8.31cm

Distance Director 2 --> Director 3 Elements

Dist = 10% Wavelength = 10% of 69.28cm = 6.93cm

2.4. Building

To avoid any interference, a wood base boom used to build the antenna.

A 56cm long plywood boom (4x2cm section) were salvaged from an Ikea bed.

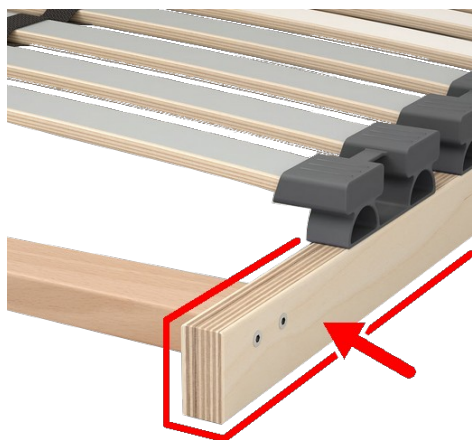


Fig 17: salvaged plywood

While preparing holes in your boom, do remember that the depth of the element in the boom will affect the antenna performance!

Do not hesitate to check it on the DL6WU Yagi-Uda calculator

<https://3g-aerial.biz/en/online-calculations/antenna-calculations/dl6wu-yagi-uda-antenna-online-calculator>

Director and reflector are mounted into 3mm diameter holes. The holes are drilled in the boom at exactly 1cm from the top.

Elements must be perfectly straight and perfectly aligned!

The dipole is positioned into a triangle cut-out made in the boom.

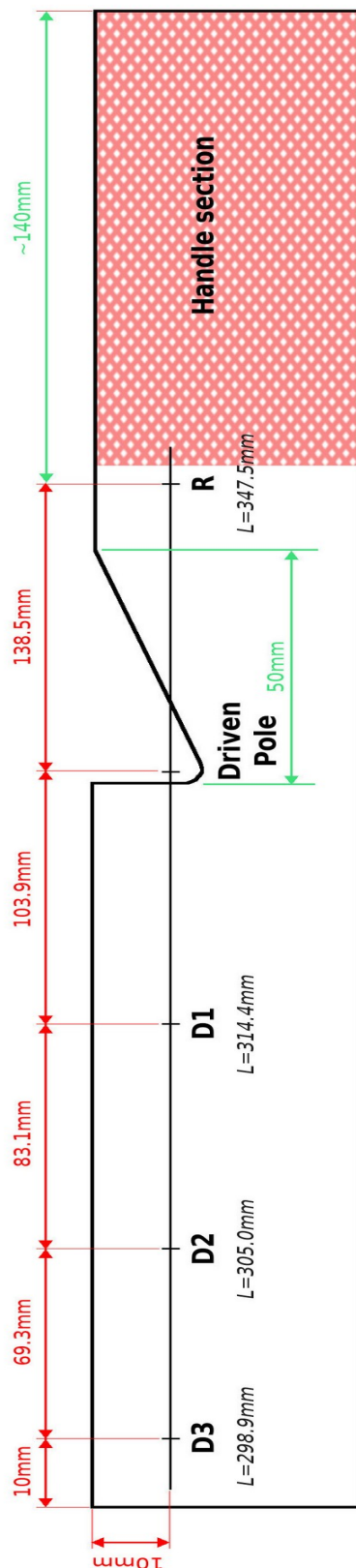


Fig 18: Boom drawing

The elements have been secure in place with elastic bands and zip ties.



It is essential to :

1. Have all the poles **paralleled** to each-other.
2. Have all poles **perfectly aligned** on the line!

Using wood tool (eg: wood chisels) will allow you to create and adjust the appropriate receptacle to place the dipole in.

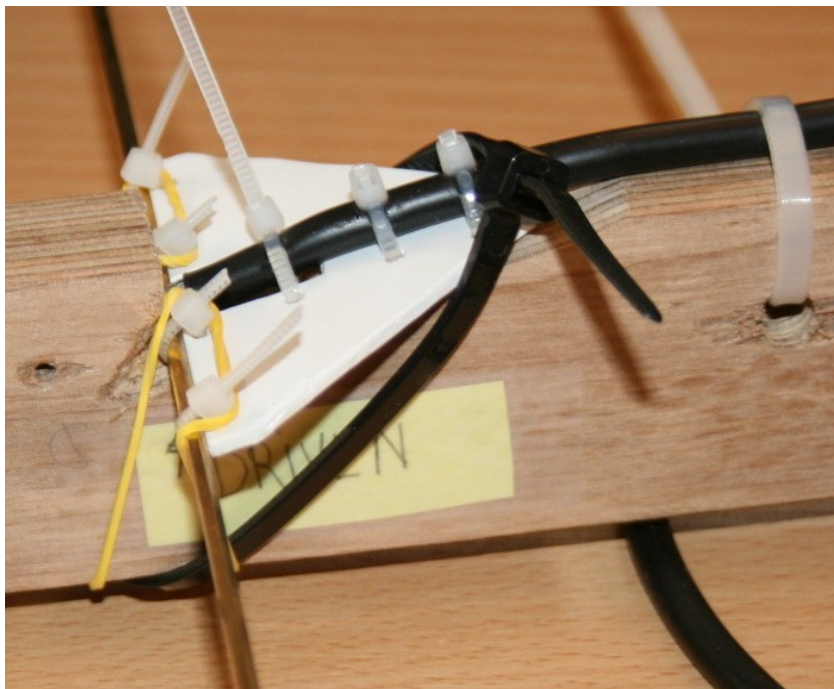


Fig 19: positioning the dipole on the Yagi boom

The figure 20 show the general overview of the final antenna

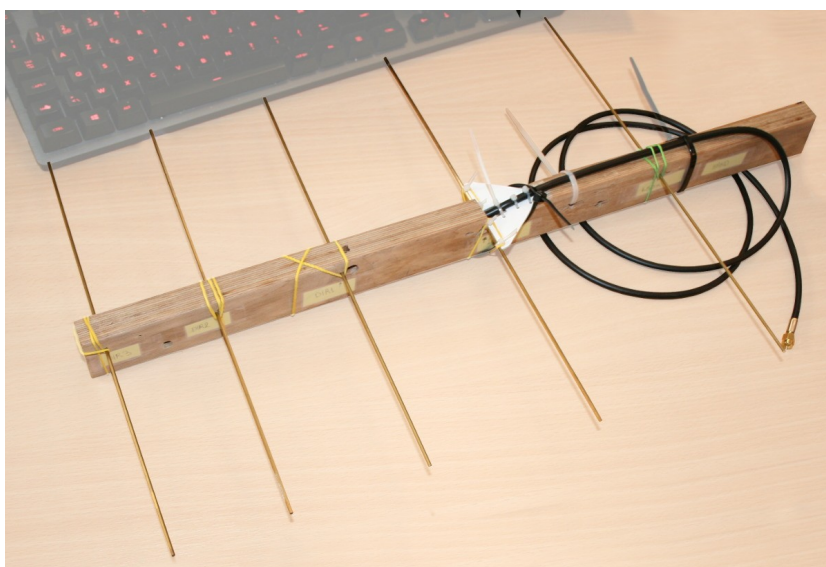


Fig 20: finalized Yagi antenna

The next figure show a **balun** made with 3 to 4 tight turns of the coaxial behind the reflector pole.

At this stage I did follow the HAM recommendation. I'm not able to determine the efficiency of the balun.

2.5.Common error

Using hand drill for drilling the boom

As the elements must be properly aligned, this implies that drilled holes must be perfectly perpendicular to the boom (so the holes parallel to each other).

Using a floor standing drill would avoids miss-alignment!

Use a punch

While starting to drill a hole, it is quite easy to slightly slip/deviate from the marked position.

As precision is essential, use a punch to precisely mark the drilling position.

Handling

While using the antenna, always handle it behind the reflector!

Keeps you away for metallic parts.

Use the right polarization to receive/send data.