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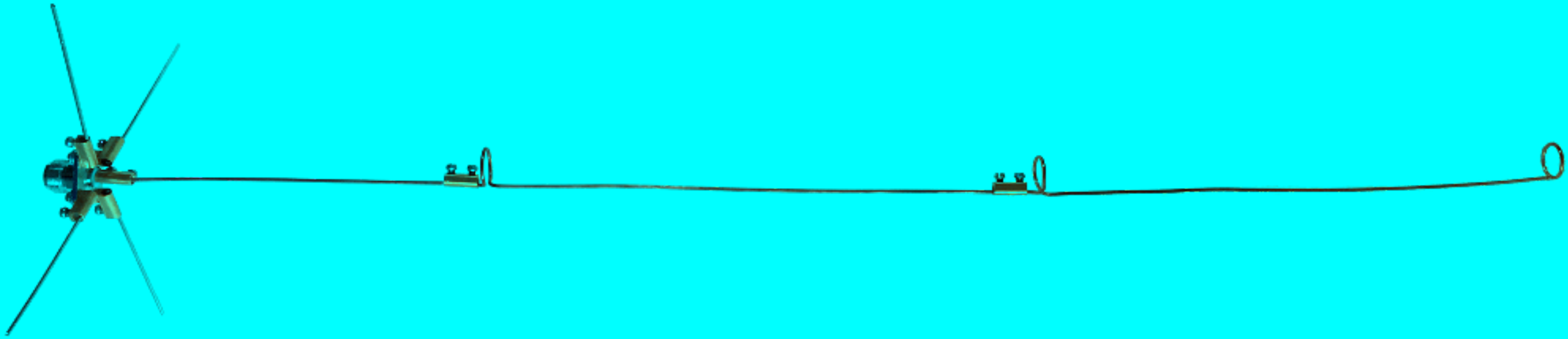
LORA / LORAWAN TUTORIAL 46

Collinear Antenna



v1.0.0

INTRO

- In this tutorial I will explain what a collinear antenna is and how to build one.

ATTENTION

- **The antennas built in this tutorial are intended for test and educational purpose and should be used indoors.**
- **The antennas are constructed in such a way so it can be easily disassembled and its parts can be re-used in other antenna projects.**
- **The antennas are not properly constructed and the antenna performance can be improved by using better materials, parts or another way of construction.**

COLLINEAR ANTENNA

- A collinear antenna is actually an array of dipole antennas stacked one above the other so that they are all in a straight line, i.e., "co linear.''

- On internet you can find several designs how to build a collinear antenna:

  - **Collinear antenna 1**
    https://www.thethingsnetwork.org/forum/t/diy-external-antenna-for-gateway/3011

  - **Collinear antenna 2**
    https://github.com/IRNAS/ttn-irnas-gw/

- I have build both antennas and will demonstrate how these antennas performs in this tutorial. Please note: I have made some modifications to both designs.

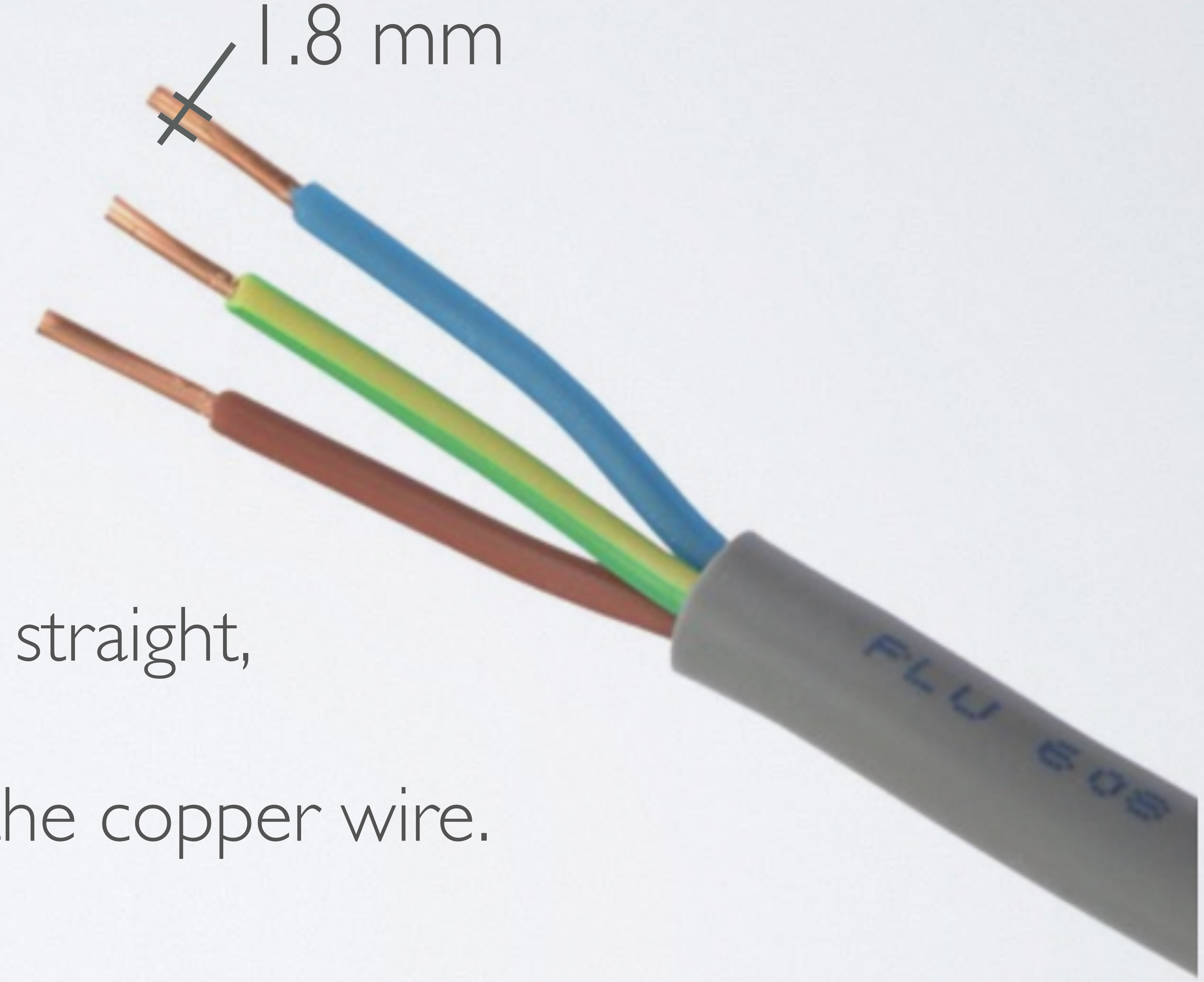
Collinear Antenna 1

BUILD COLLINEAR ANTENNA 1

- Bill of materials
  - Type N female chassis mount 4-hole connector
    LxW: 2.5 x 2.5 cm / 1" x 1"
    Hole diameter: 3.5 mm / 0.137"
    Impedance: 50Ω
    Material: Metal alloy
    Cost: € 0.96

BUILD COLLINEAR ANTENNA 1

- Outdoor cable XMVK 3x2.5 mm^2 grey.
  The copper wire has a diameter of 1.8 mm.
  Only 1 meter is needed.
  Cost: € 1.75 per meter

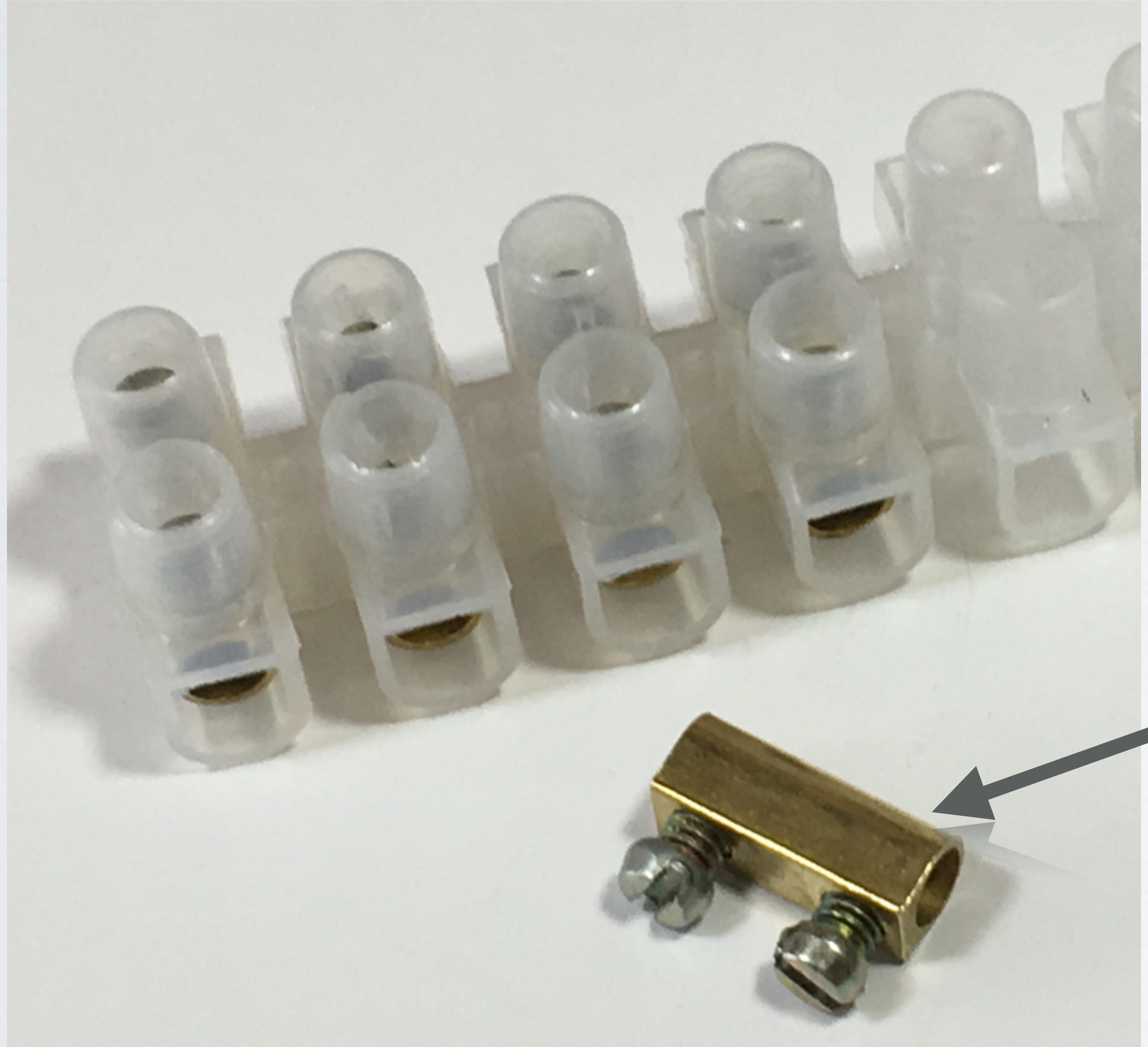


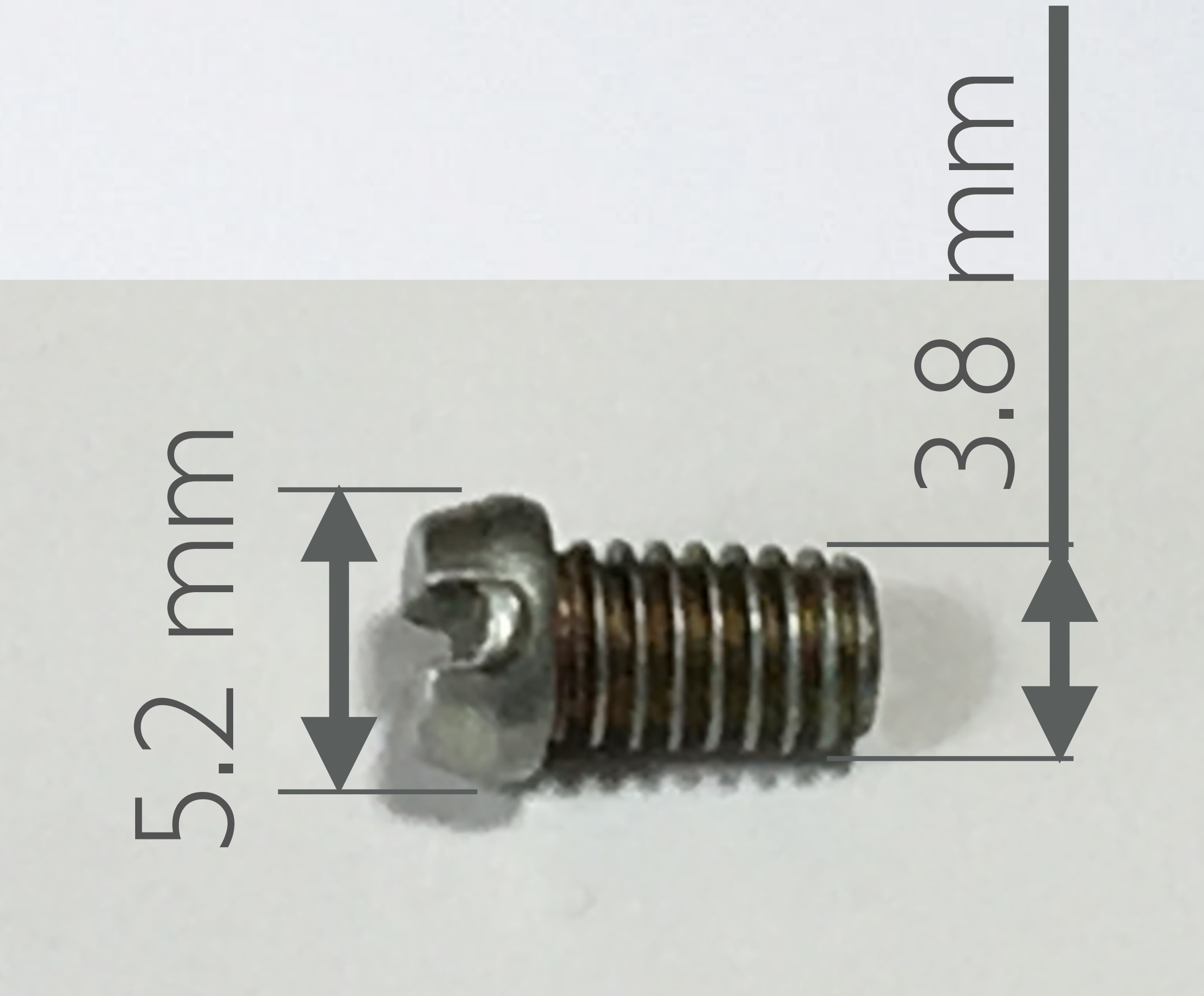
- The electrical insulator can be easily removed using a Stanley knife.

- The copper wire can be stretched out.
  The stretched out wire will be stiffer, more straight, and the wire diameter will decrease.
  In this tutorial I have **NOT** stretched out the copper wire.

BUILD COLLINEAR ANTENNA 1

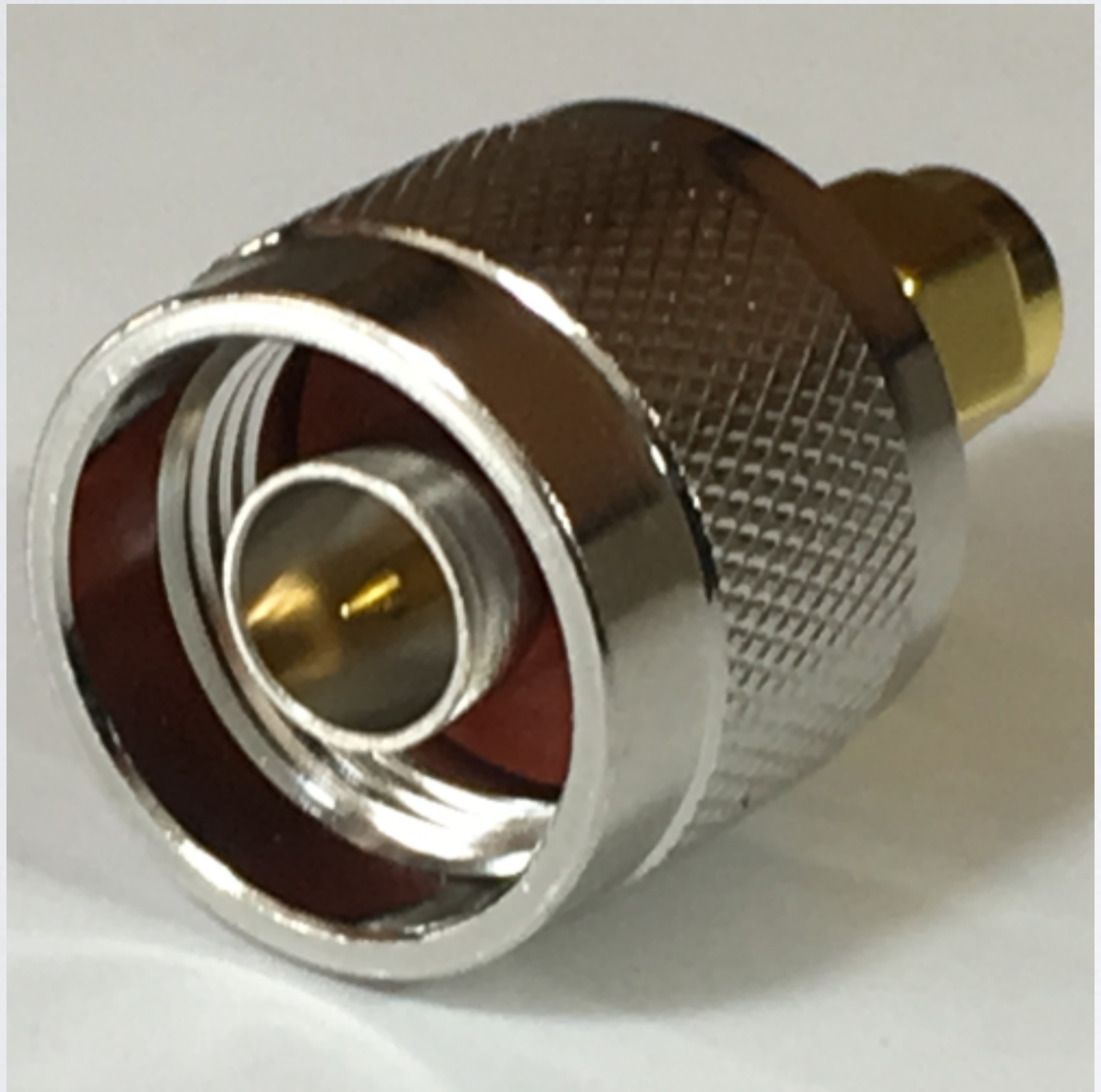
- Terminal strip block (3 Ampere)
  Cost: € 1.80 (3 strips, each strip has 12 terminals)

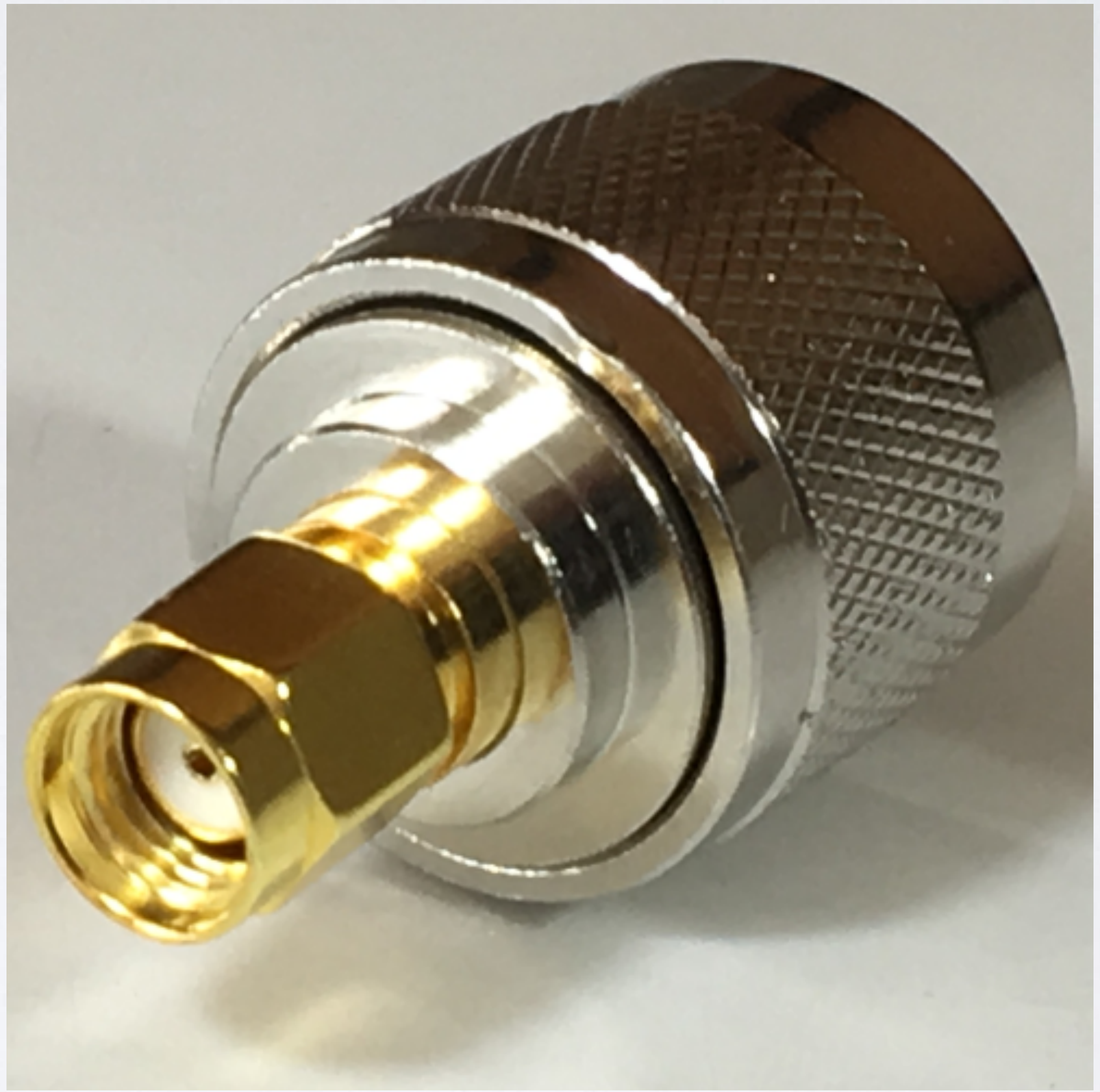




BUILD COLLINEAR ANTENNA 1

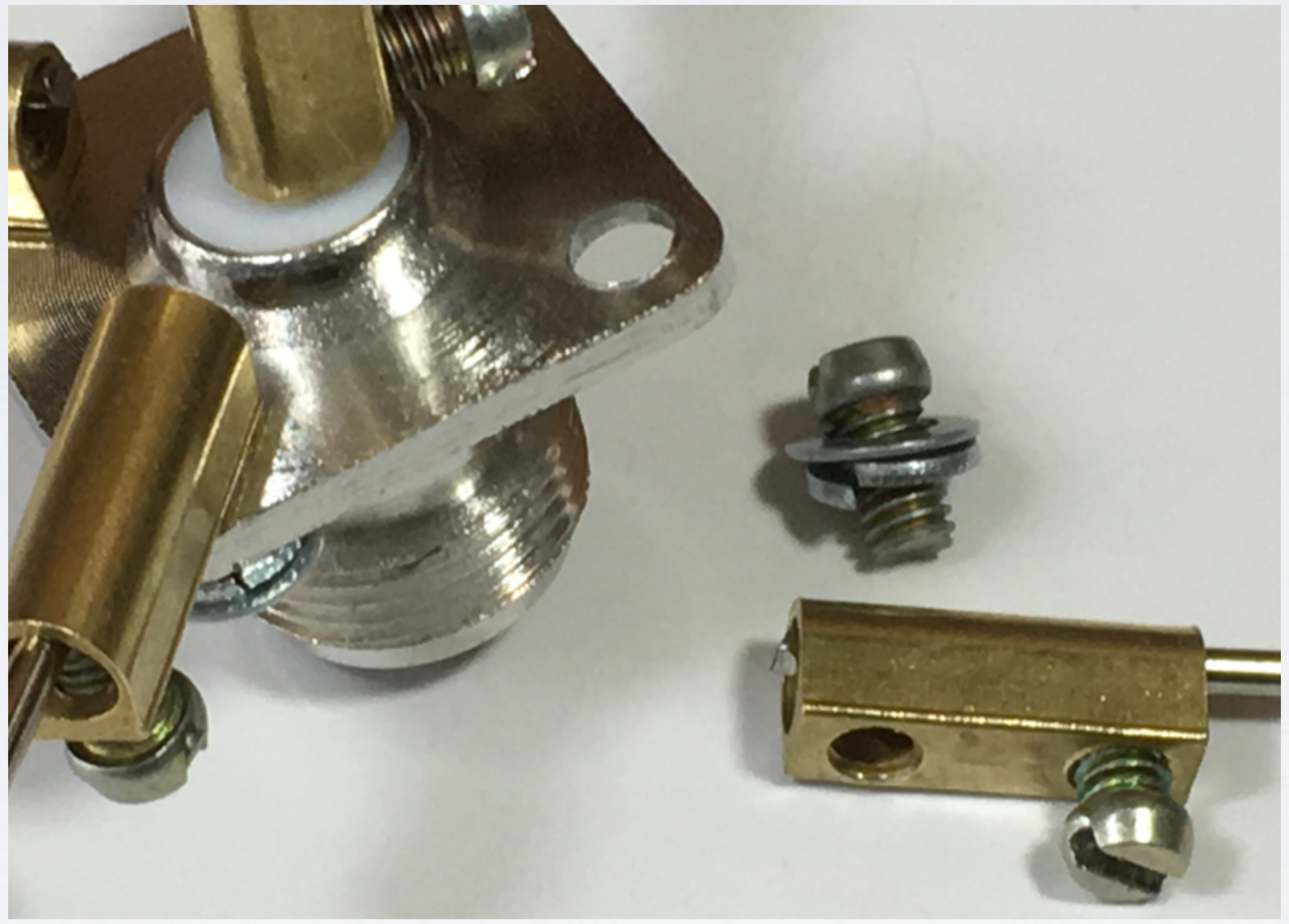
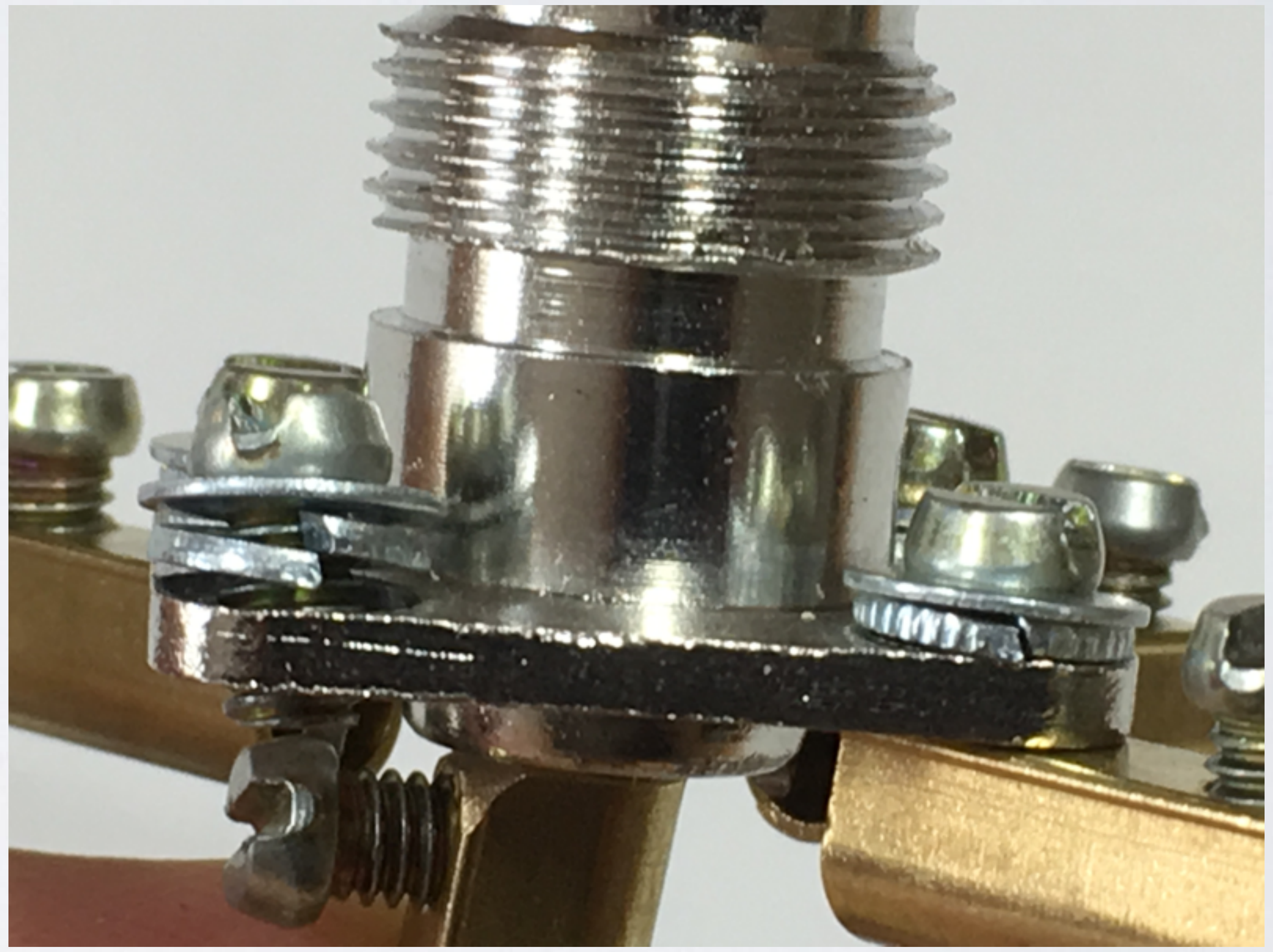
- Type N male to RP-SMA male plug adapter coaxial cable connector.
  Cost: € 1.44





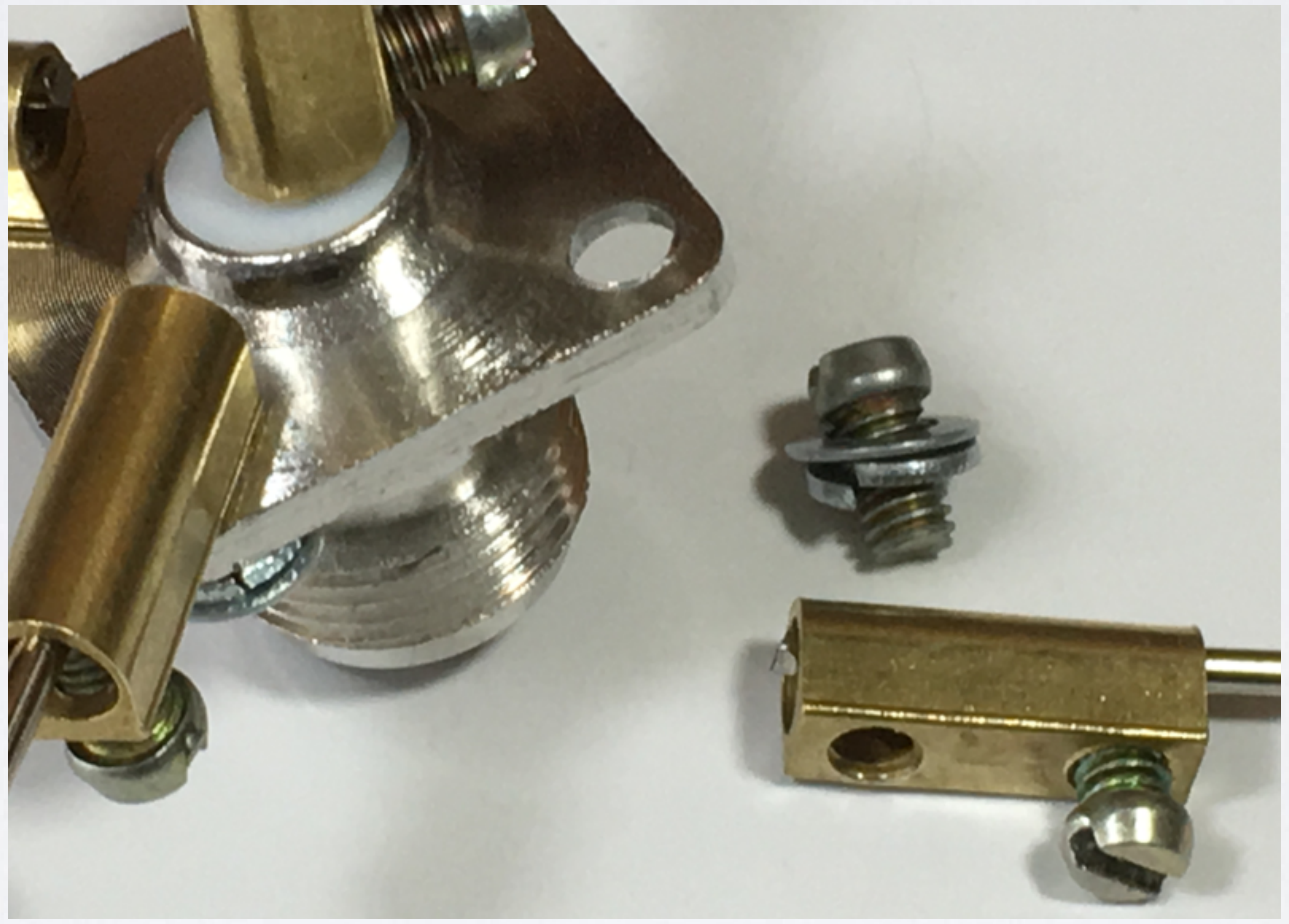
BUILD COLLINEAR ANTENNA 1

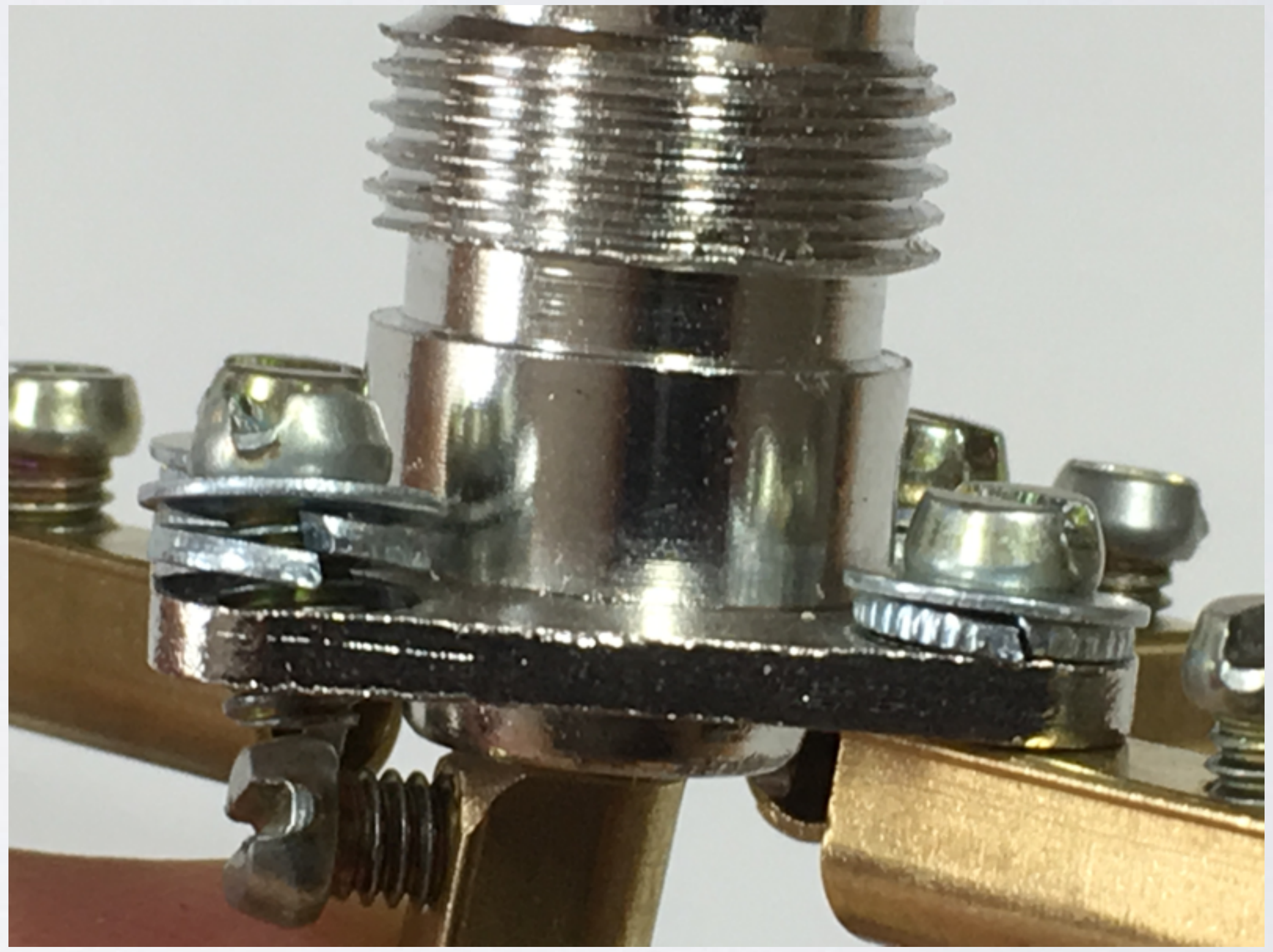
- Metal washer 7.8 x 4.4 x 0.5 mm (outer diameter, inner diameter, thickness)
  Cost: unknown

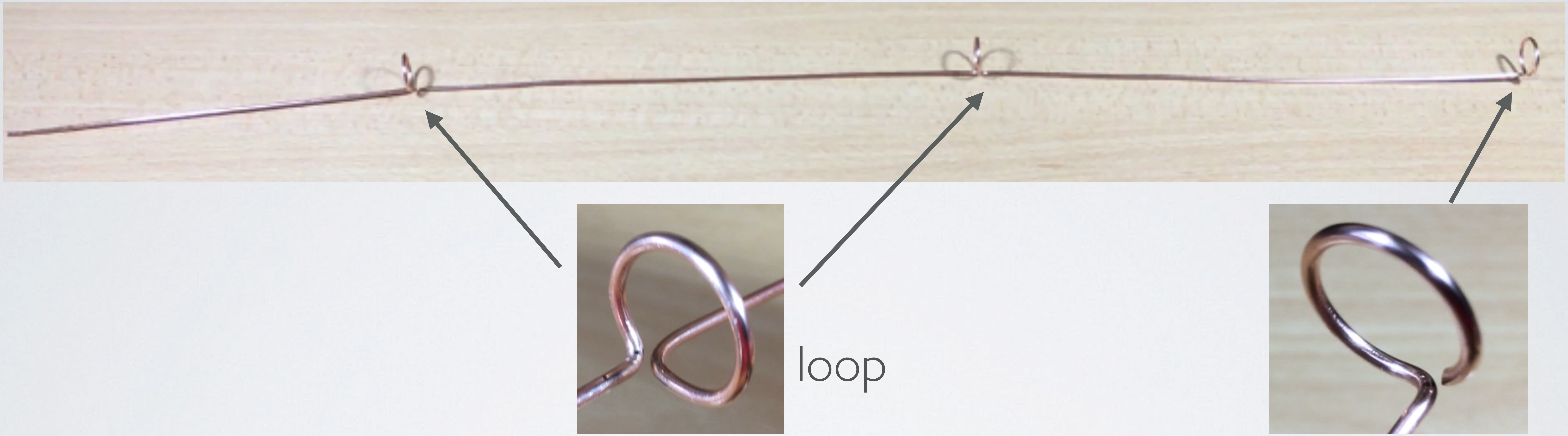
BUILD COLLINEAR ANTENNA 1

- Metal spring washer / cut washer 7.2 x 4.2 x 1.0 mm (outer diameter, inner diameter, thickness)
  Cost: unknown



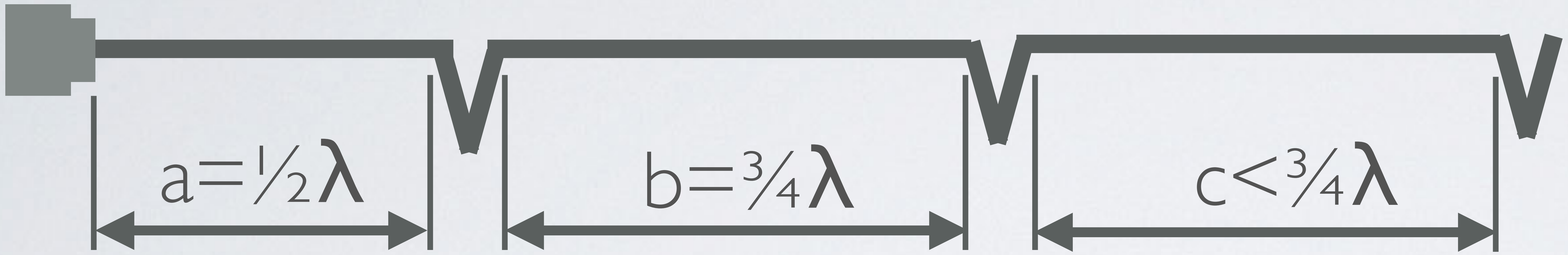


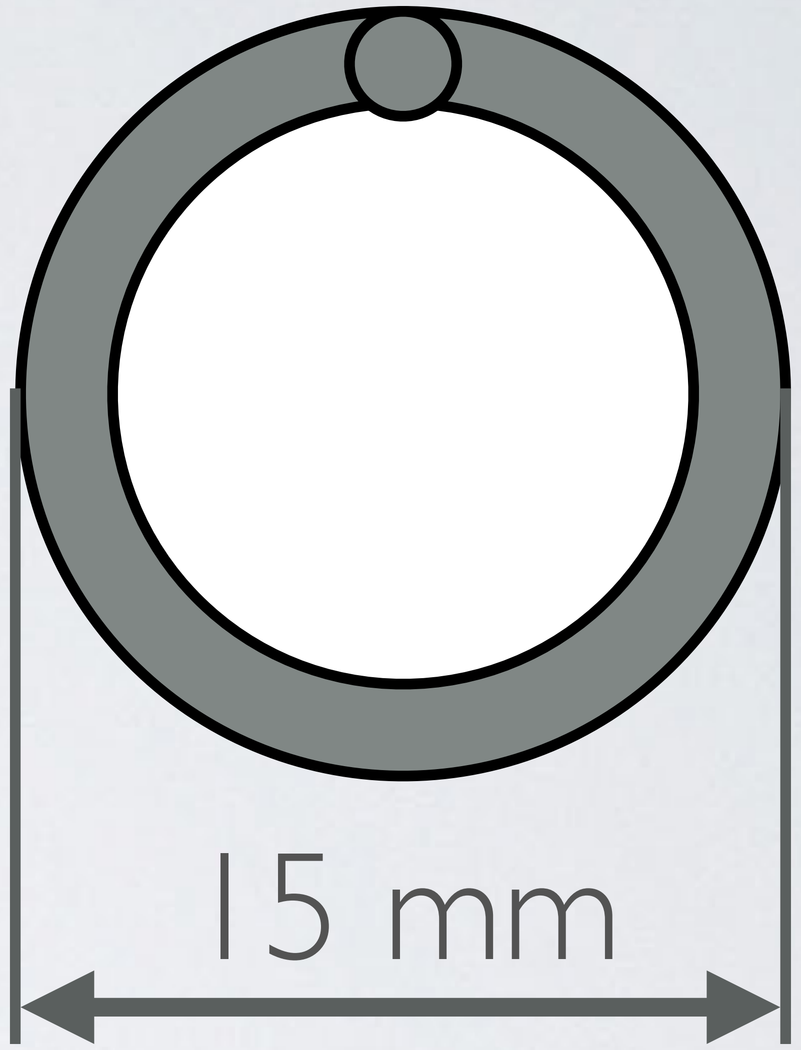
BUILD COLLINEAR ANTENNA 1



The three loops MUST all be wound in the **same** direction (clockwise or anti-clockwise).

BUILD COLLINEAR ANTENNA 1



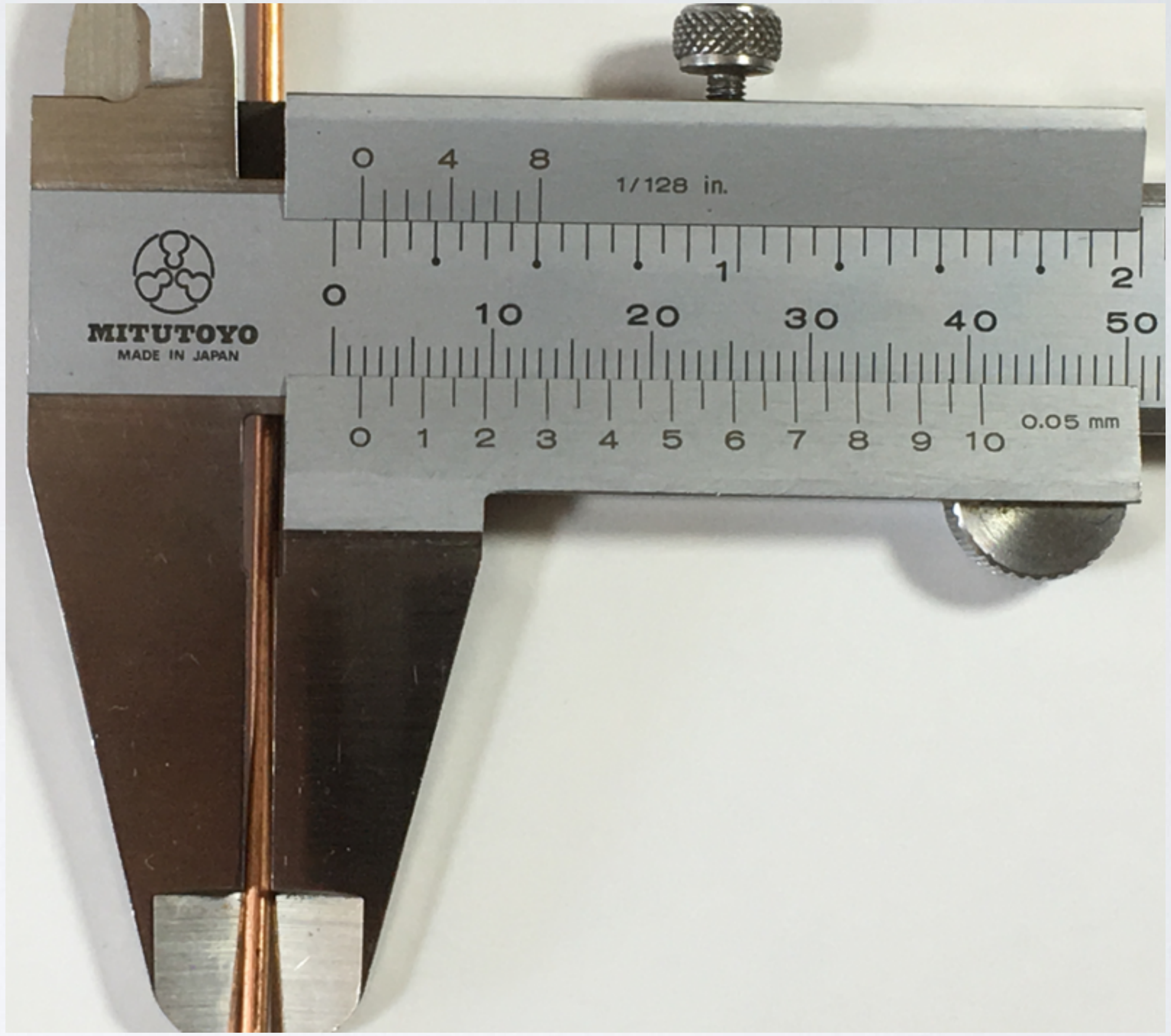


- Frequency (f) = 868 MHz
  $c = \lambda \times f$
  299792458 (m/s) = λ x 868000000 (1/s)
  λ = 0.3453 m = 345 mm

- Length a = ½λ = 173 mm
  Length b = ¾λ = 259 mm
  Length c = ¾λ - (4% x ¾λ) = 249 mm

BUILD COLLINEAR ANTENNA 1

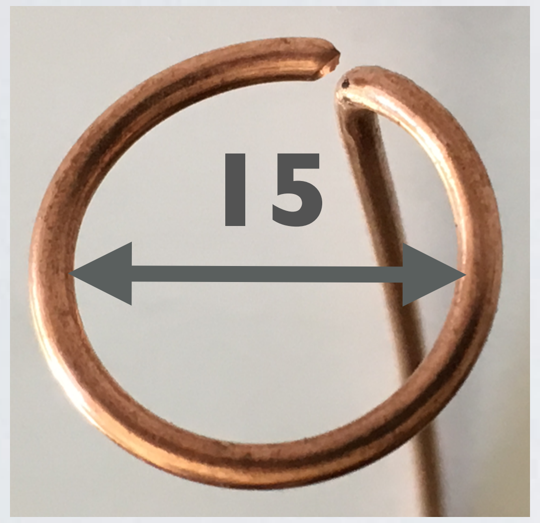
Loop inner diameter = 15.2 mm
According to the design, the outer diameter should be 15 mm, but my outer diameter is 15.2 + 1.8 + 1.8 = 18.8 mm
I will NOT change this!



Copper wire diameter = 1.8 mm

BUILD COLLINEAR ANTENNA 1

- Attention:
  Let's say you have a copper wire with a diameter of 1.8 mm and you want to create a loop with an inner diameter of 15 mm.



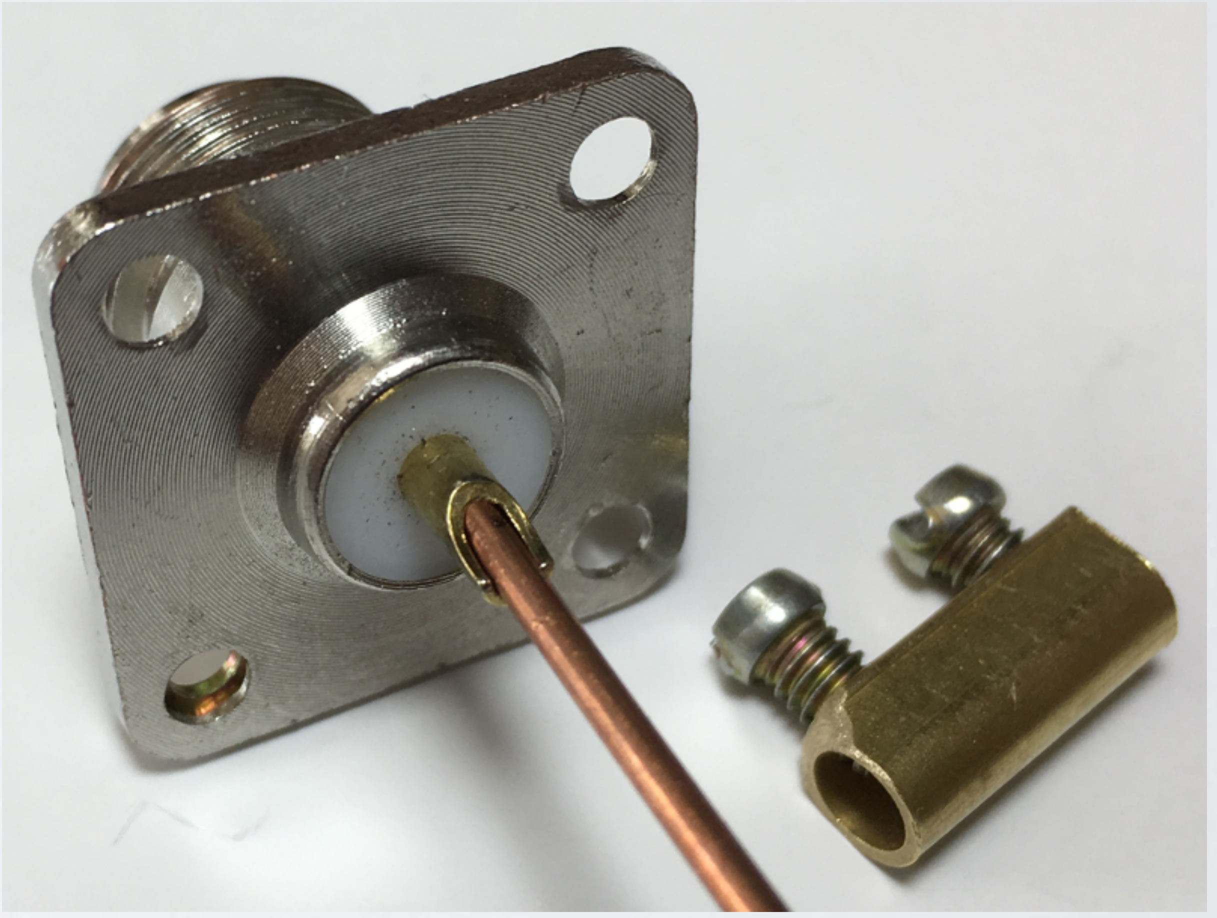
- If you use a cylinder with an outside diameter of 15 mm and you wrap a wire around this cylinder, you will not make a loop with an inside diameter of 15 mm.

- The copper wire "expands" a little bit. You need a cylinder with an outer diameter slightly smaller than 15 mm. You need to experiment with different cylinder sizes.

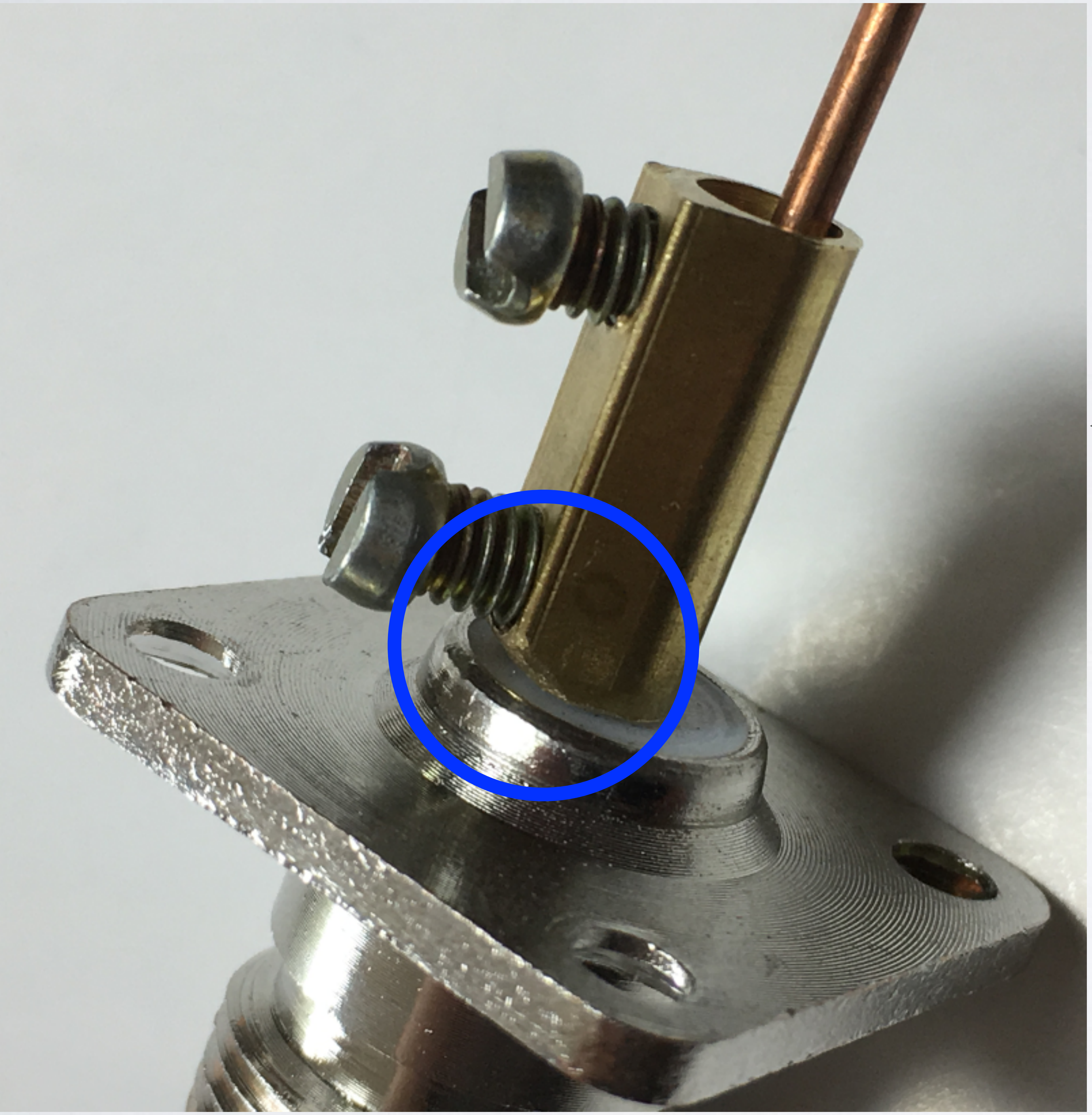
BUILD COLLINEAR ANTENNA 1

- The collinear antenna will be attached to type N female chassis mount 4-hole connector using a terminal.

- But first I have to round the edges of this terminal using a Dremel tool.

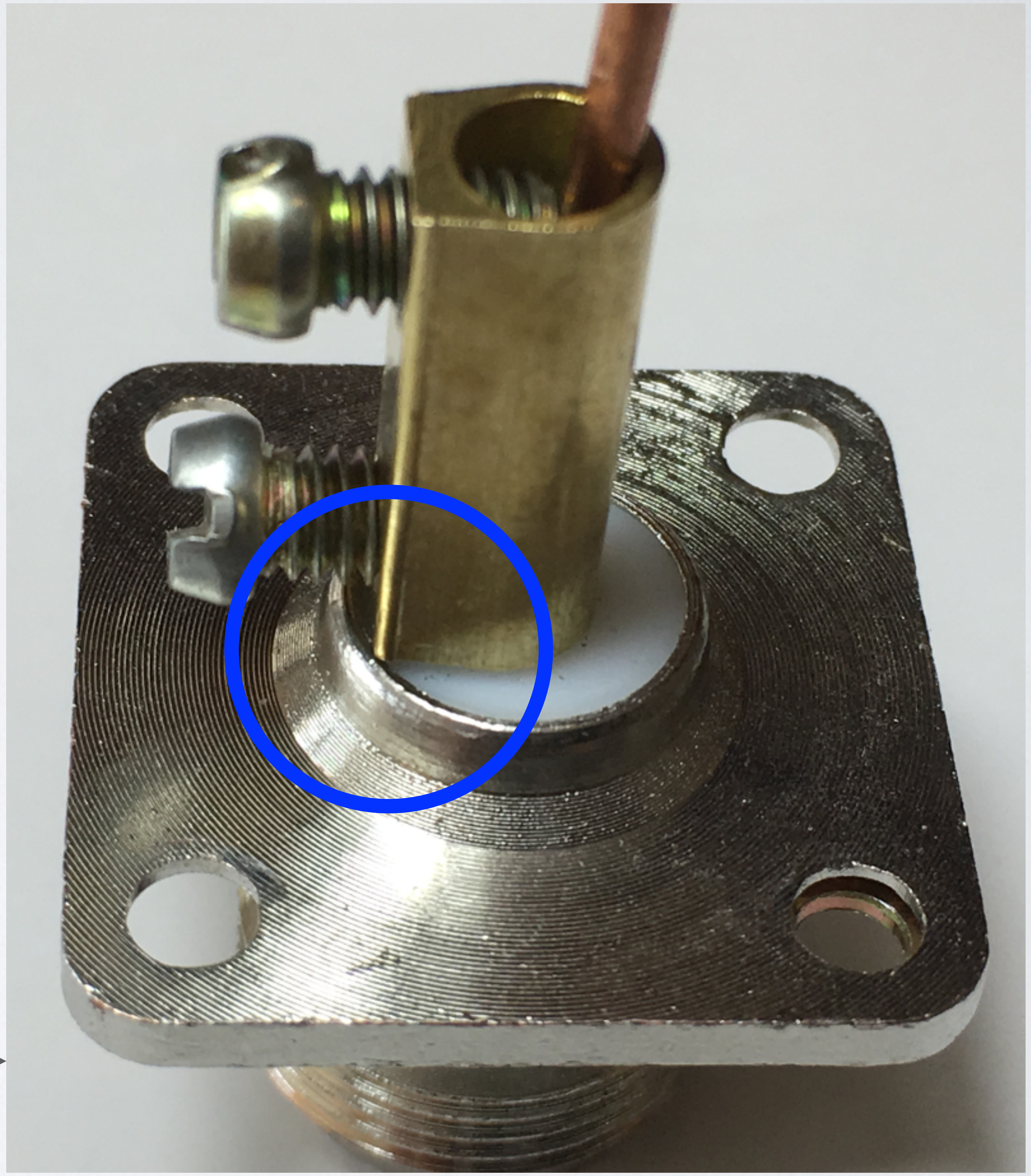


BUILD COLLINEAR ANTENNA 1



Rounded, terminal block does not touch type N chassis.

Not rounded, terminal block does touch type N chassis.



MEASURING COLLINEAR ANTENNA | PARAMETERS

- I have used the N1201SA antenna analyser to measure the antenna parameters.

- Unfortunately the measured VSWR, Z and S11 antenna parameters are not great.

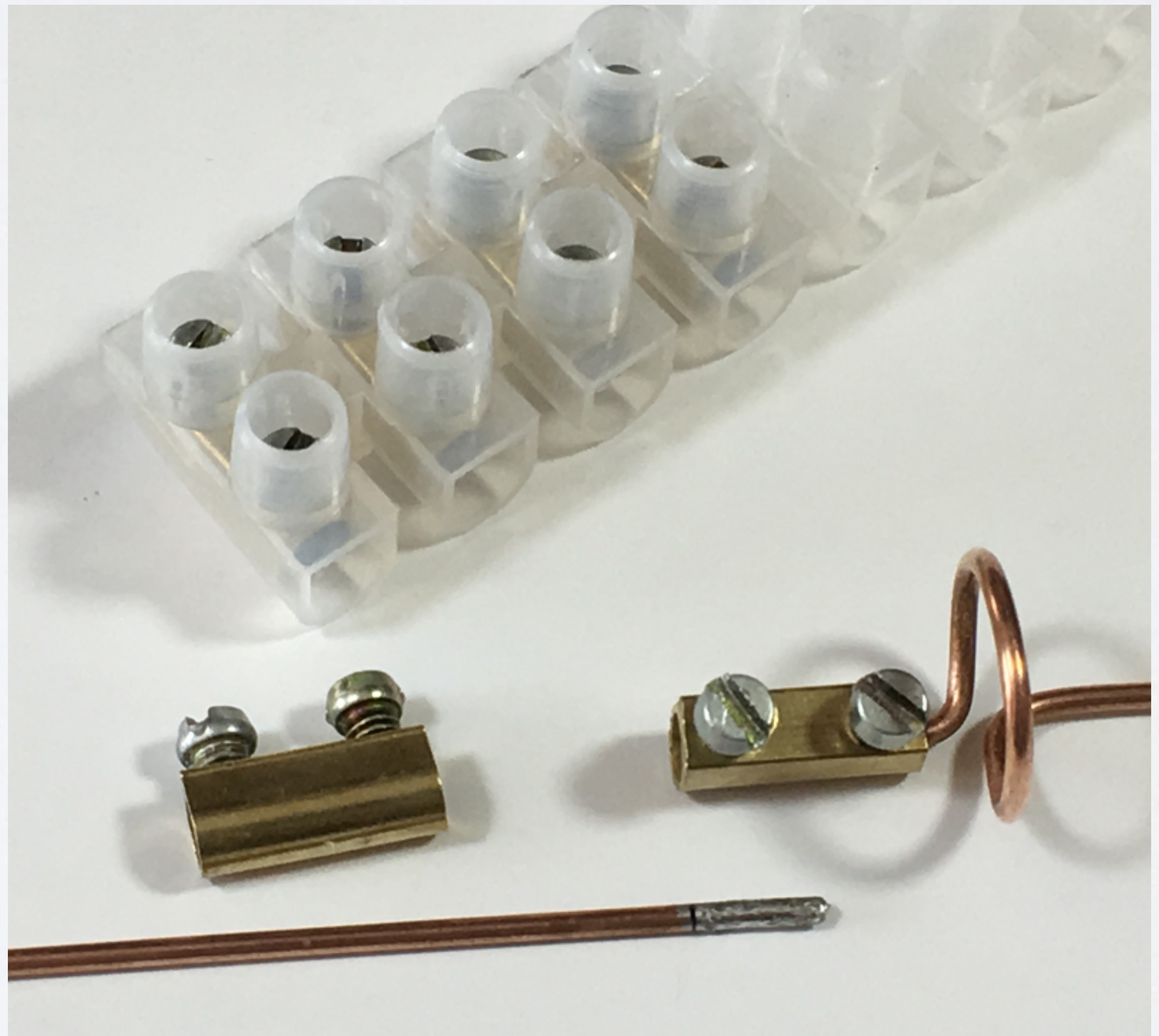
- **The VSWR is greater than 6.**

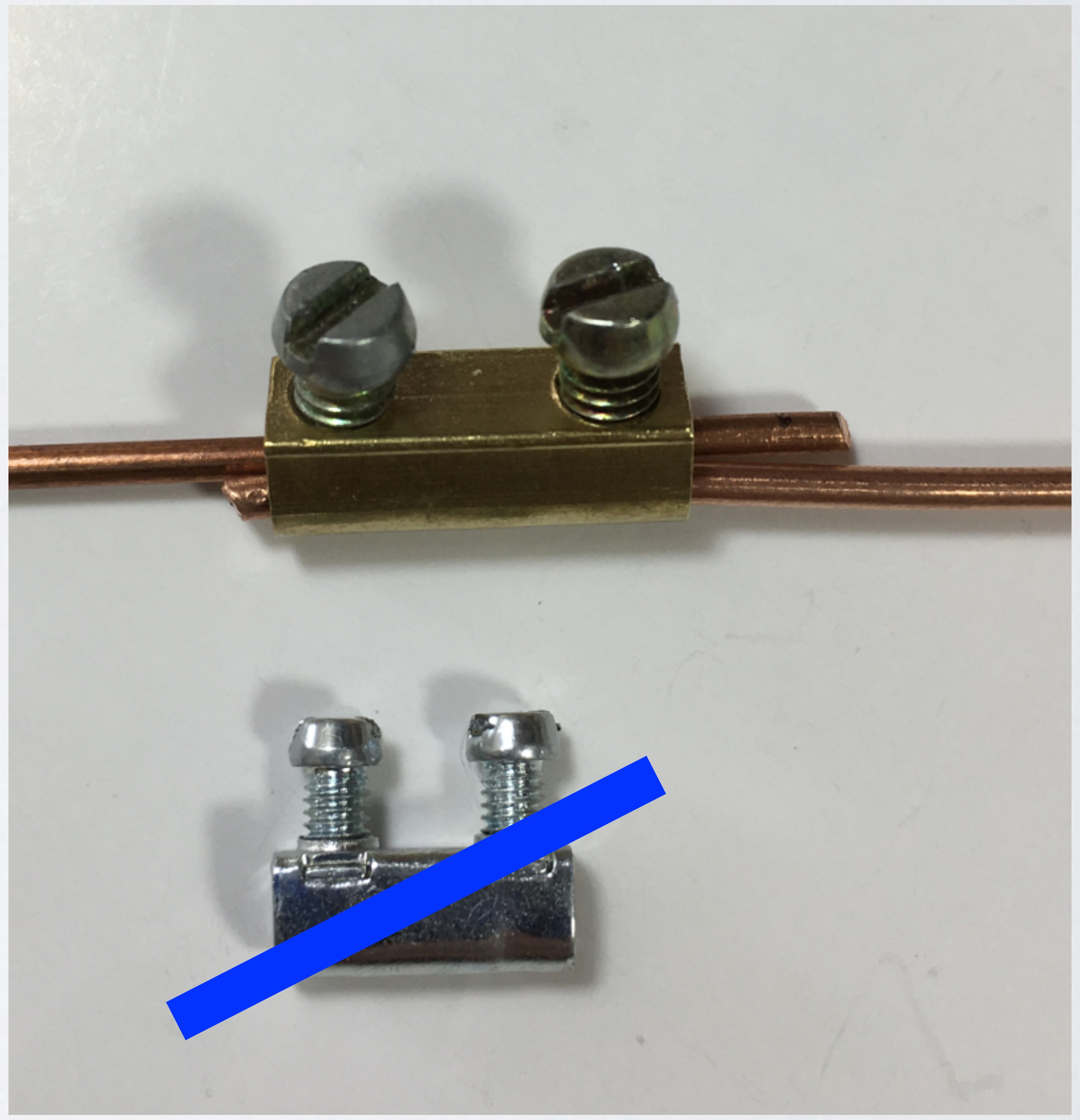
- To lower the VSWR I made some modifications to the antenna design.

COLLINEAR ANTENNA I DESIGN MODIFICATIONS

- I cut the antenna at two places…

- …and I used two terminals to connect the antenna parts and to adjust the lengths.



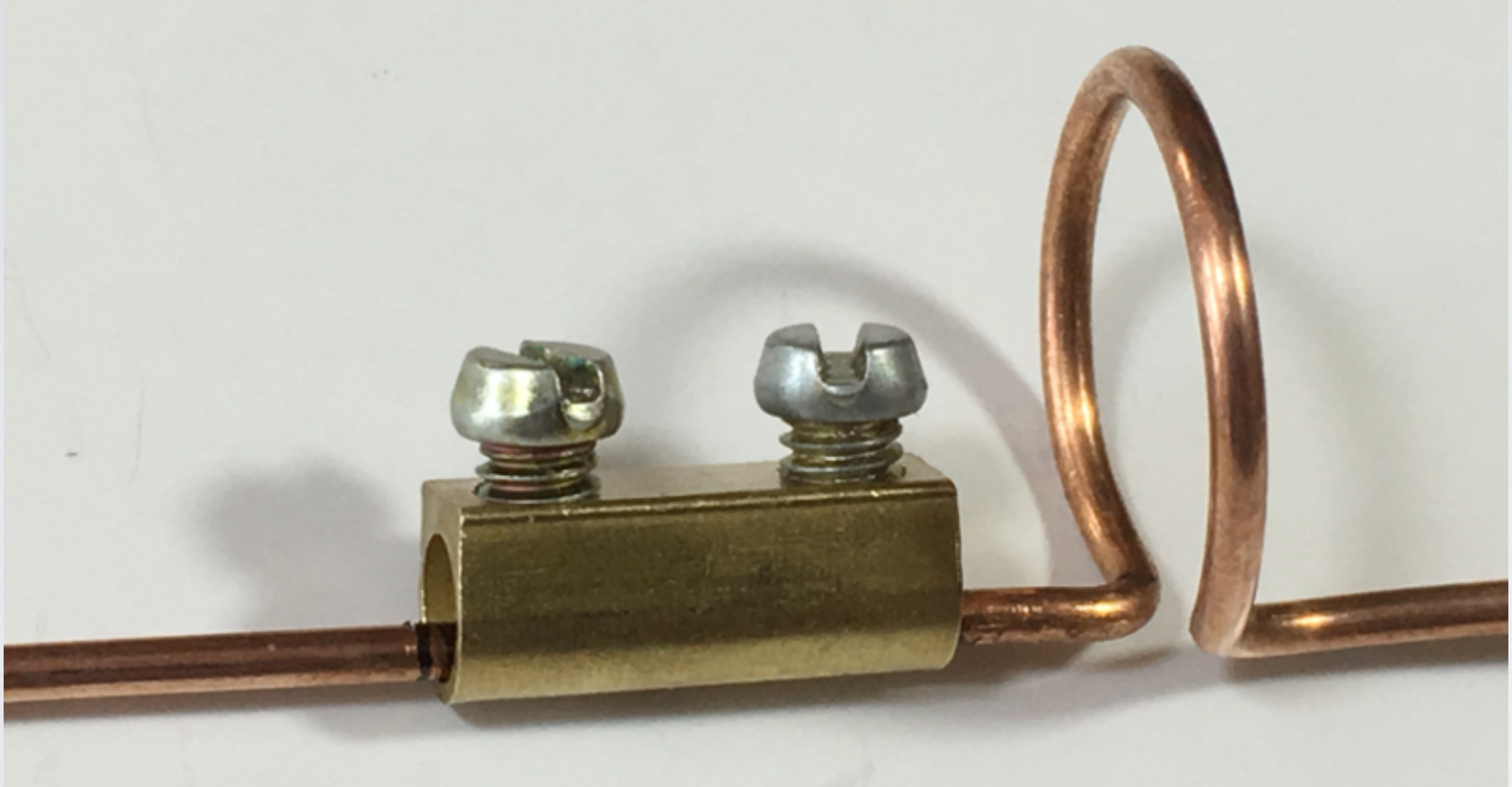


COLLINEAR ANTENNA | DESIGN MODIFICATIONS

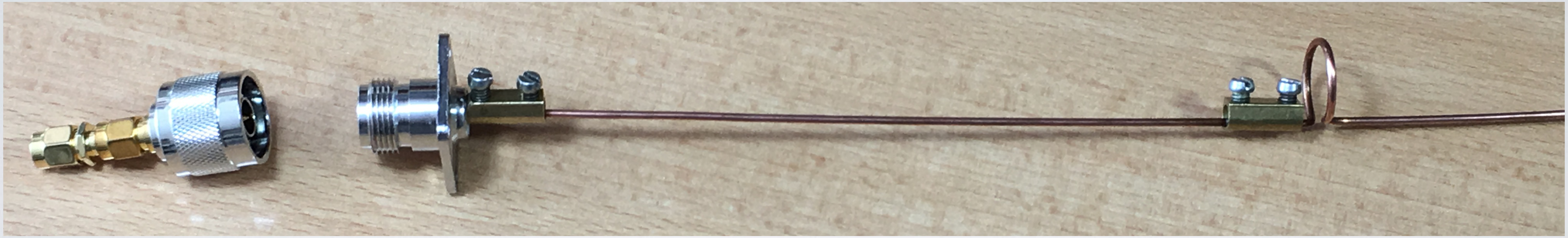
- **ATTENTION:**
  It is NOT recommended to cut your antenna and use terminals to tune your antenna. I have done this as an experiment.

- **Using terminals will alter the antenna radiation pattern.**
  PLEASE DO NOT DO THIS!

COLLINEAR ANTENNA | DESIGN MODIFICATIONS



COLLINEAR ANTENNA | DESIGN MODIFICATIONS



MEASURING COLLINEAR ANTENNA 1 PARAMETERS

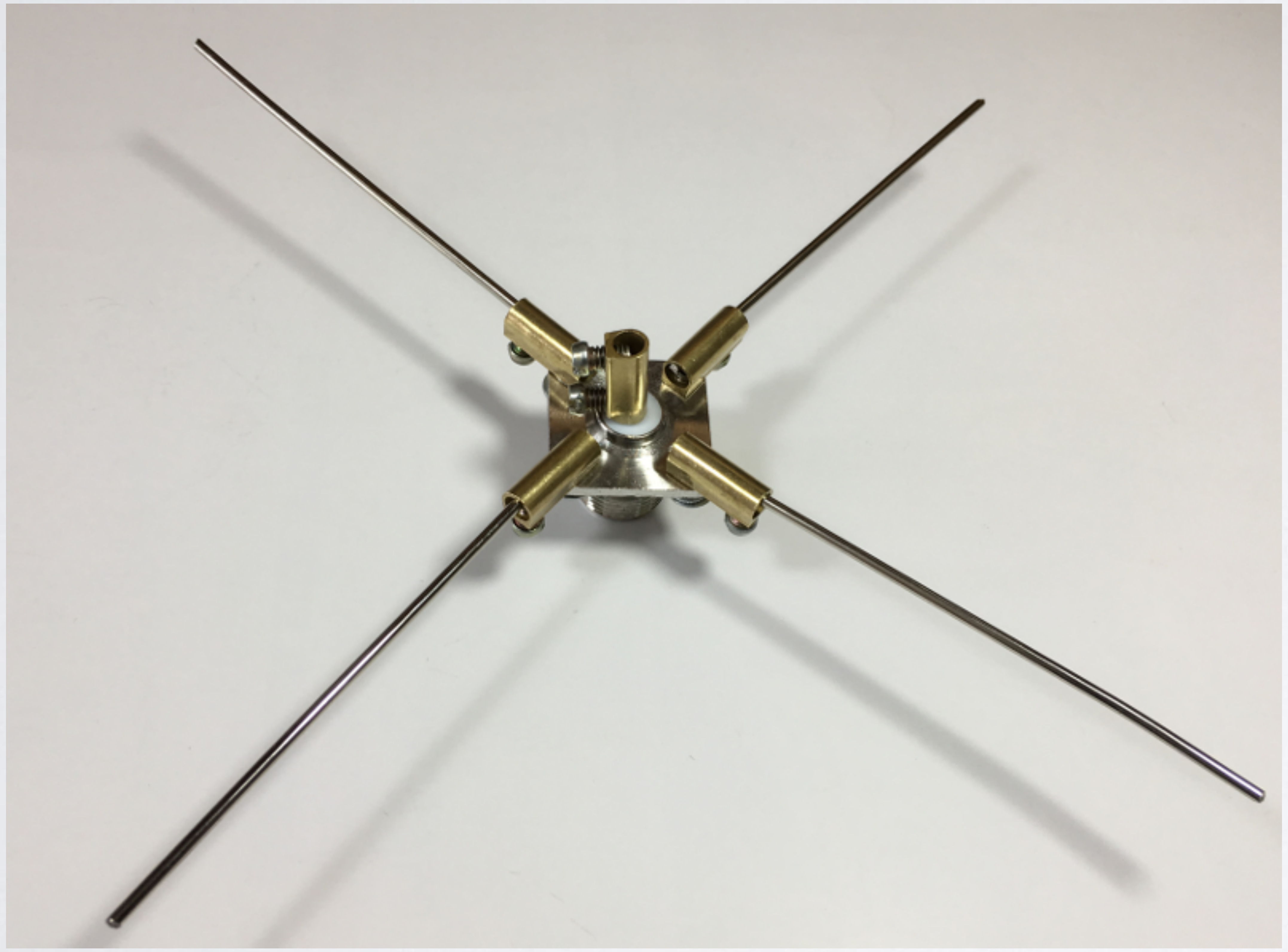
- The lengths are adjusted and the antenna parameters are measured using the N1201SA Antenna Analyser.

- The VSWR is slightly improved, it is now 5 but this is still bad.

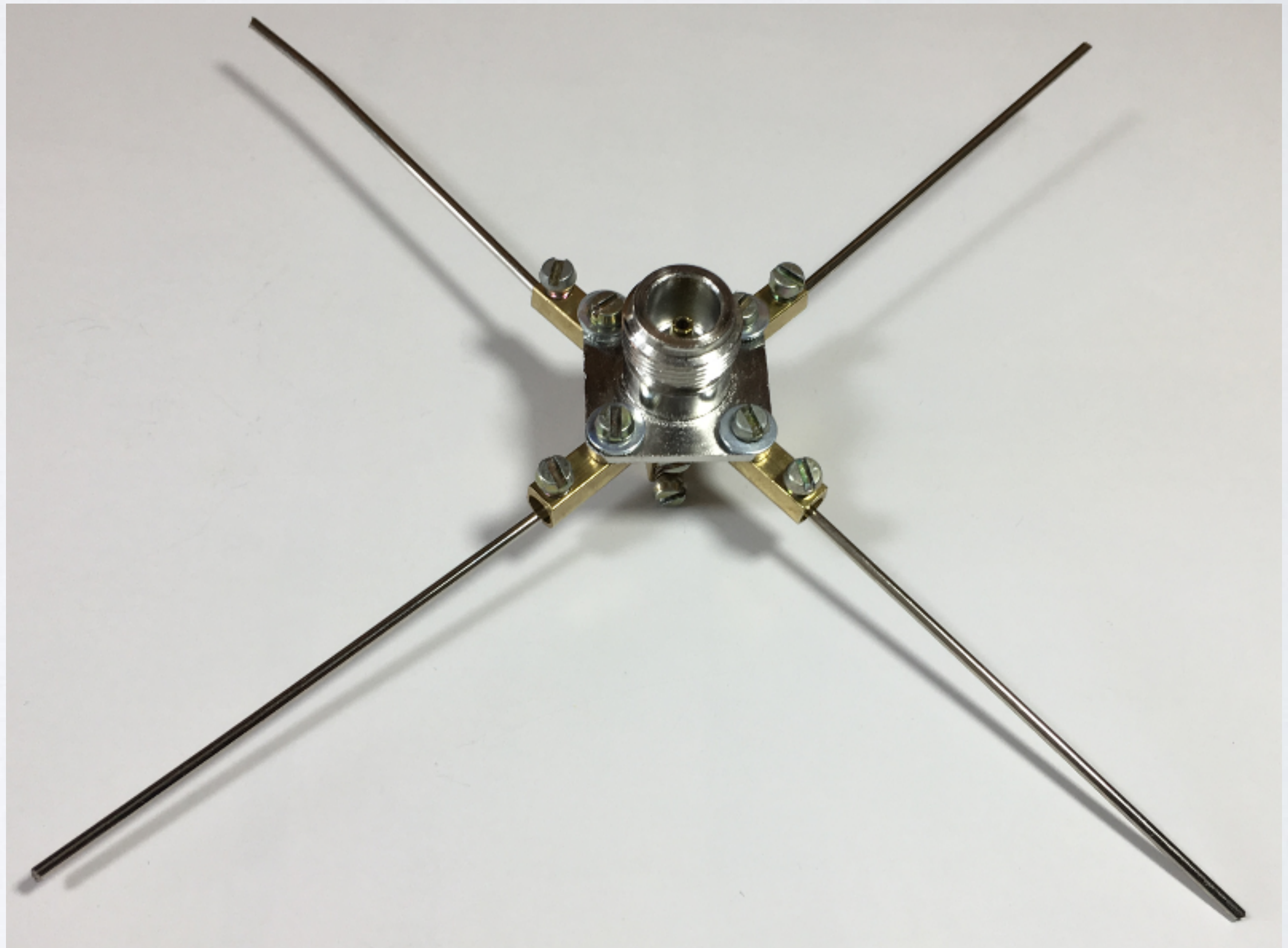
COLLINEAR ANTENNA 1 WITH RADIALS

- In an attempt to lower the VSWR, four stainless steel radials (L=90 mm) are attached to the type N female chassis mount 4-hole connector. The radials are not bend.

top view

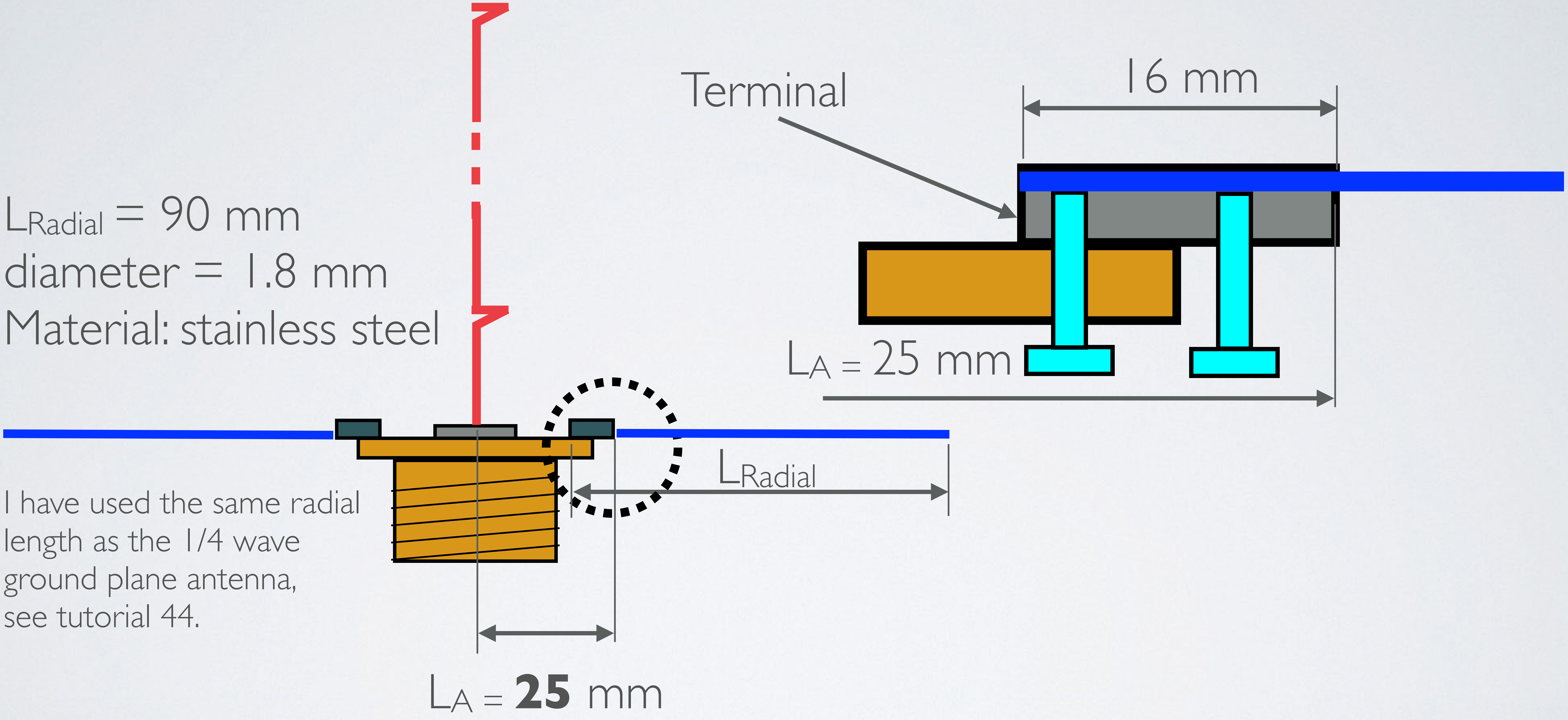


bottom view



COLLINEAR ANTENNA 1 WITH RADIALS

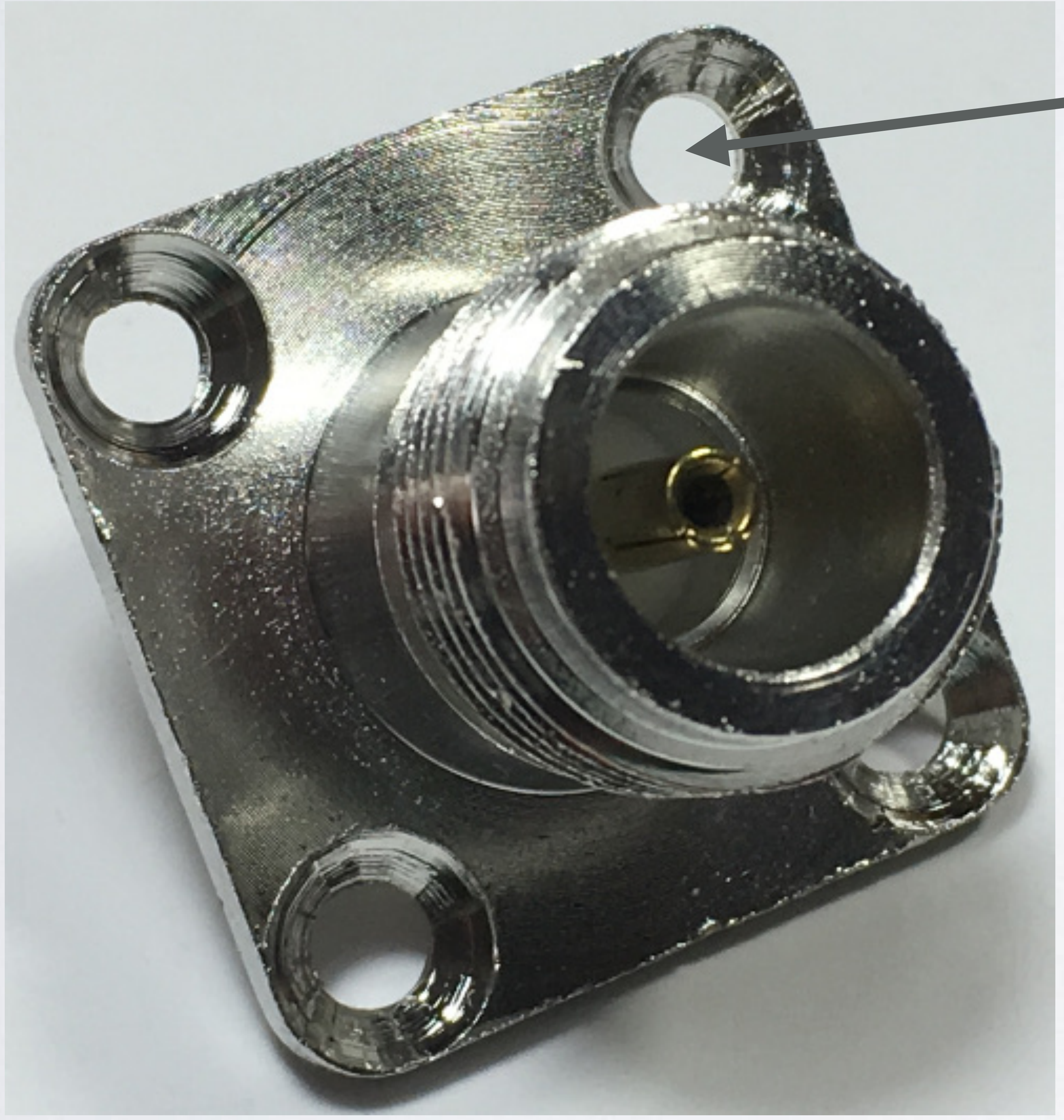
L_{Radial} = 90 mm
diameter = 1.8 mm
Material: stainless steel



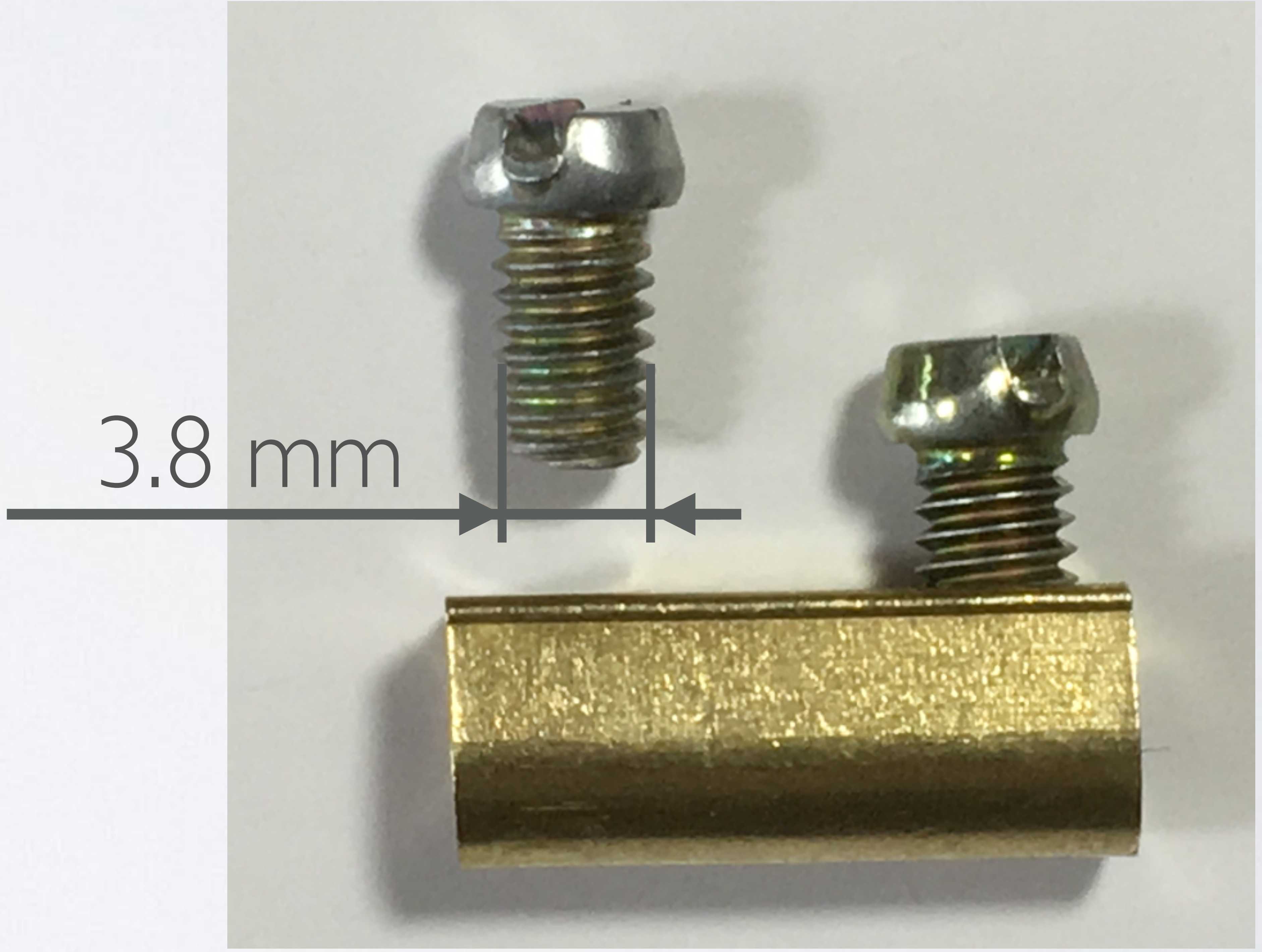
I have used the same radial length as the 1/4 wave ground plane antenna, see tutorial 44.

COLLINEAR ANTENNA 1 WITH RADIALS

- The type N female chassis mount has 4-holes each with a diameter of 3.5 mm.
- Increase the hole size to 4 mm because the terminal screw diameter is 3.8 mm.



Make the hole diameter 4 mm

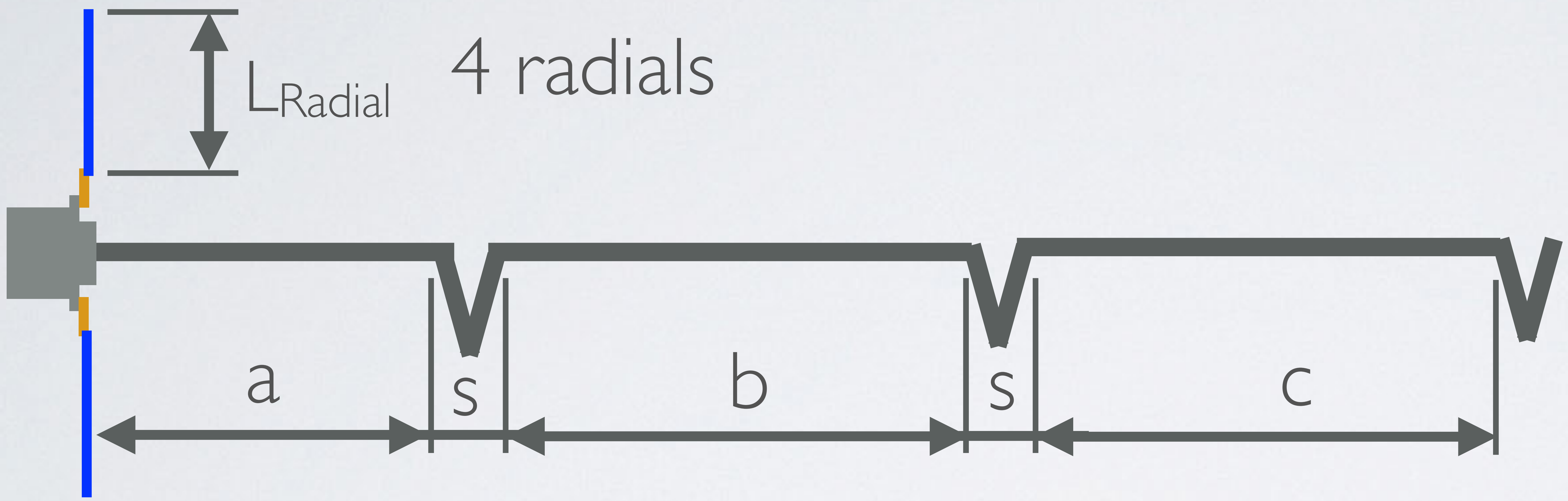


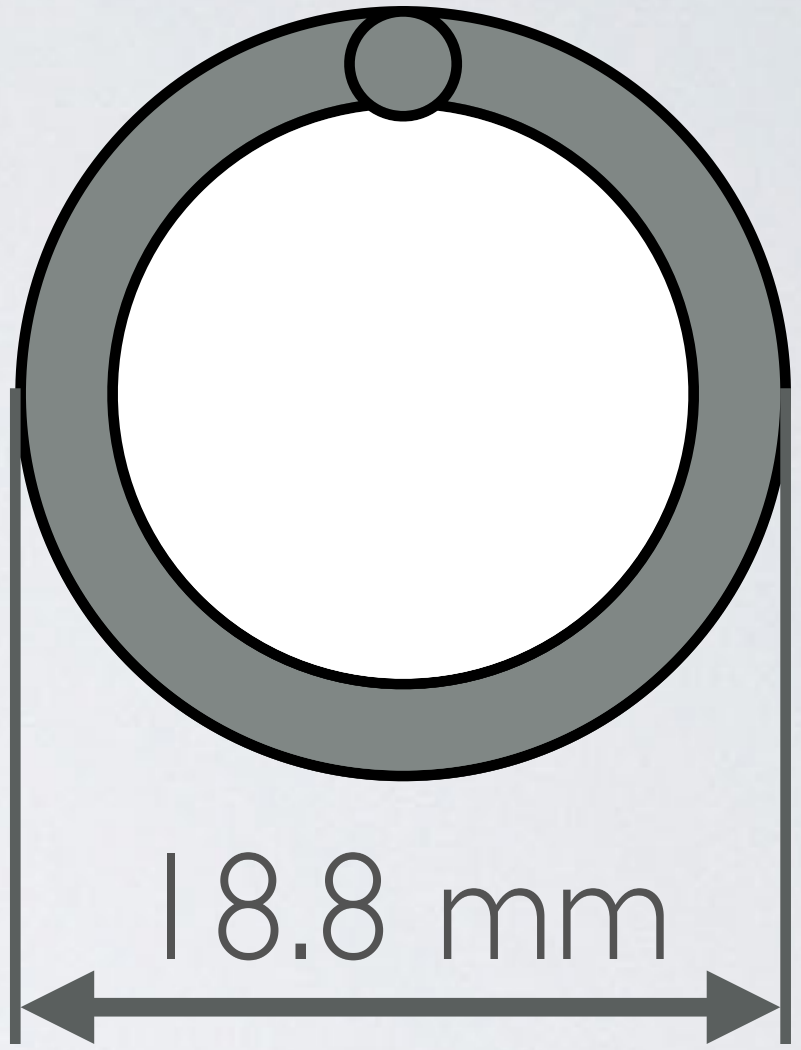
COLLINEAR ANTENNA 1 WITH RADIALS

- For the radials, I have used the stainless steel wires (called ribs) from an old umbrella because I wanted the radials to be more rigid.

Note:
Use a multimeter and verify if the wires measures 0 Ω.

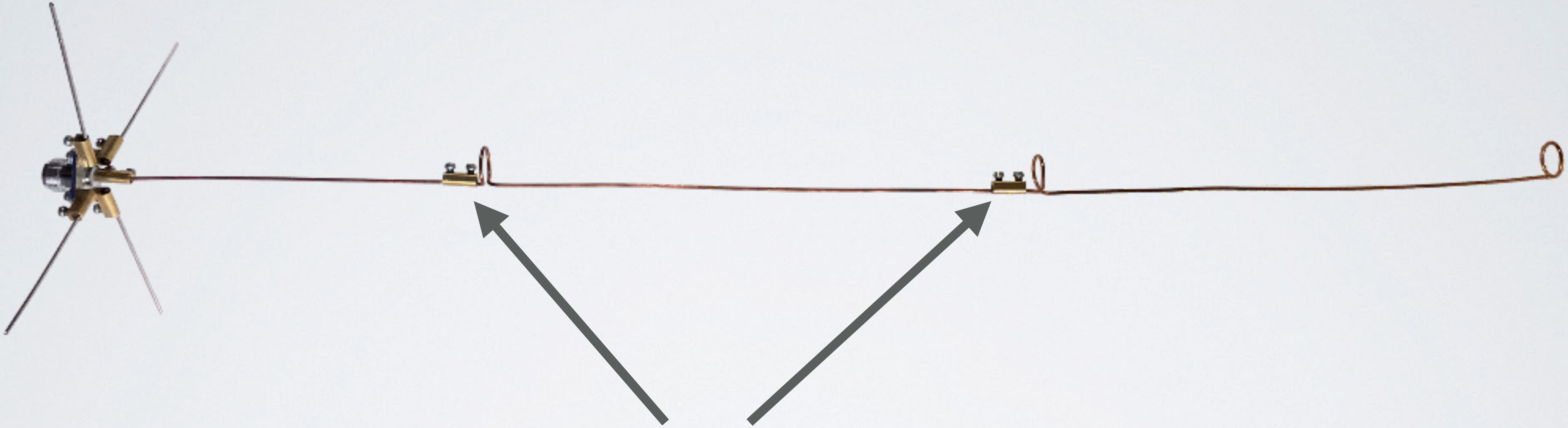
COLLINEAR ANTENNA | FINAL DESIGN





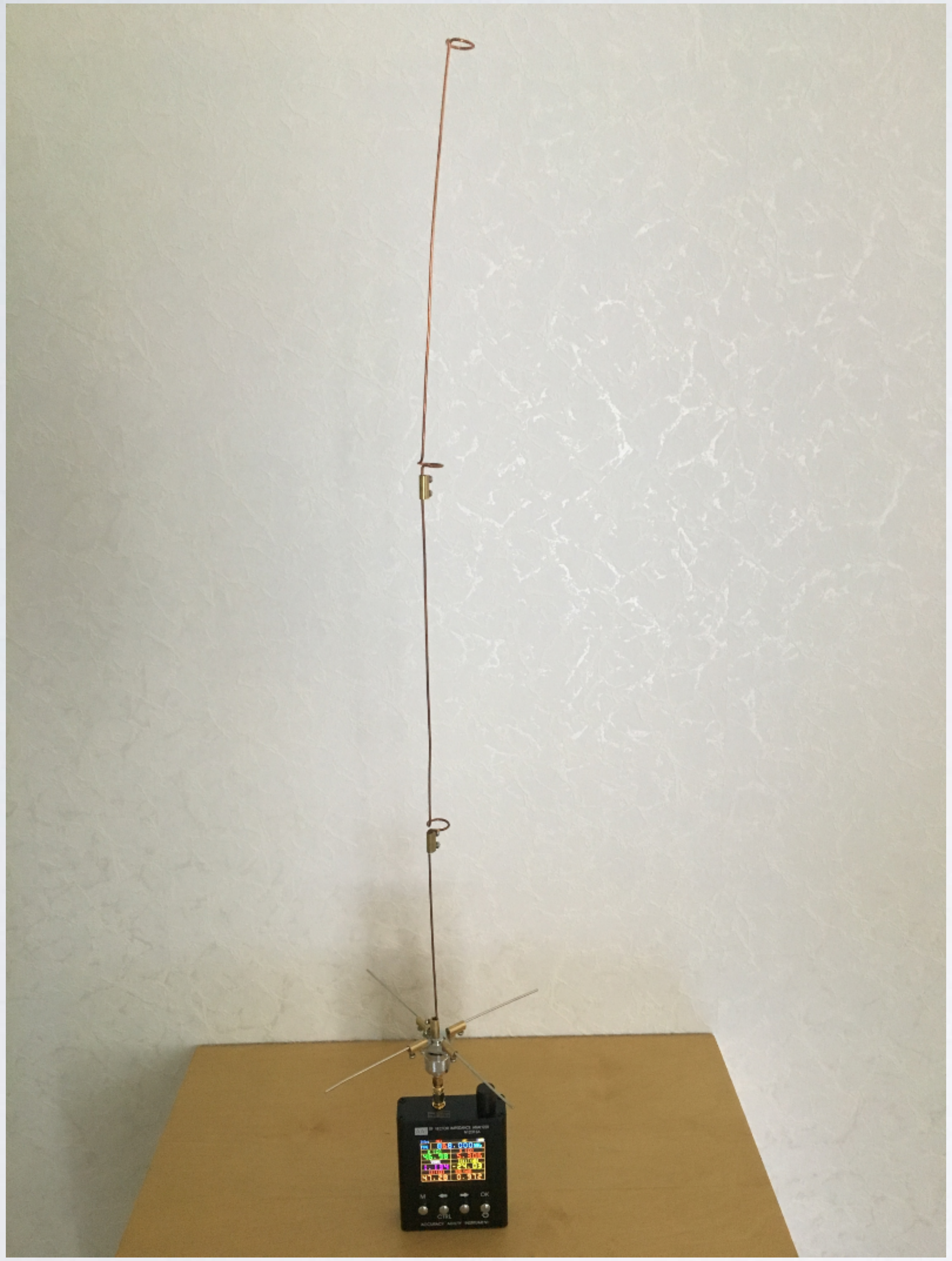
- Length a = 175 (Original design 173 mm)
  Length b = 259 (Original design 259 mm)
  Length c = 249 (Original design 249 mm)
  Spacing s = 2.8 mm
  L_{Radial} = 90 mm
  diameter = 1.8 mm (radiator & radials)
  Material = copper (radiator), stainless steel (radials)

COLLINEAR ANTENNA | FINAL DESIGN



It is NOT a good idea to cut your antenna and use terminals. I have done this as an experiment!

COLLINEAR ANTENNA I FINAL DESIGN

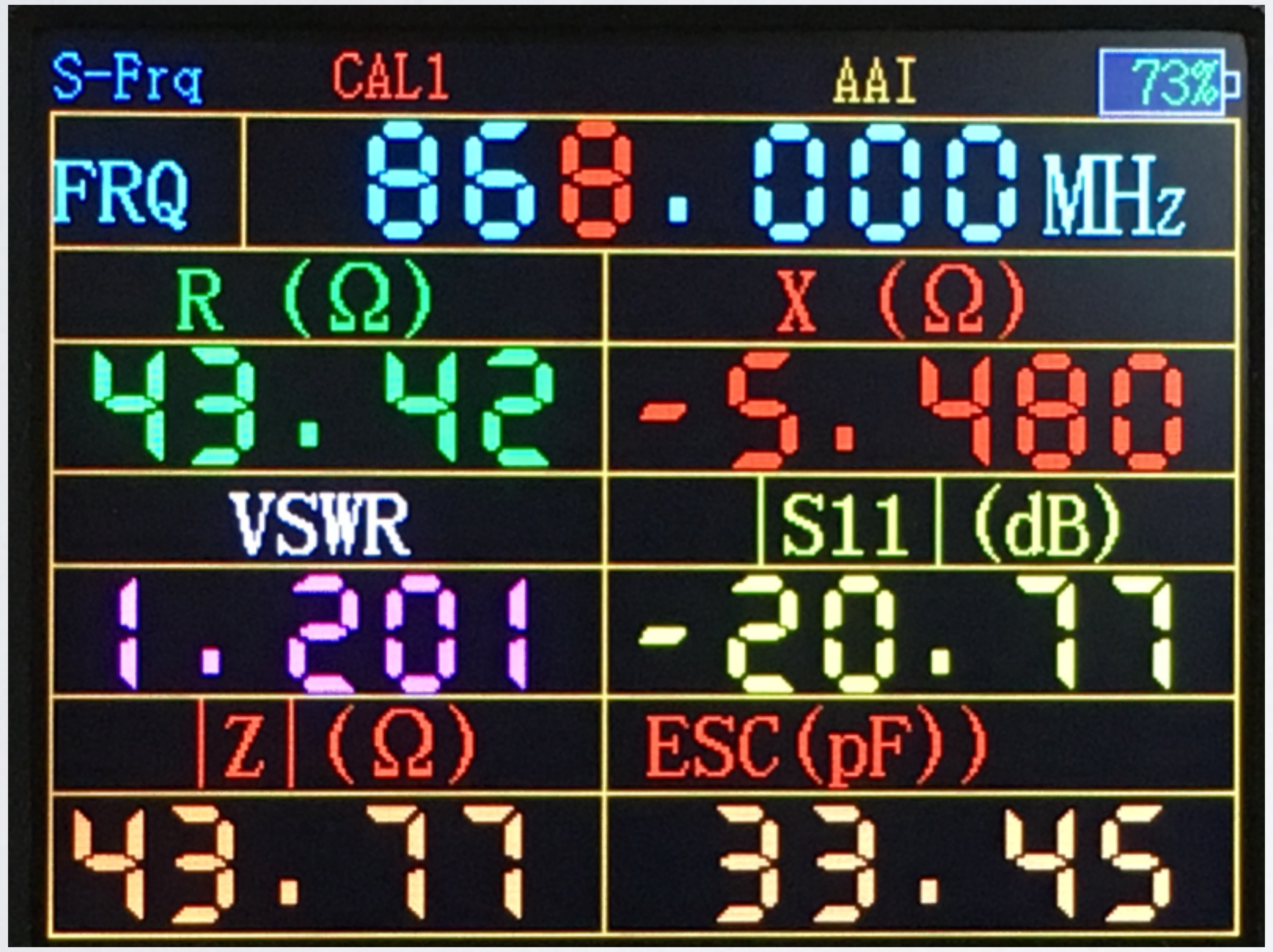


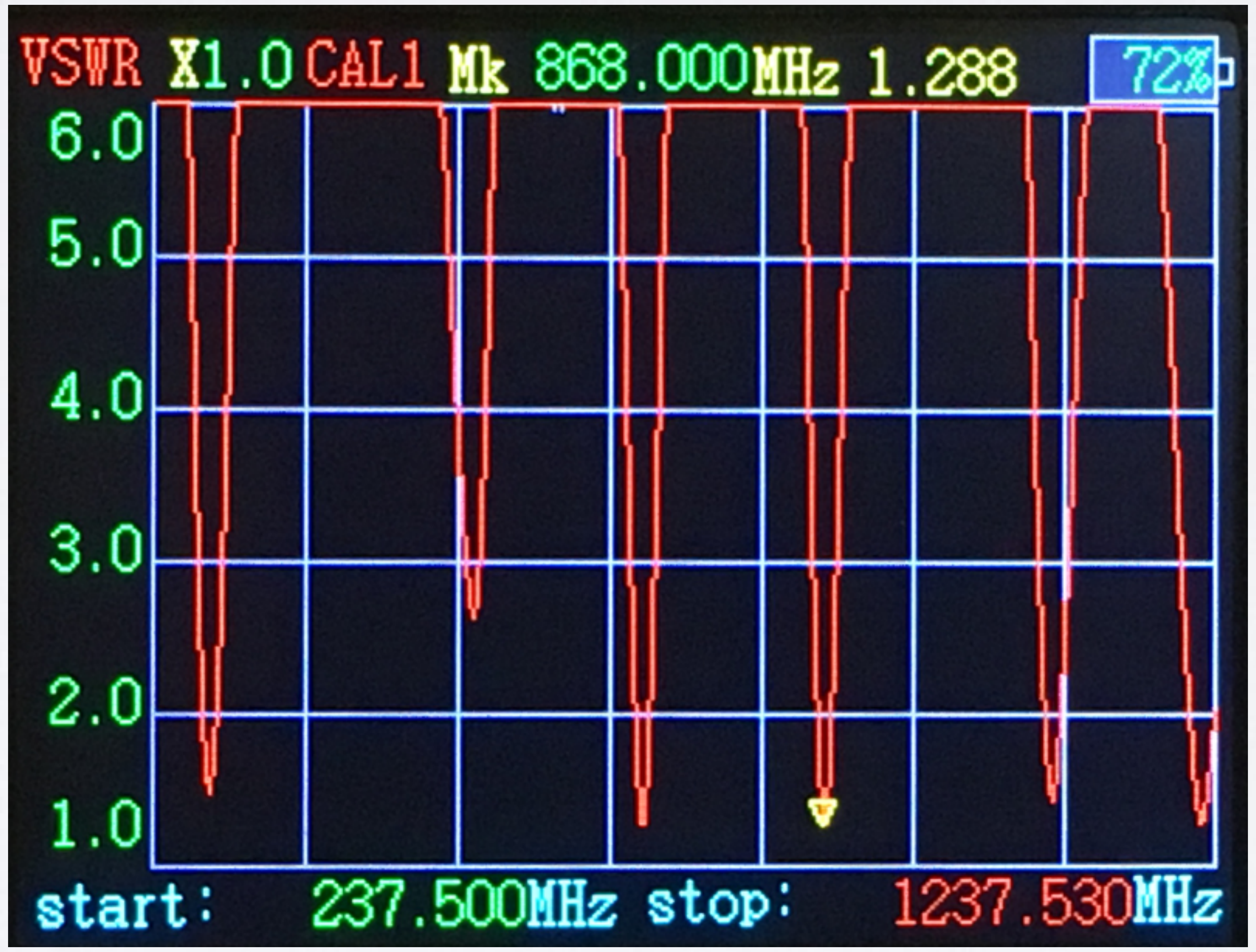
The antenna analyser with the collinear antenna and radials (= ground plane).

Measuring antenna parameters

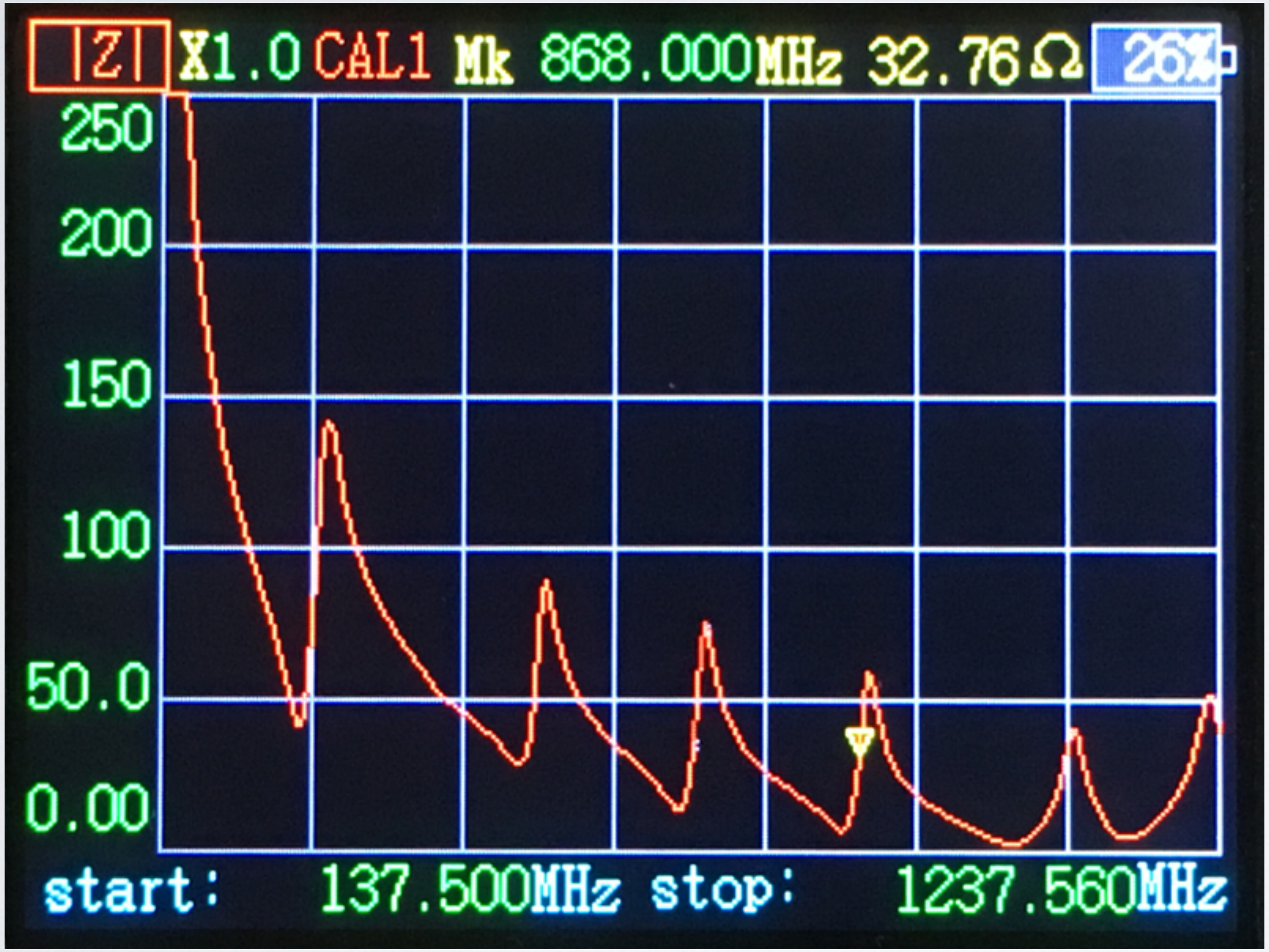
MEASURED ANTENNA PARAMETERS

- Based on the collinear antenna 1 final design (see previous slide) and using 4 radials:
  VSWR ≈ 1.2 ← Good. It is < 2
  Z ≈ 44Ω ← Good. Should be approx. 50Ω
  S11 ≈ -21 dB





MEASURED ANTENNA PARAMETERS

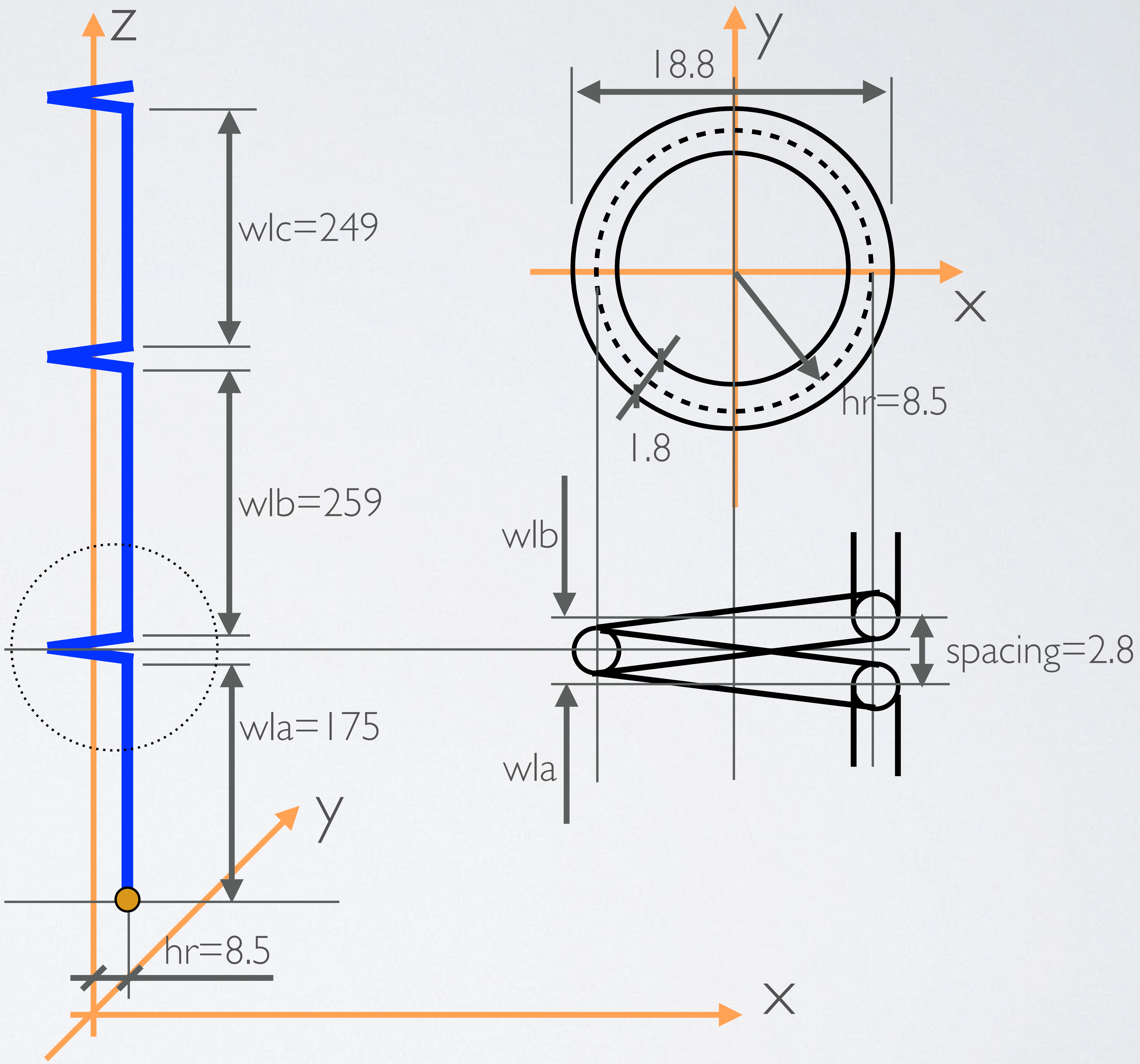


ANTENNA MODELLING NEC-2

- **collinear antenna 1**
  f = 868 MHz

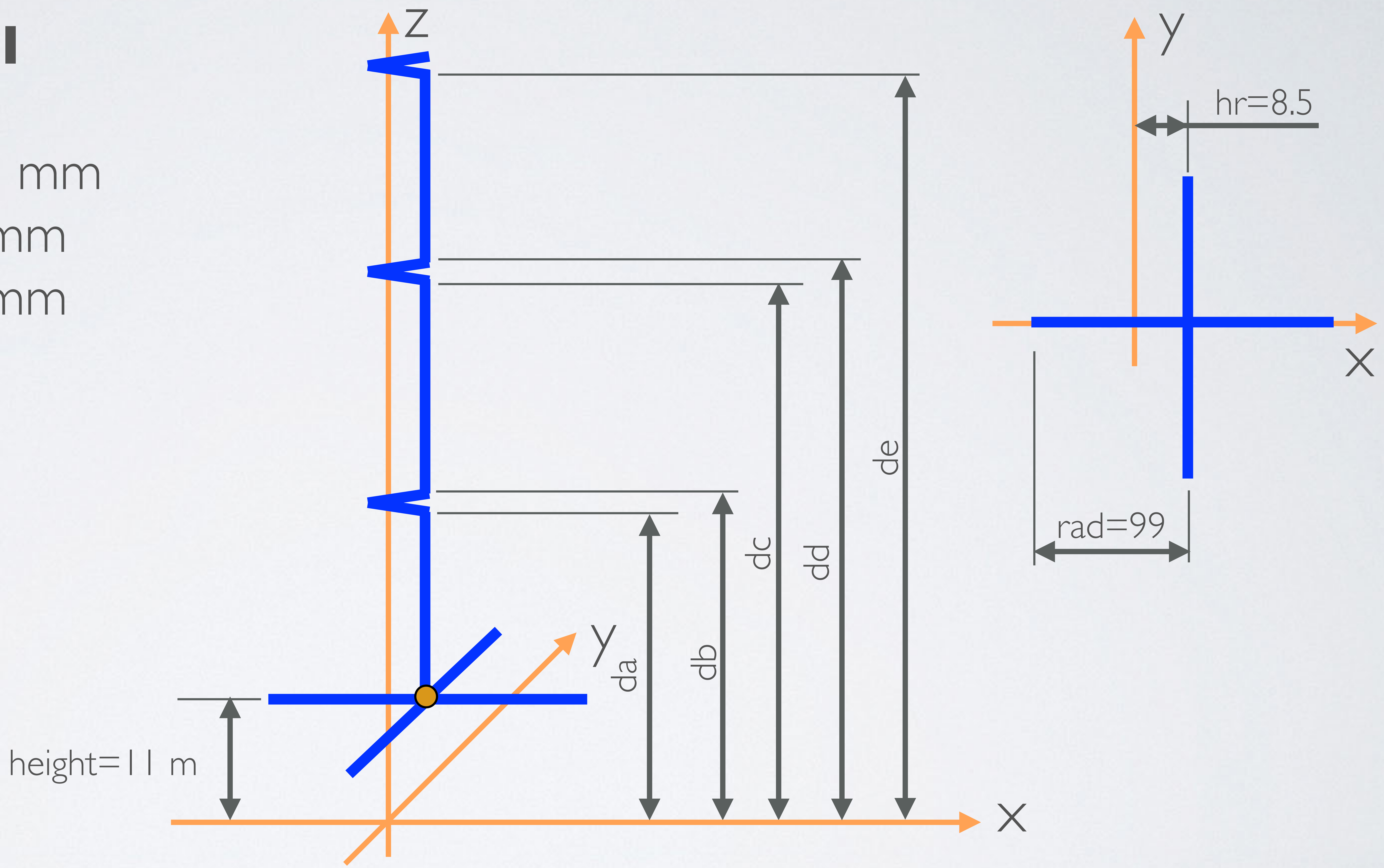
  Material antenna: copper
  Material radials: stainless steel

  All units in mm
  Drawing not to scale

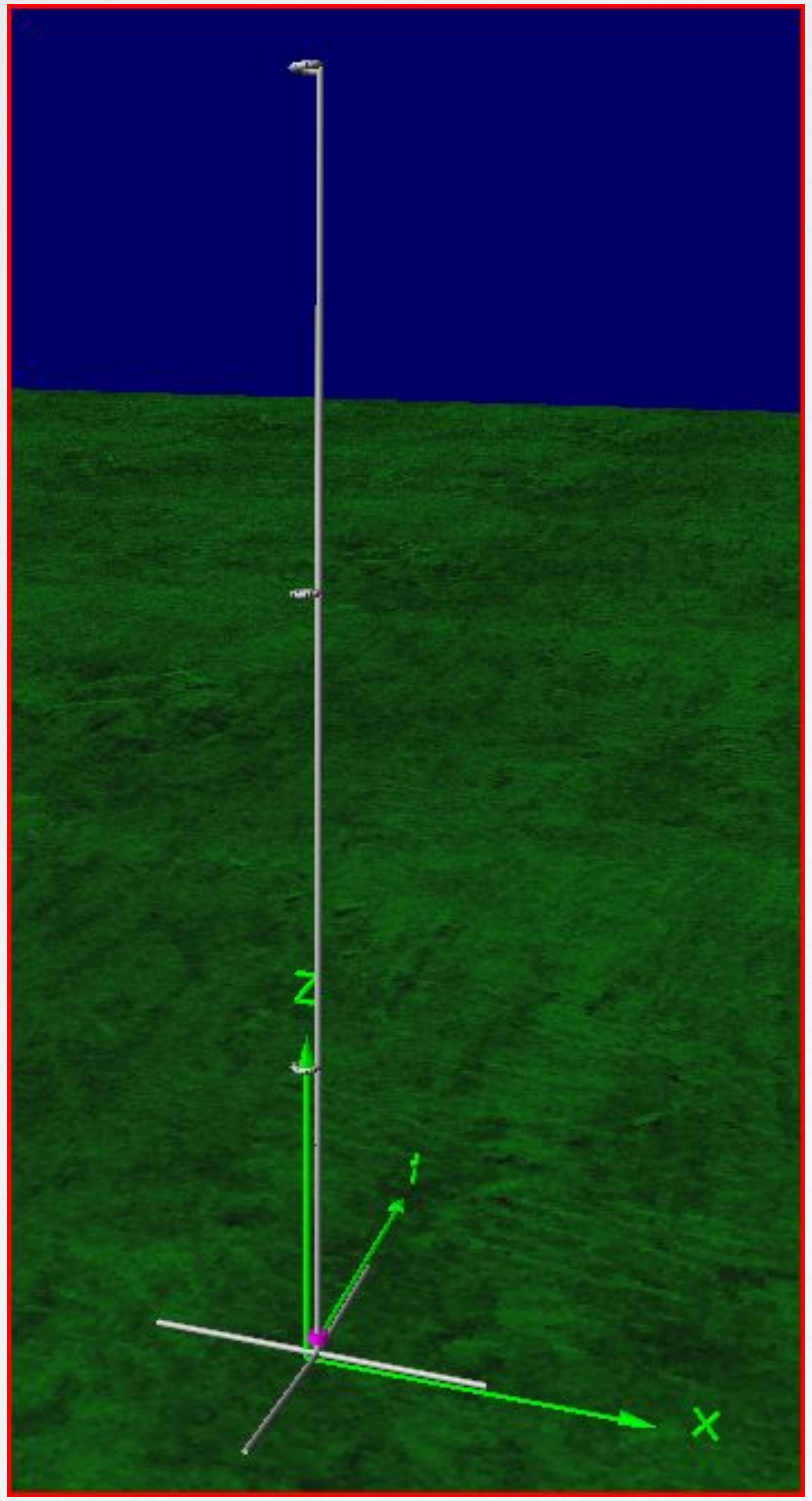


ANTENNA MODELLING NEC-2

- **collinear antenna 1**
  f = 868 MHz
  radiator diameter = 1.8 mm
  radials diameter = 1.8 mm
  radials length rad= 99 mm
  da = height+wla
  db = da+spacing
  dc = db+wlb
  dd = dc+spacing
  de = dd+wlc
  All units in mm
  Drawing not to scale

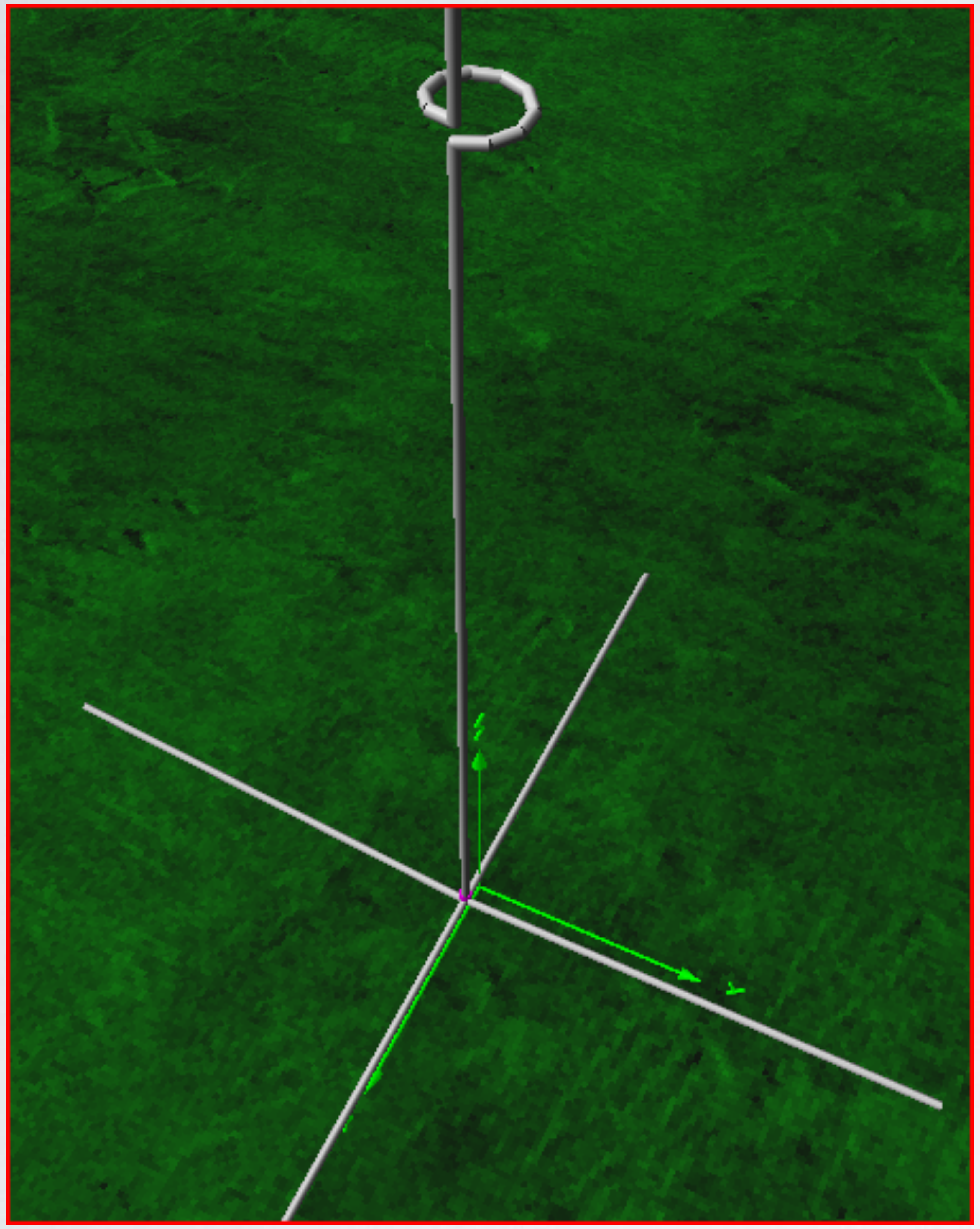


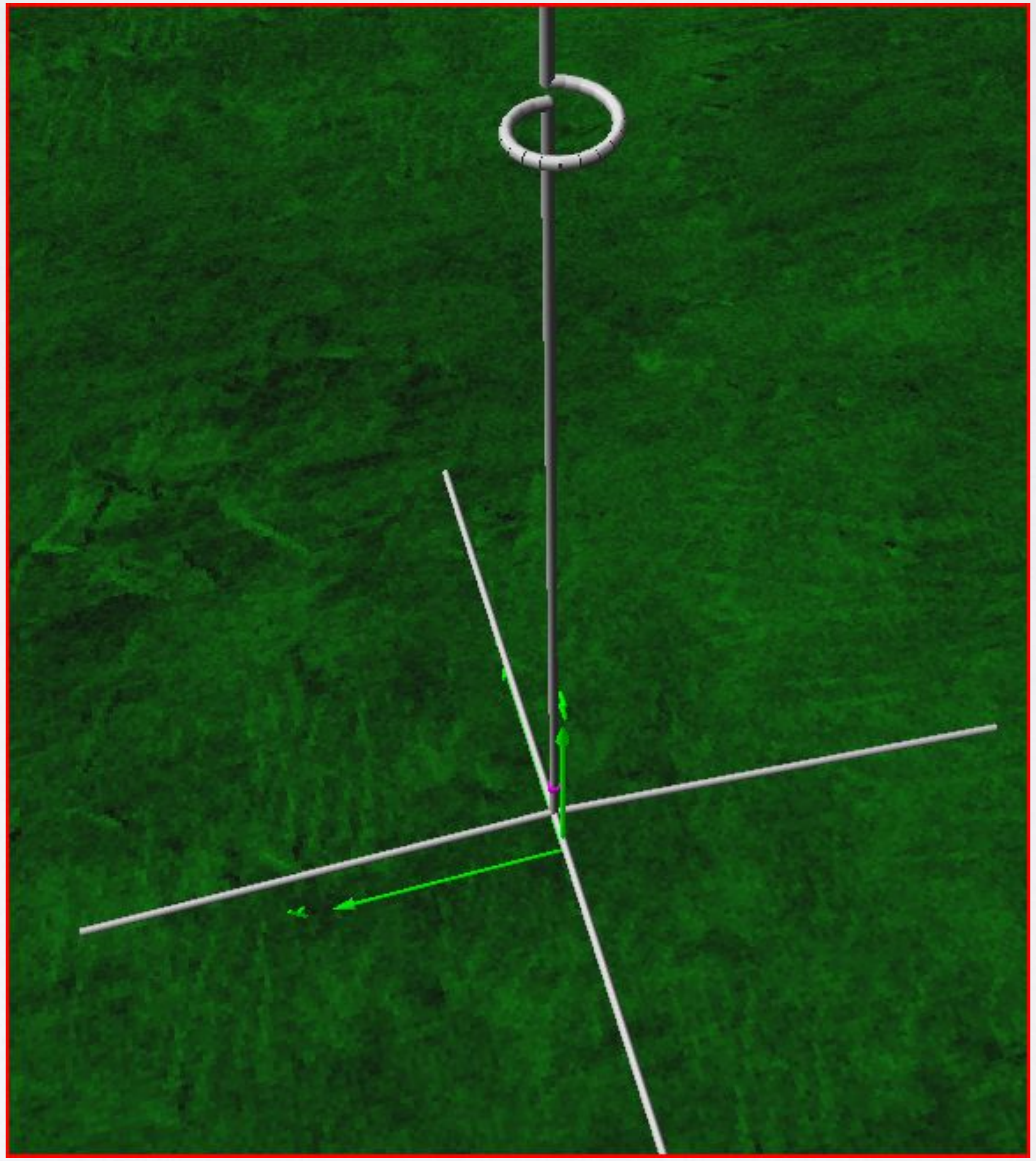
ANTENNA MODELLING NEC-2



Created in 4NEC2

ANTENNA MODELLING NEC-2



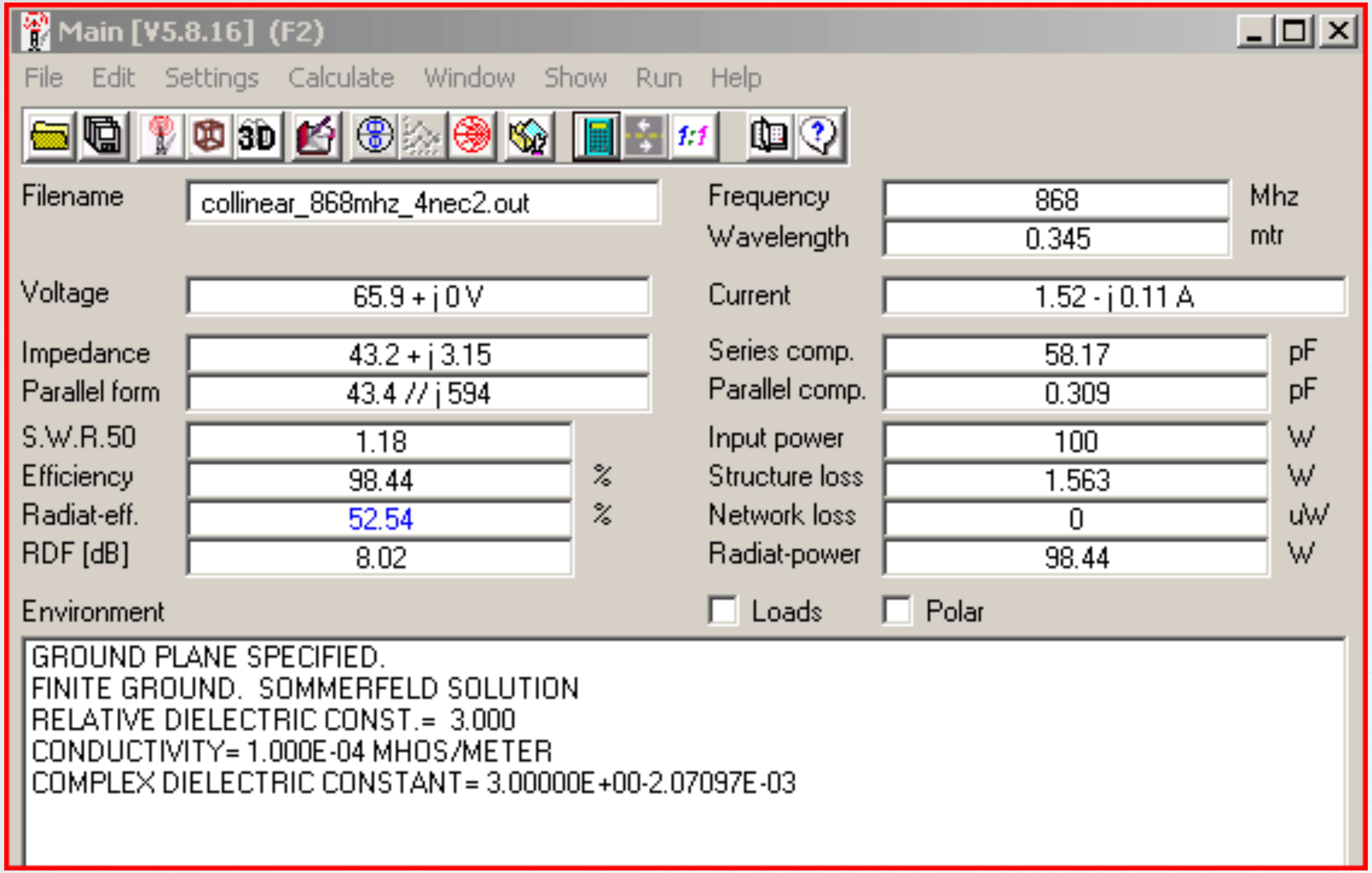


Created in 4NEC2

ANTENNA MODELLING NEC-2

- 4NEC2 card deck:
  https://www.mobilefish.com/download/lora/collinear_868mhz_4nec2.nec.txt

ANTENNA MODELLING NEC-2

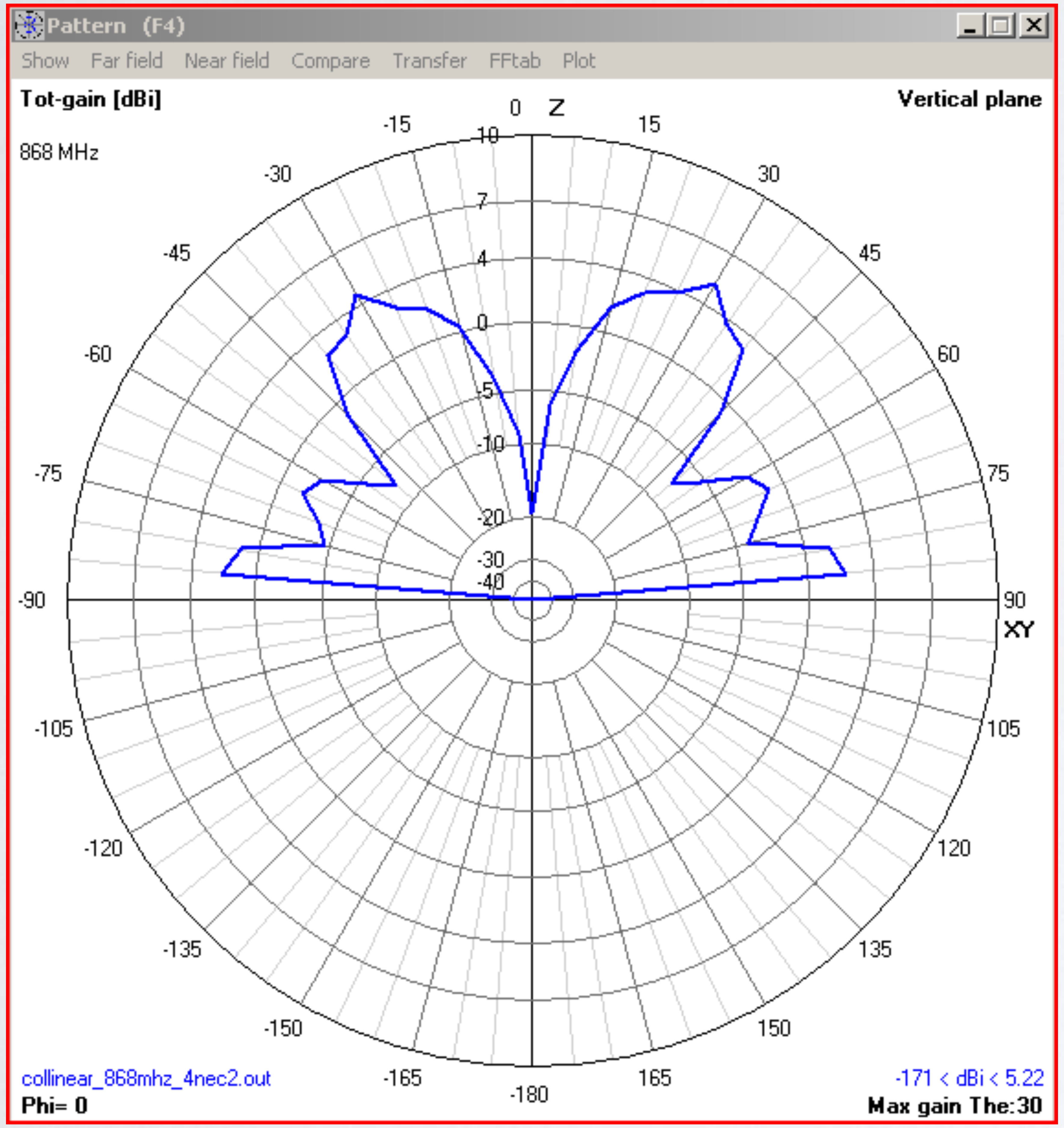


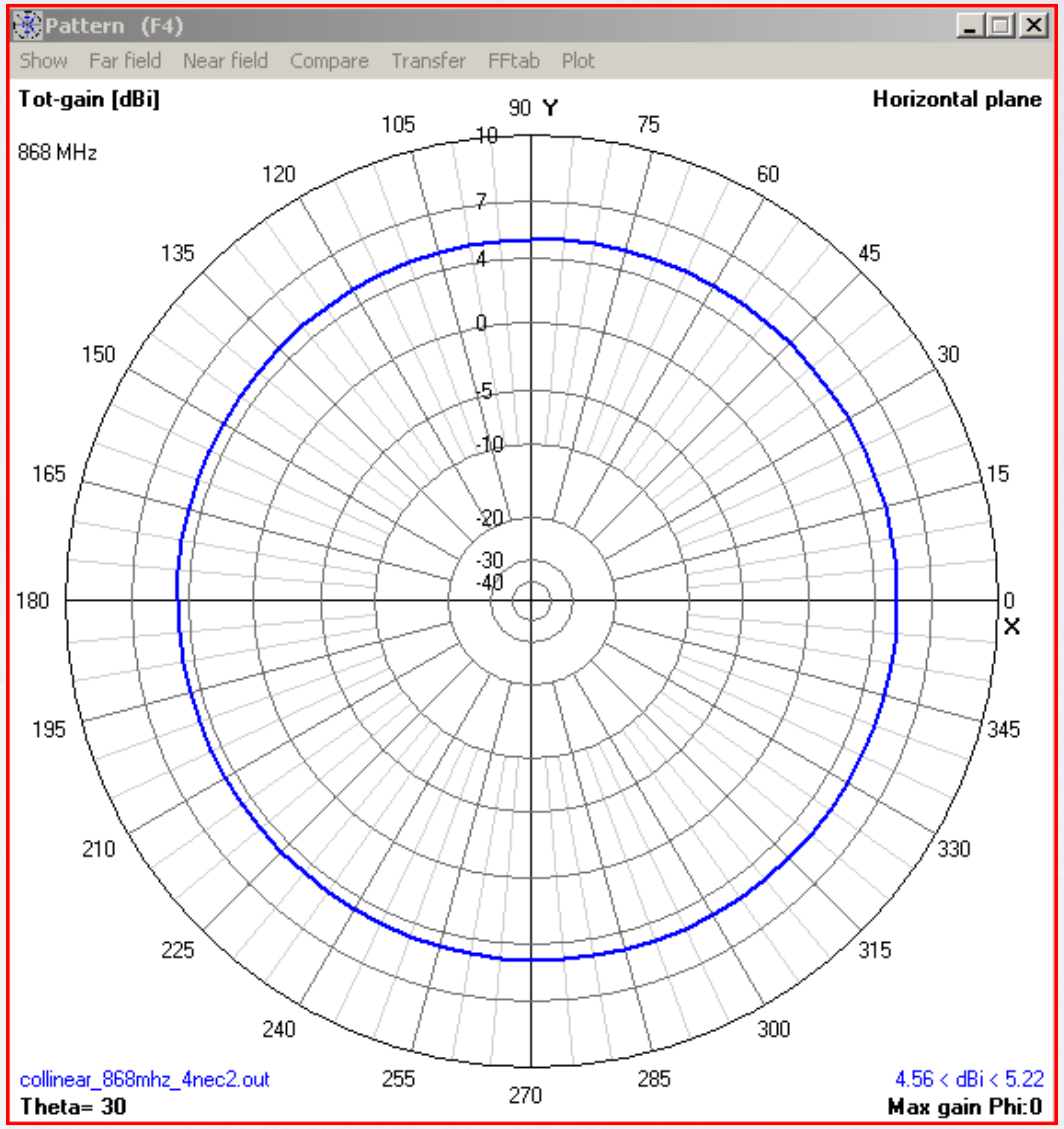
VSWR=1.18

Ground: **Real ground** Ground type: **City industrial area** Height: **11 m above ground**

ANTENNA MODELLING NEC-2

- Ground: **Real ground** Ground type: **City industrial area**



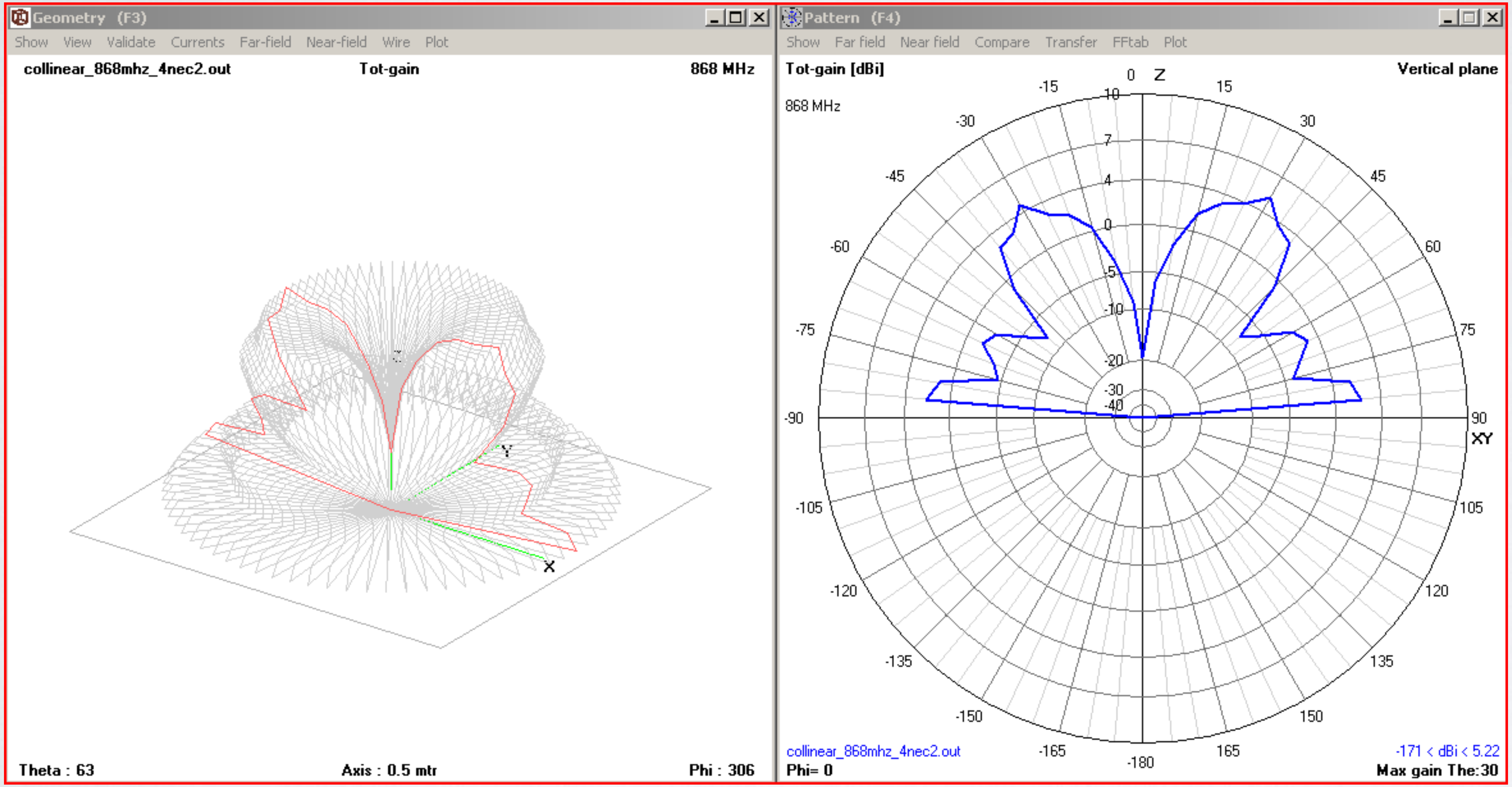


Height: 11 m above ground

Max gain: 5.22 dBi @ Θ=30°

ANTENNA MODELLING NEC-2

- Ground: **Real ground** Ground type: **City industrial area**

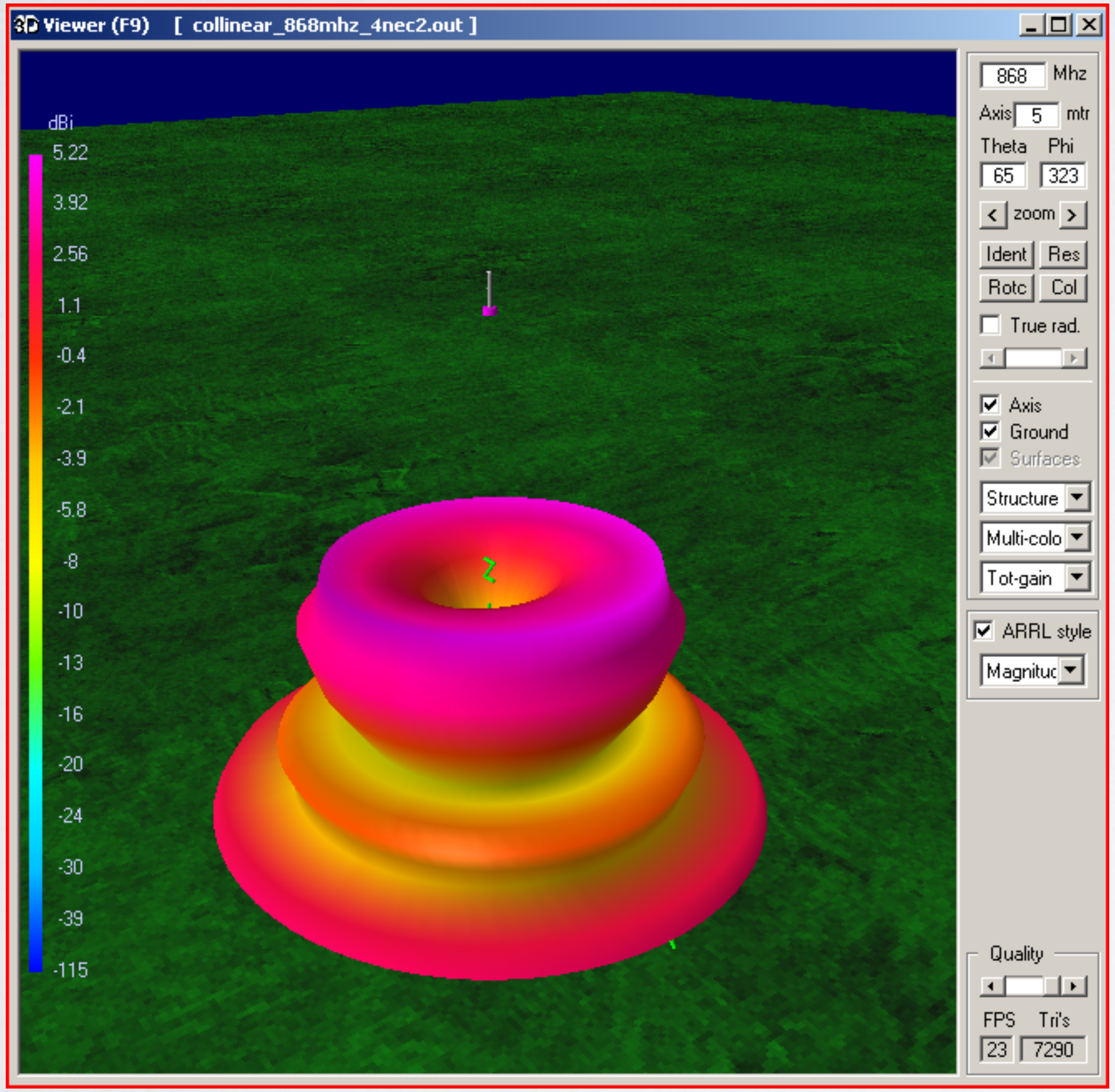


Height: 11 m above ground

Max gain: 5.22 dBi @ Θ=30°

ANTENNA MODELLING NEC-2

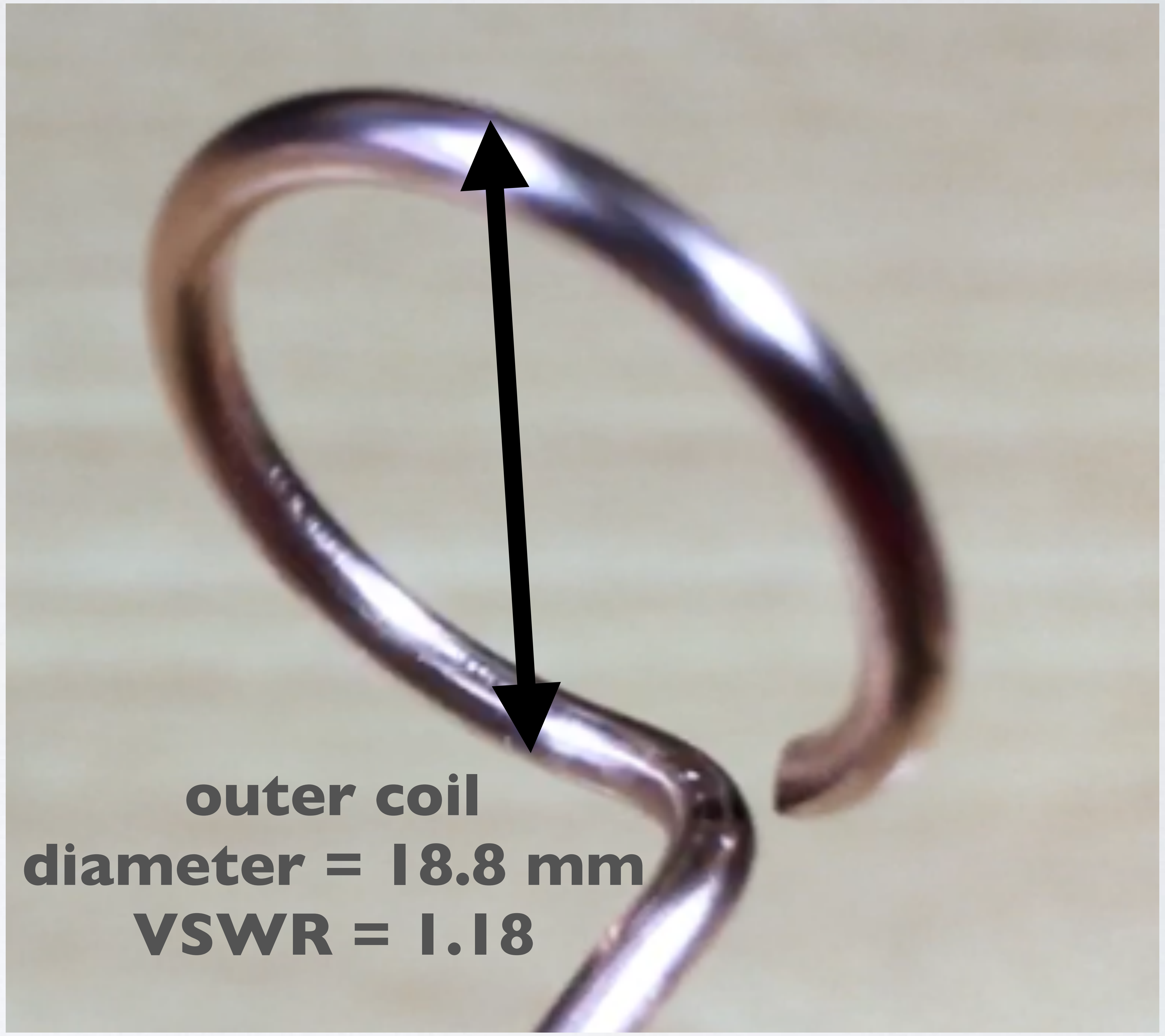
- Ground: **Real ground** Ground type: **City industrial area**



Height: 11 m above ground

ANTENNA MODELLING NEC-2

- I have noticed that the coil diameters plays an important role.
- If the coil diameter is even 1 mm off, you will get a different VSWR.
- If outer coil diameters = 19.8 mm, VSWR=2.23
- If outer coil diameters = 17.8 mm, VSWR=1.93

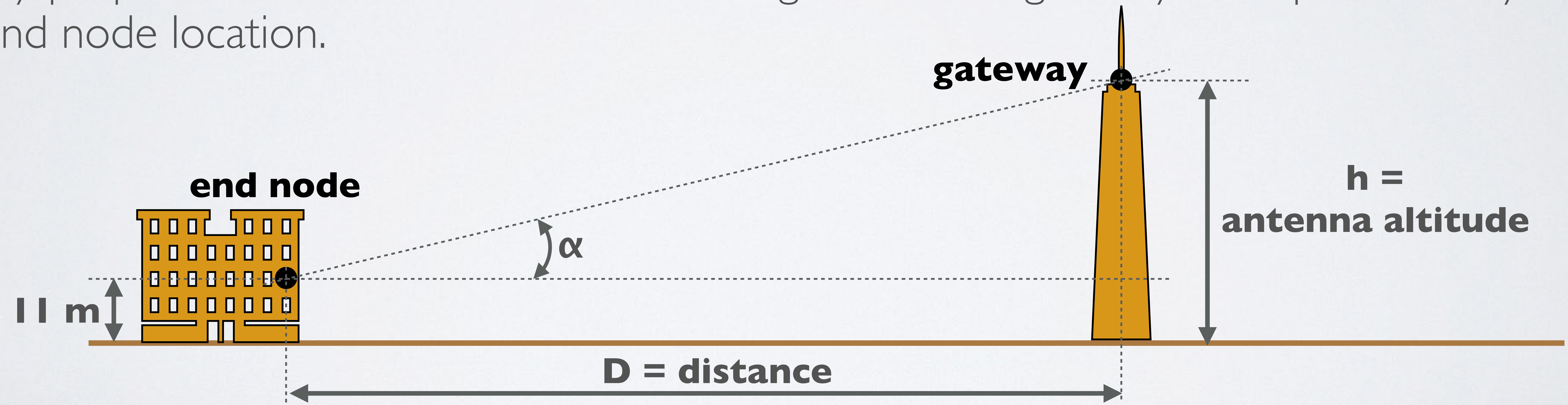


GATEWAY ANTENNA ELEVATION ANGLES

- There are several gateways in my area which are able to receive my sensor data. My end node is placed indoors at an altitude of 11 m in front of a window.

- I made an overview of all the gateways which were able to receive my sensor data over the last year.

- My purpose is to calculate the elevation angles of these gateways, compared to my end node location.



GATEWAY ANTENNA ELEVATION ANGLES

- **Elevation angle α = $\tan^{-1}$ ((h-11) / distance)**

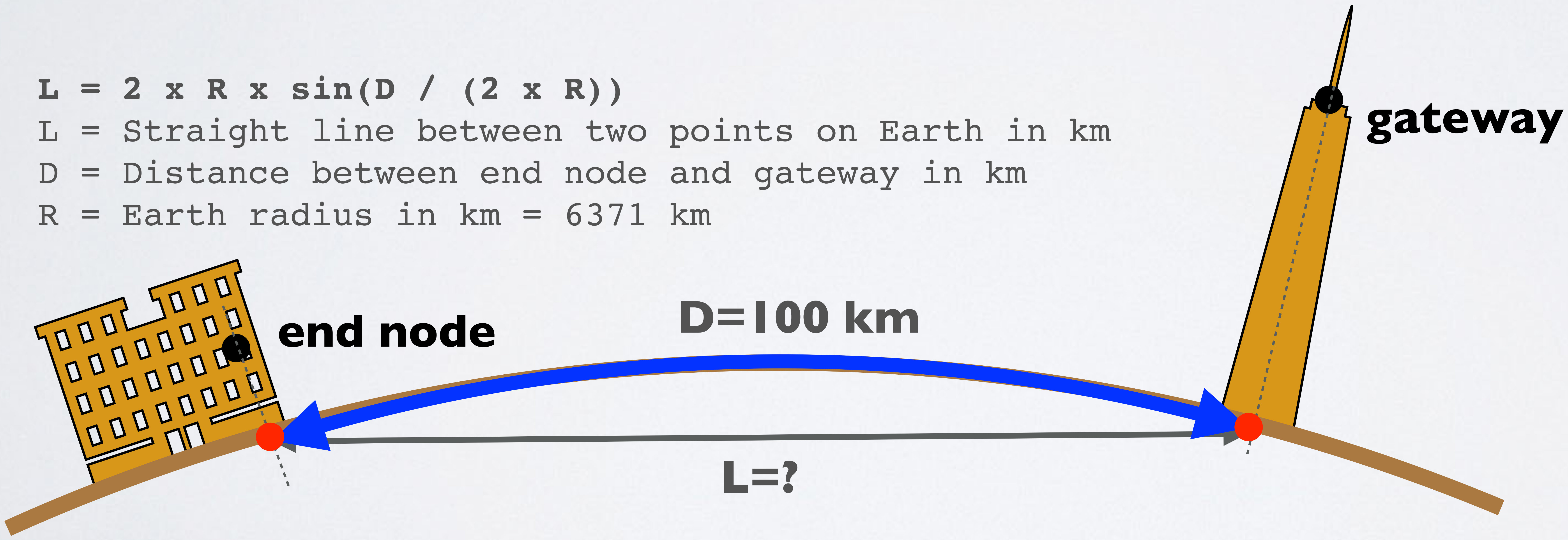
- The Earth curvature can be neglected. The proof can be found in the next slide.

GATEWAY ANTENNA ELEVATION ANGLES

- Let's assume the largest distance (D) between end node and gateway is 100 km.
  In most cases you will never reach this distance.

- If D = 100 km, the straight line L = 99.9989 km.
  This means distance L is almost the same as distance D.
  This is the proof that the Earth curvature can be neglected.

```
L = 2 x R x sin(D / (2 x R))
L = Straight line between two points on Earth in km
D = Distance between end node and gateway in km
R = Earth radius in km = 6371 km
```



GATEWAY ANTENNA ELEVATION ANGLES

Gateway	Distance from end device to gateway [km]	Ant. altitude [m]	Ant. placement	Elevation angle α [°]
eui-aa555a0000088013	1.57	42	Outdoor	1.13
eui-0ba0000000000001	5.02	20	Outdoor	0.10
zeezicht	1.23	10	Indoor	-0.05
eui-0000024b08030c5f	14.4	40	Outdoor	0.12
eui-000080029c10db9b	4.36	30	Outdoor	0.25
eui-000080029c10dbb3	6.73	5	Outdoor	-0.05
eui-000080029c10dc24	14.7	45	Outdoor	1.32
eui-60c5a8fffe760e60	4.15	30	Outdoor	0.26
eui-dca632fffe43df3e	0.458	10	Indoor	-0.13
eui-b827ebfffedcc77d	0.816	7	Indoor	**-0.28**
eui-7276ff000b031ebb	0.73	38	Outdoor	**2.12**

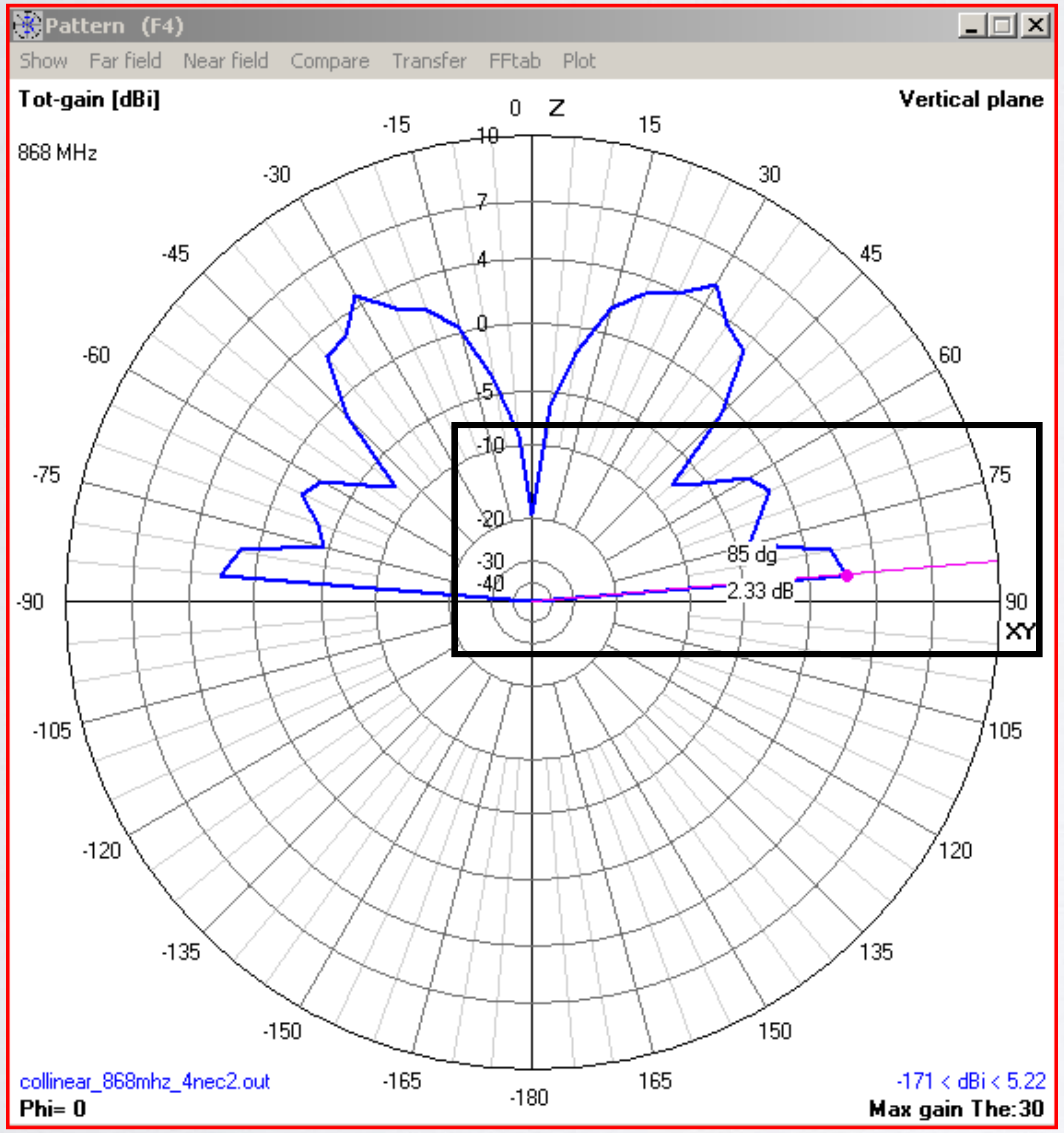
https://drive.google.com/open?id=18SKbHVEIFHU6YjzYpgZL98vuHcmV4OPQ&usp=sharing

GATEWAY ANTENNA ELEVATION ANGLES

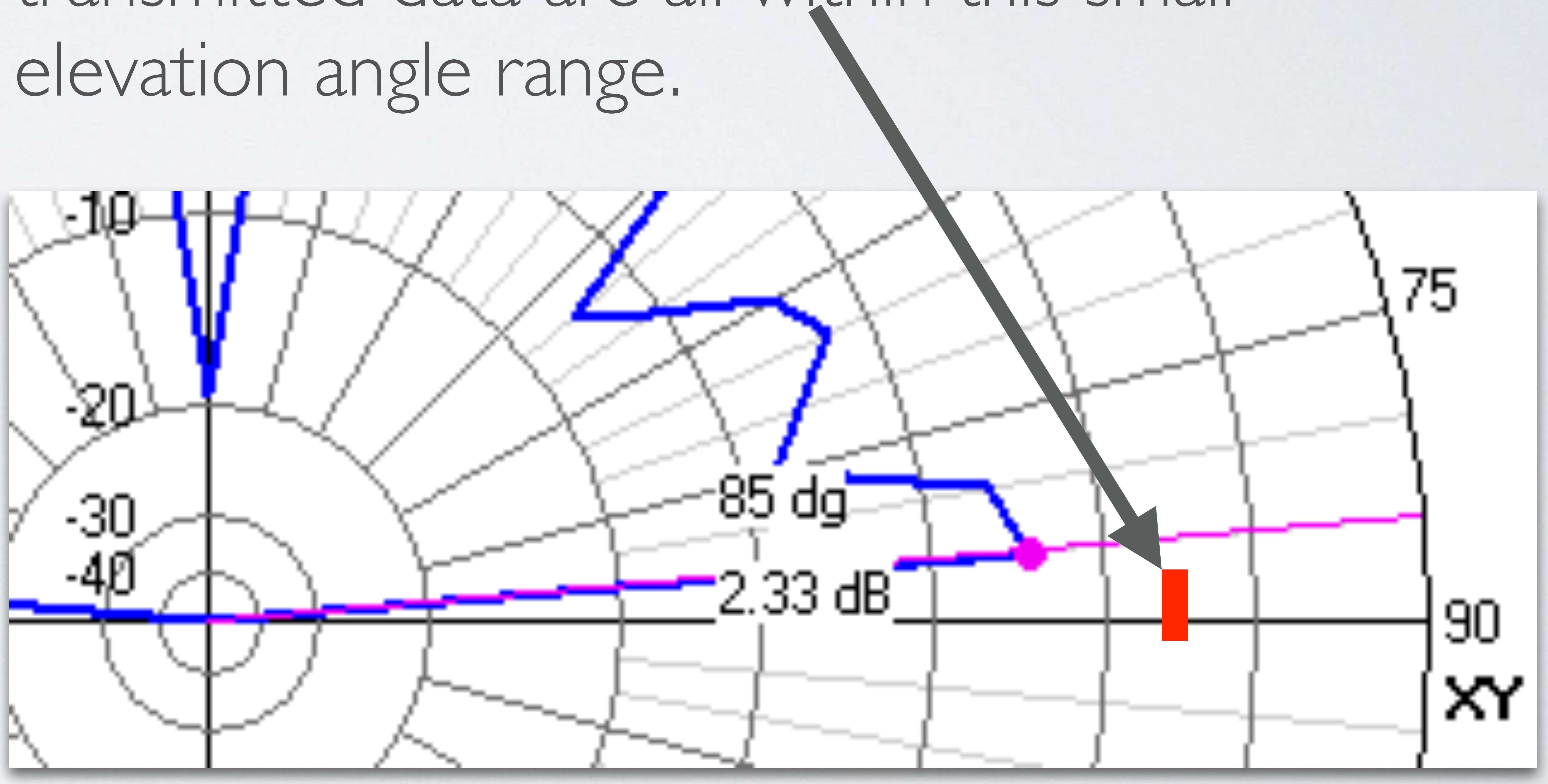
- Looking at the previous table, the gateway antennas in my area are placed at elevation angles between -1° and +3° based on my end node location.

COLLINEAR ANTENNA I

- Ground: **Real ground** Ground type: **City industrial area**

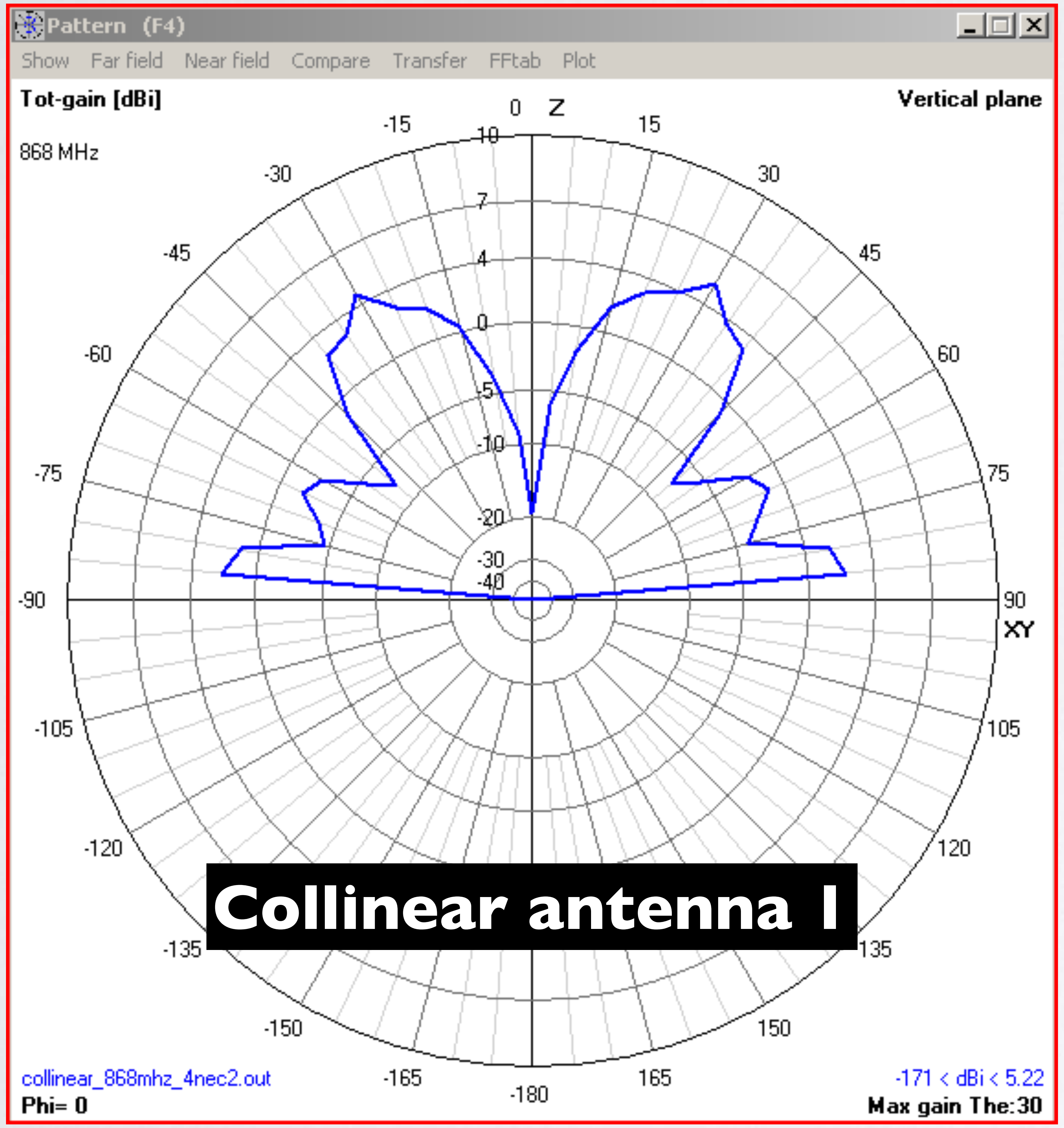


The gateways which are able to receive my transmitted data are all within this small elevation angle range.

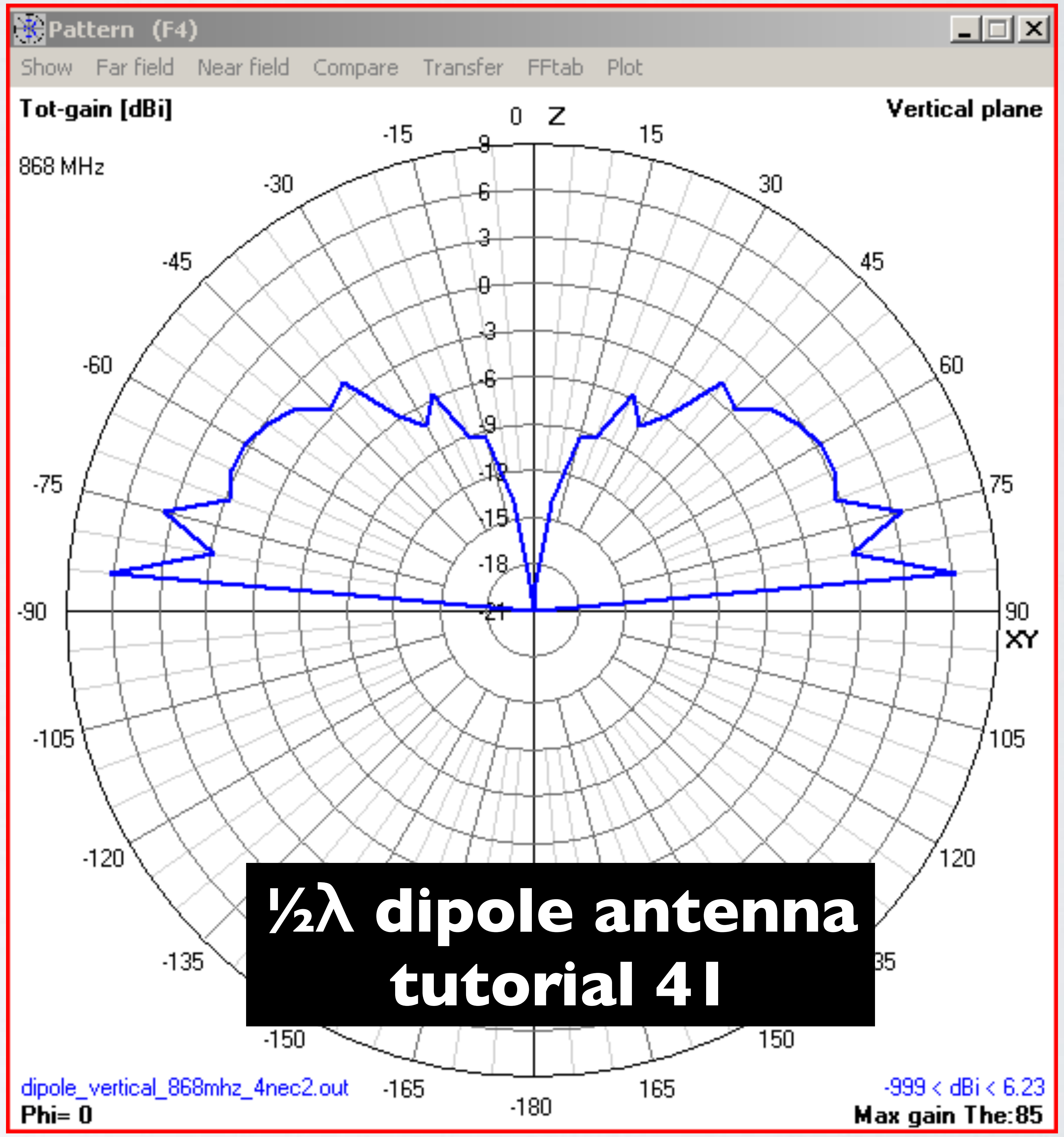


COLLINEAR ANTENNA 1

- Ground: **Real ground** Ground type: **City industrial area**



Height: 11 m above ground



COLLINEAR ANTENNA 1 PERFORMANCE TESTS

- How well does my self build collinear antenna 1 perform?
  To answer this question, two performance tests will be conducted.

- **Performance test A**:
  The collinear antenna 1 is attached to an end node, which is located inside a building, and transmit messages which will be received by nearby gateways in my area.
  The average RSSI is calculated and also the total time it took to receive 10 messages.
  The test will be repeated using a sleeve dipole antenna.

- **Performance test B**:
  The collinear antenna 1 is attached to an end node and transmit messages which will be received by a dedicated gateway 6 meters away. Both devices are indoors.
  The average RSSI is calculated and also the total time it took to receive 10 messages.
  The test will be repeated using a ½λ dipole antenna.

COLLINEAR ANTENNA | PERFORMANCE TESTS

- Performance test A and B are simple tests and will give me a **ROUGH INDICATION** how well my antenna performs compared to the ½λ dipole antenna.

- Both tests are conducted indoors which means the walls reflects the transmitted signals thus influencing the measurements. Therefore take the results with a grain of salt!

- A much better method to tell how your antenna actually performs in the real world, see this procedure: https://github.com/LoRaTracker/AntennaTesting

COLLINEAR ANTENNA 1 PERFORMANCE TEST A

- The collinear antenna 1 performance is compared with a sleeve dipole antenna. More information about sleeve dipole antennas, see tutorial 43.

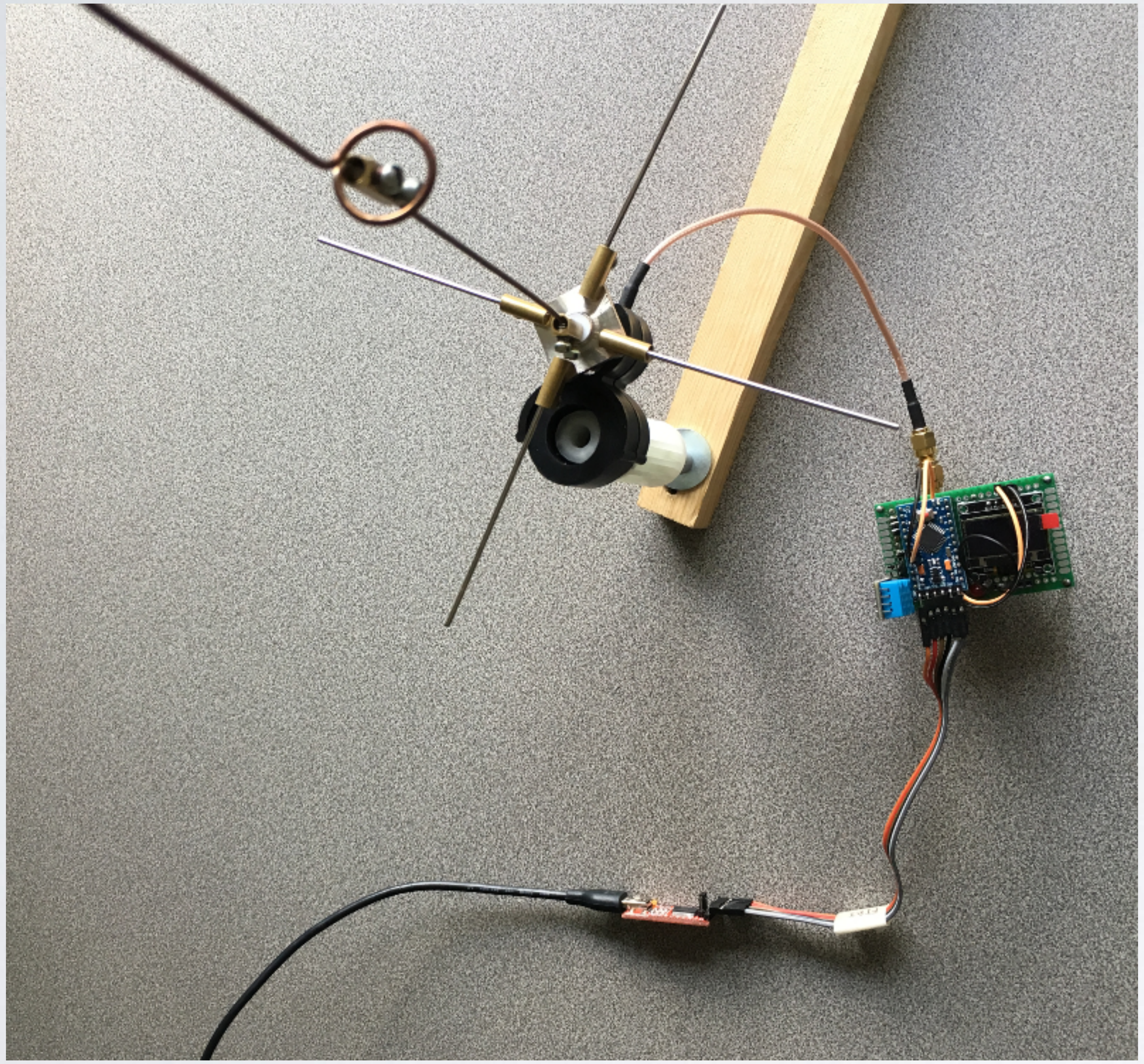
- For this test I am using the end node and antenna C as demonstrated in tutorial 33.

- More information about this end node, see: https://www.mobilefish.com/developer/lorawan/lorawan_quickguide_build_lora_node_rfm95_arduino_pro_mini.html

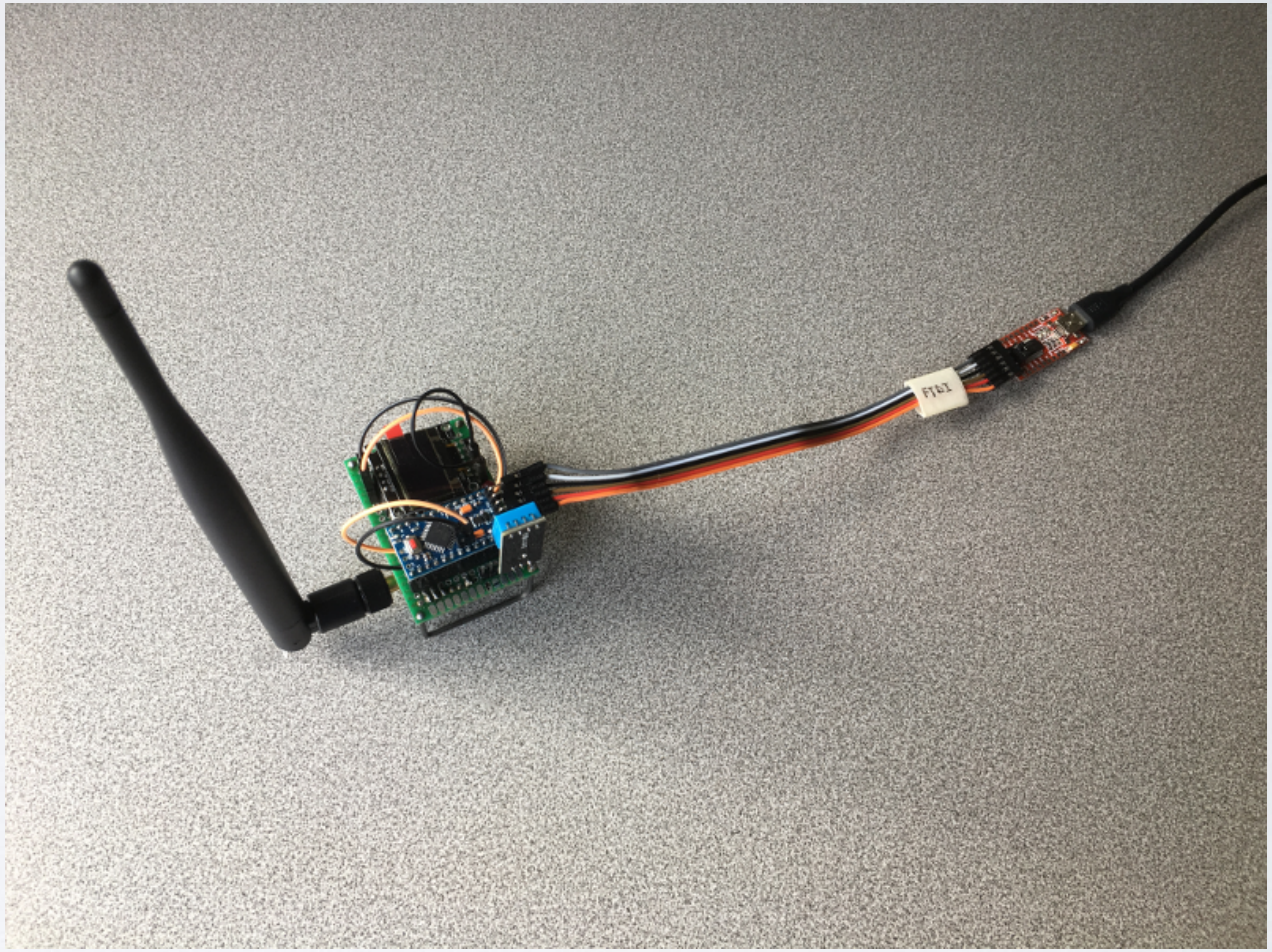
- The end node uses the MCCI LoRaWAN LMIC Library: https://github.com/mcci-catena/arduino-lmic

- The end node uses the following sketch: https://www.mobilefish.com/download/lora/ttn-otaa-pro-mini-sensors.ino.txt

COLLINEAR ANTENNA 1 PERFORMANCE TEST A



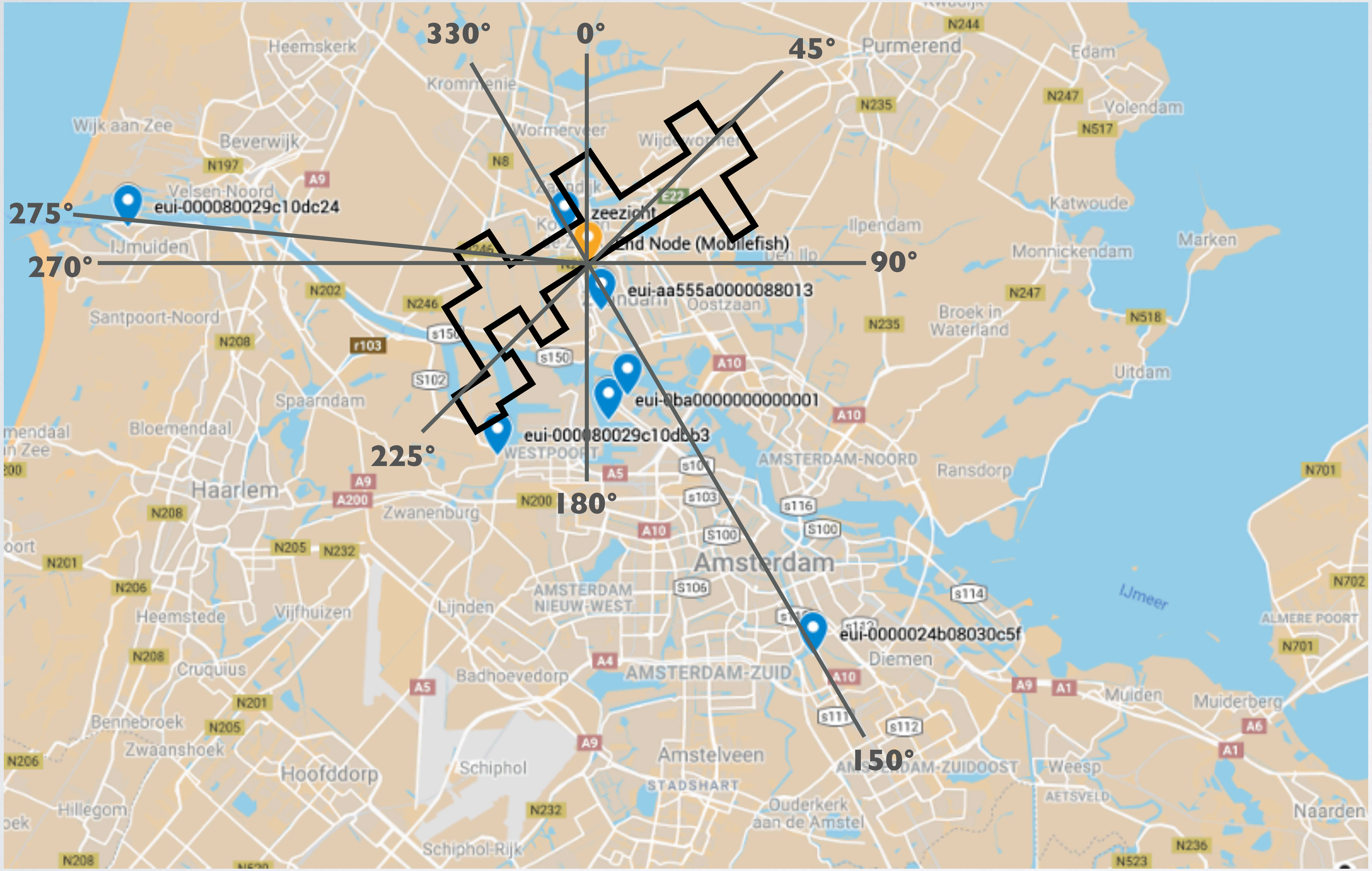
Collinear antenna 1 + end node



Sleeve dipole + end node

mobilefish.com

ANTENNA TEST SETUP



The building circumference.

The end node is placed inside the building in front of a window.

Two end node locations:

Location A, facing East and South. Altitude = ~11m

Location B, facing West and North. Altitude = ~11m

COLLINEAR ANTENNA 1 PERFORMANCE TEST A

- I have NOT modified the end node transmission power when using collinear antenna 1.

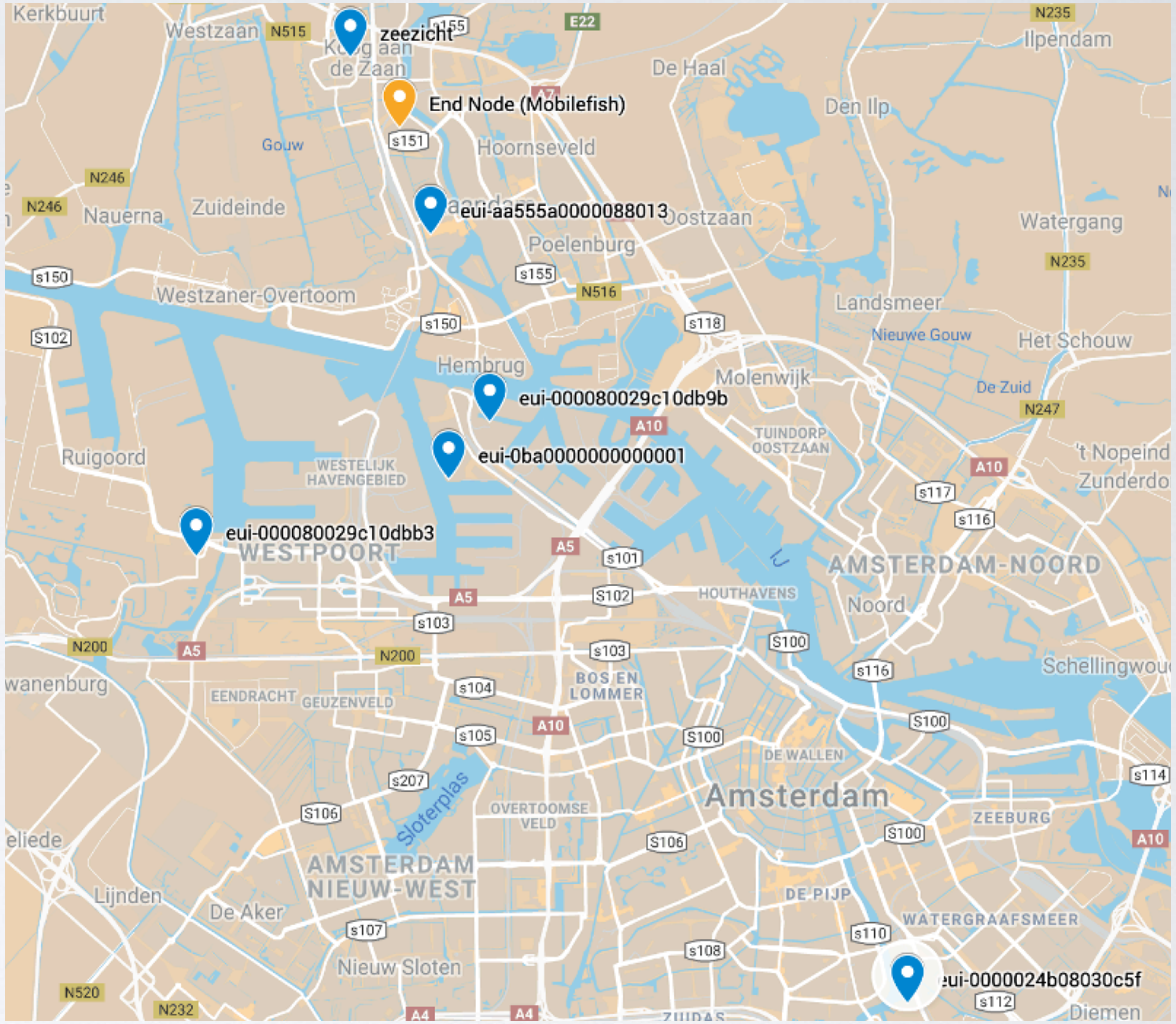
- In my area there are several gateways and I know that these gateways, which are connected to The Things Network, can receive my transmitted data.

- Collinear antenna 1 is attached to the end node at location A and transmits data. I have done the same with the sleeve dipole antenna. In both cases two messages per minute were transmitted.

- The logged data can be found at: https://www.mobilefish.com/download/lora/collinear_test_results.txt

ANTENNA TEST RESULTS

- One or more gateways were able to receive my transmitted sensor data, see: https://drive.google.com/open?id=18SKbHVEIFHU6YjzYpgZL98vuHcmV4OPQ&usp=sharing



COLLINEAR ANTENNA 1 PERFORMANCE TEST A

- End node tx power = 14 dBm
  Data from: collinear_test_results.txt

Gateway	Distance from end device to gateway[km]	Ant. Altitude [m]	Collinear Average RSSI [dBm]	Sleeve dipole Average RSSI [dBm]	Elevation angle α [°]
eui-aa555a0000088013	1.57	42	-116.4	-116.5	1.13
eui-000080029c10dc24	14.7	45	-	-116	1.32
eui-000080029c10db9b	4.36	30	-119.5	-120	0.25

- There is no significant difference in the average RSSI values between the collinear antenna 1 and the sleeve dipole antenna.

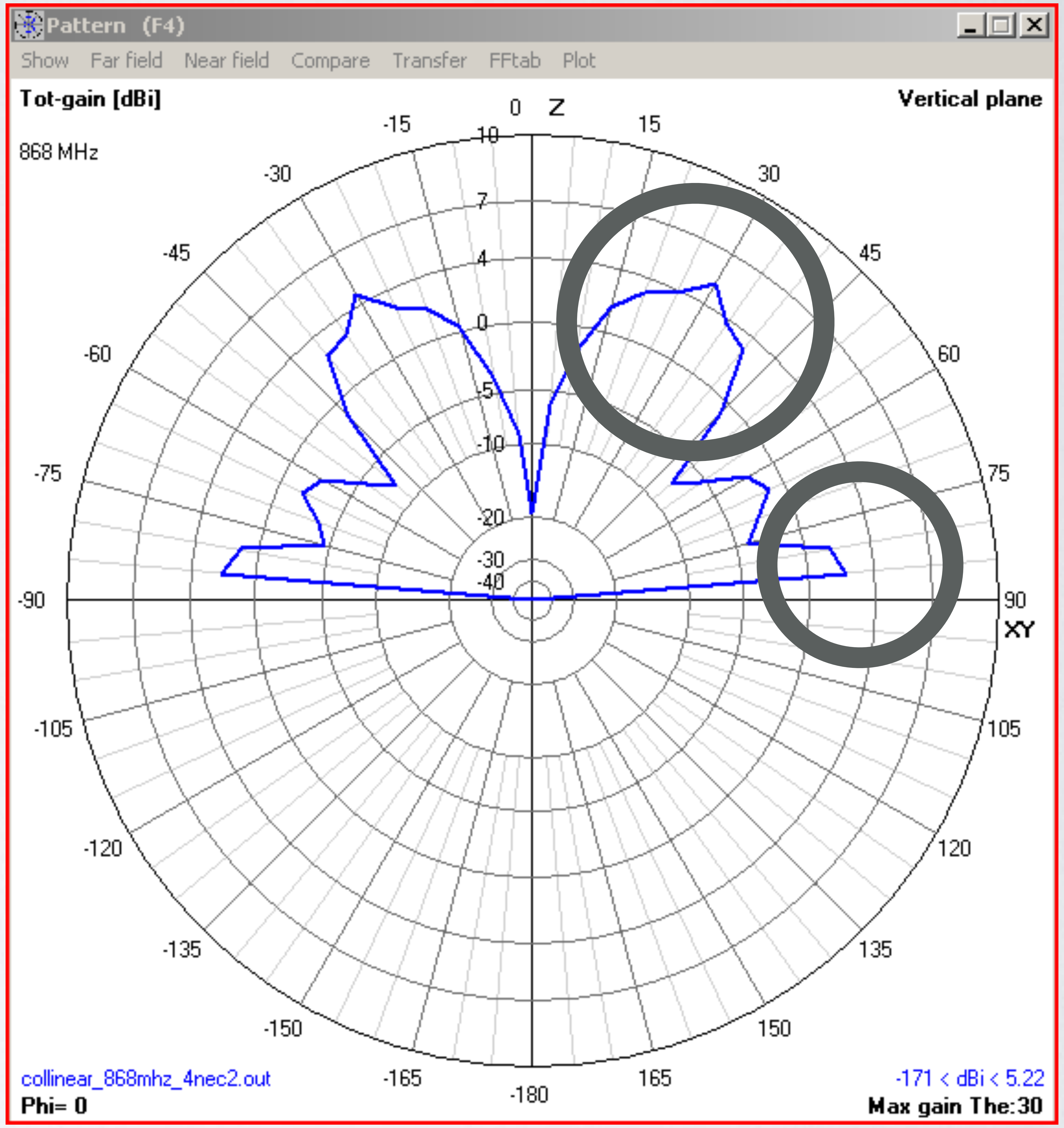
COLLINEAR ANTENNA 1 PERFORMANCE TEST A

- The time it took for the gateways to receive the 10 messages from the end node:
  Using the sleeve dipole antenna: 13 minutes
  Using collinear antenna 1: 10 minutes

- The Arduino sketch is configured to transmit 1 message per minute. In a perfect situation it should take 10 to 11 minutes to receive these 10 messages.

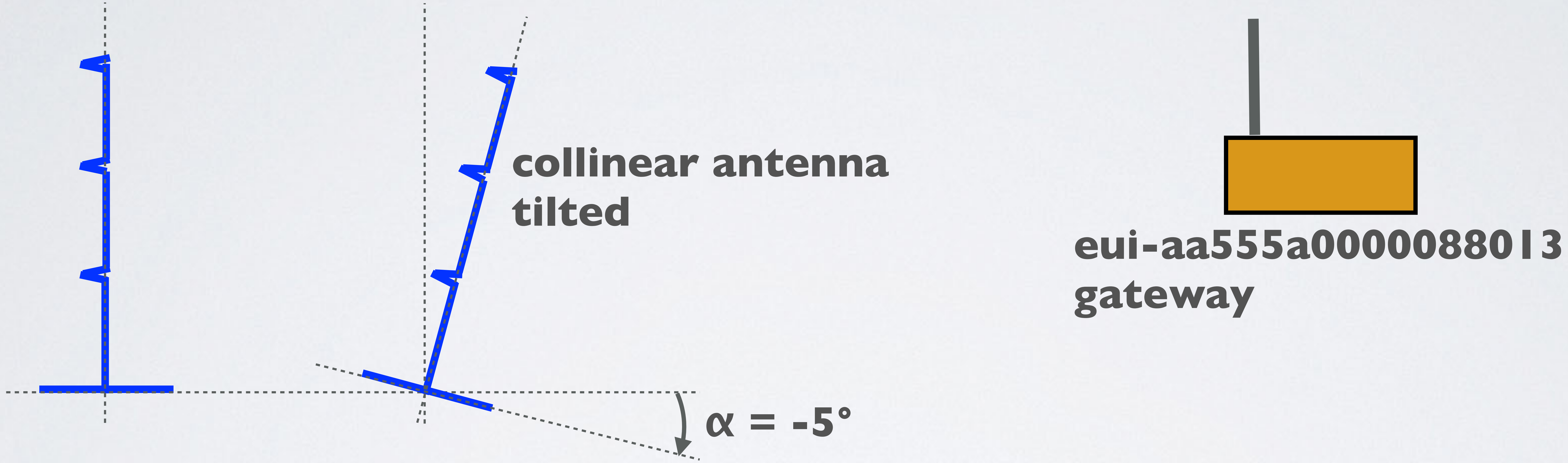
COLLINEAR ANTENNA 1 PERFORMANCE TEST A

- If you look at the radiation pattern in the vertical plane (E-plane) you can clearly see that the collinear antenna 1 performs very good at certain elevation angles.
- Question: If I slightly tilt the collinear antenna can the antenna performance be improved?



COLLINEAR ANTENNA | PERFORMANCE TEST A

- I have extended performance test A by tilting the collinear antenna at several angles.



- The logged data can be found at:
  https://www.mobilefish.com/download/lora/collinear_test_results2.txt

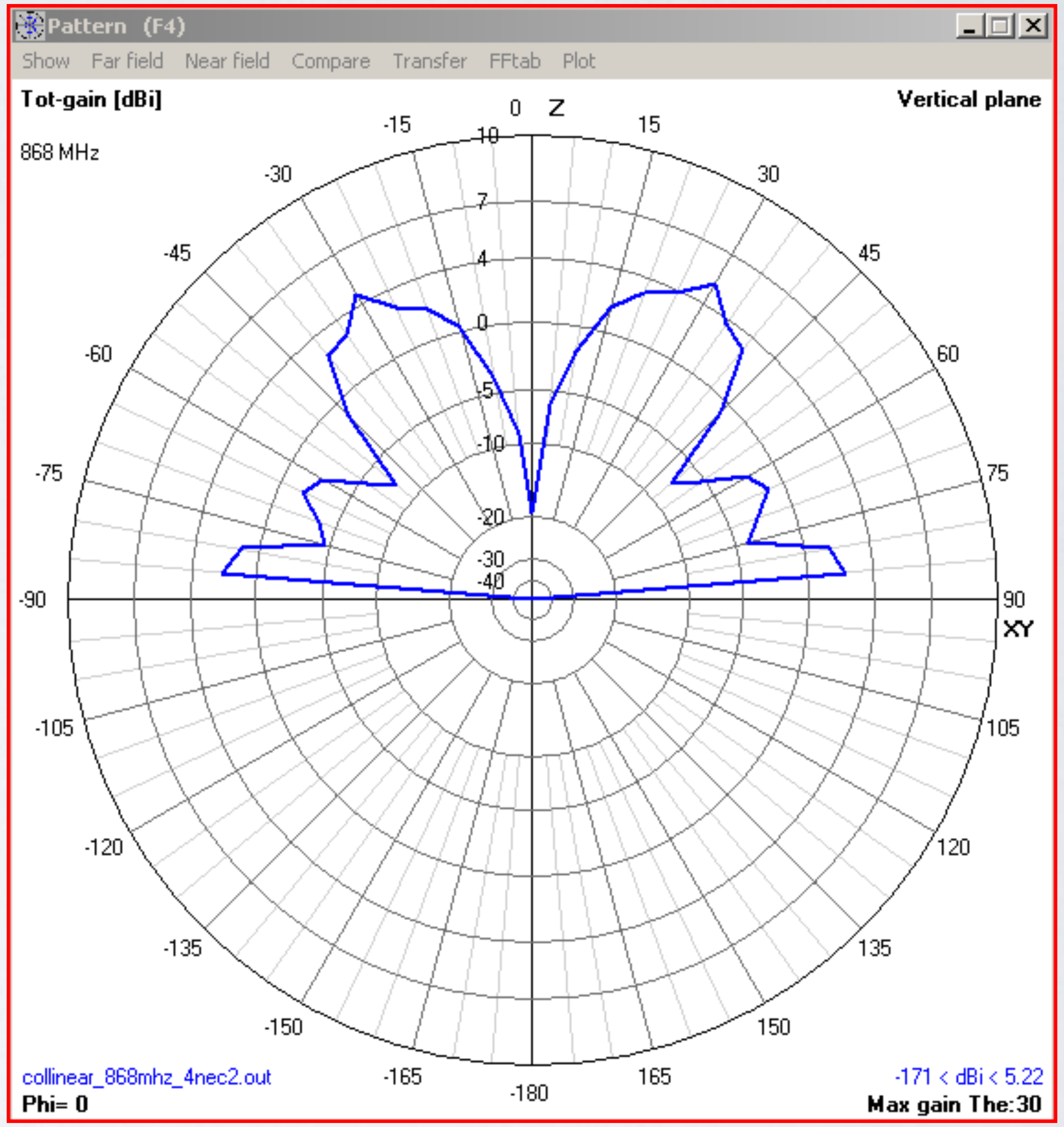
- I am only interested in the results from the eui-aa555a0000088013 gateway.

COLLINEAR ANTENNA 1 PERFORMANCE TEST A

- Two messages per minute were transmitted.

- End node tx power = 14 dBm

End node antenna	Tilt Angle α [°]	Average RSSI [dBm]	Average time to receive 15 messages [min]
Sleeve dipole	-	-116.8	10
Collinear Test a	0	-115.2	11
Collinear Test b	-5	-115.3	9
Collinear Test c	-9	-115.8	9
Collinear Test d	-15	-117.2	11



- Conclusion:
  By tilting the collinear antenna 1 (-5° & -9°) the antenna performance is improved.

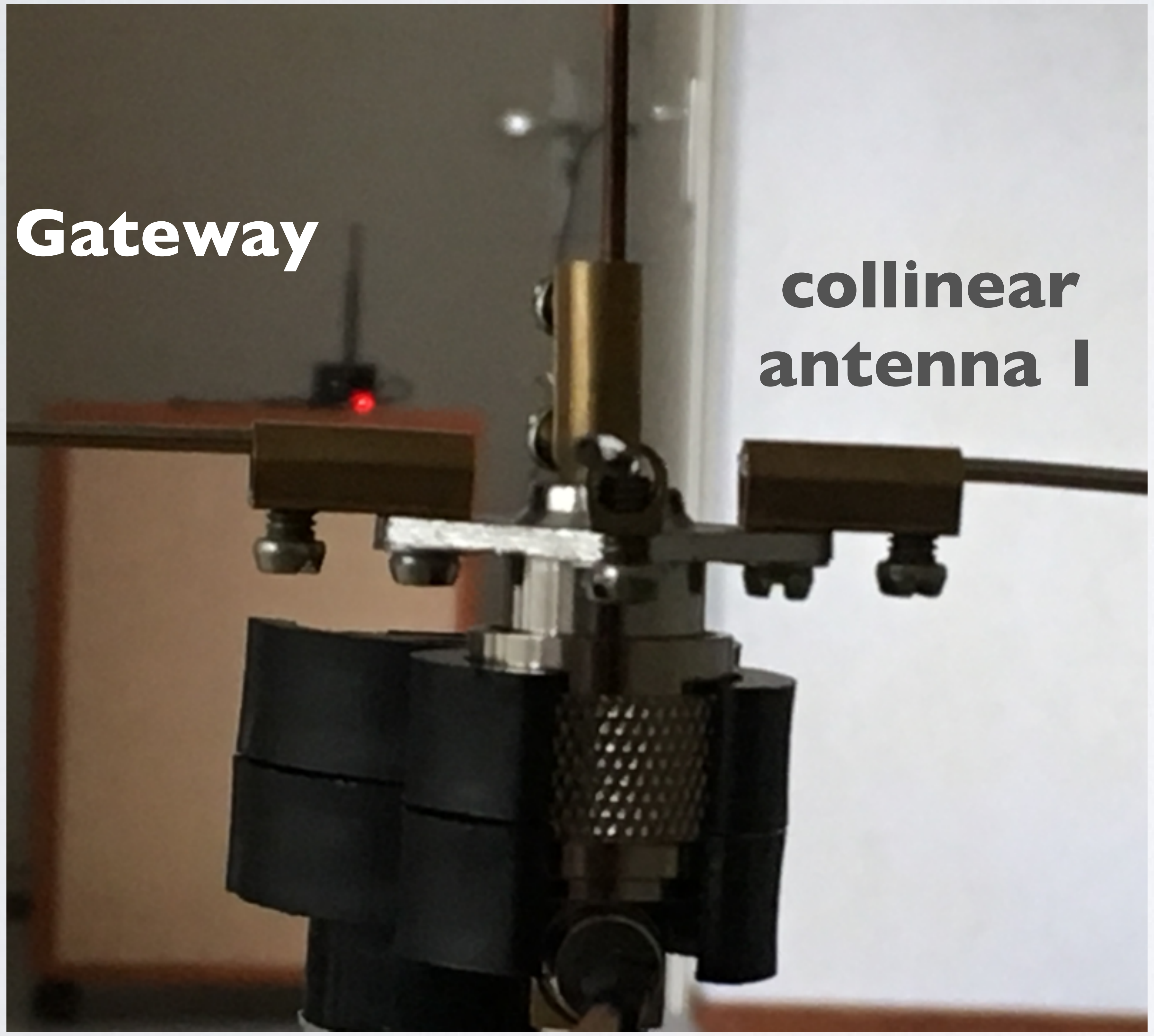
COLLINEAR ANTENNA 1 PERFORMANCE TEST B

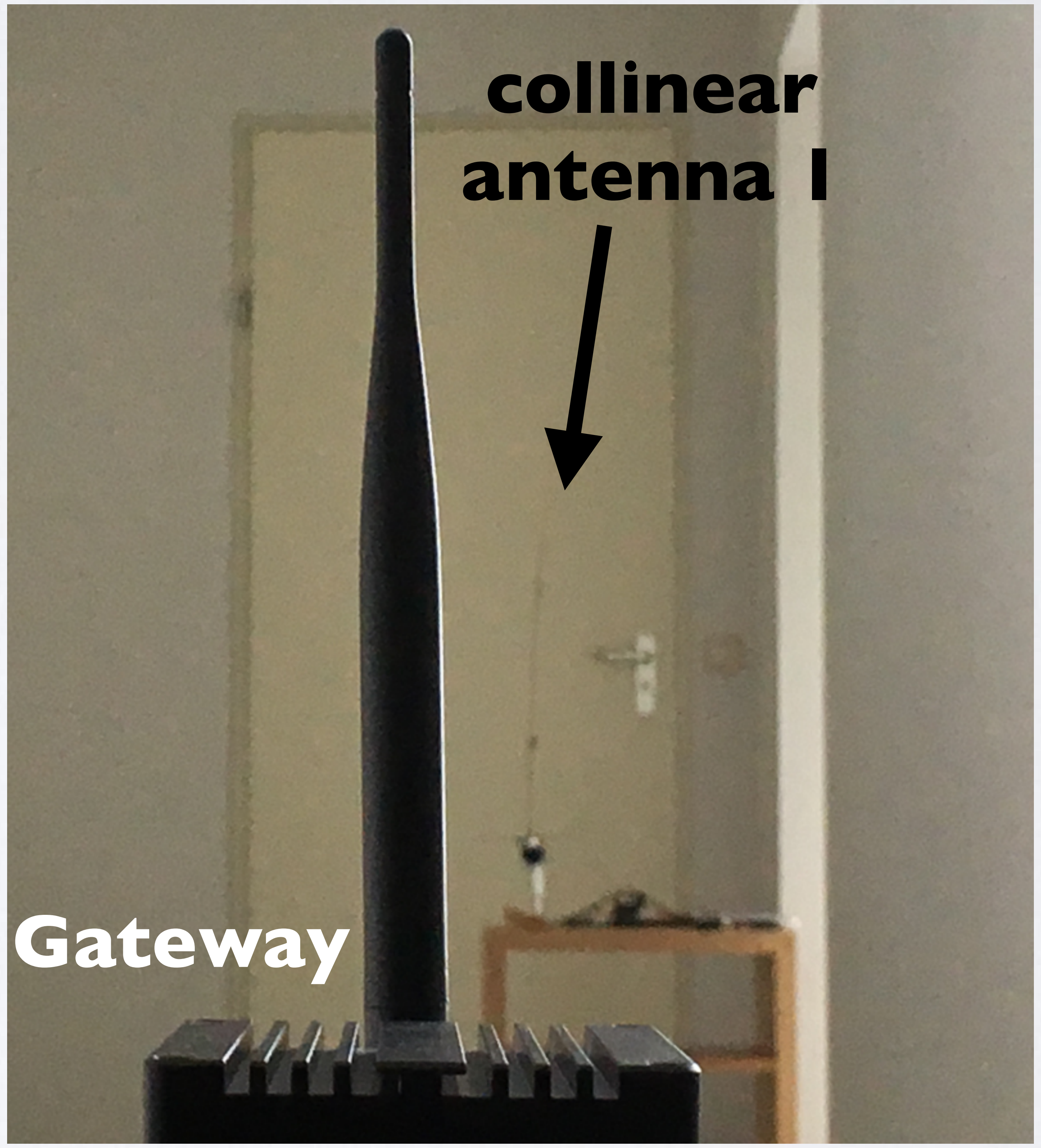
- Make sure you keep everything in your setup the same when switching from the collinear antenna 1 to the ½λ dipole antenna.

- A slight change can impact your measurements.

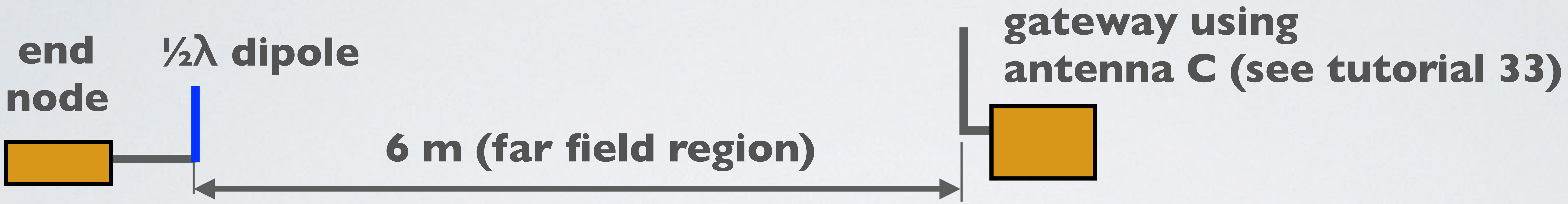
- - Do not change the height of the end node and the height of the gateway.
  - Do not change the distance between end node and the gateway.
  - Use the same end node and gateway.
  - Use the same coax cables and connectors.
  - During the measurements I did not stay in the same room.
  - The distance between transmitter and receiver should be > 4λ (Far field region)
  More information about near and far field, see tutorial 34.

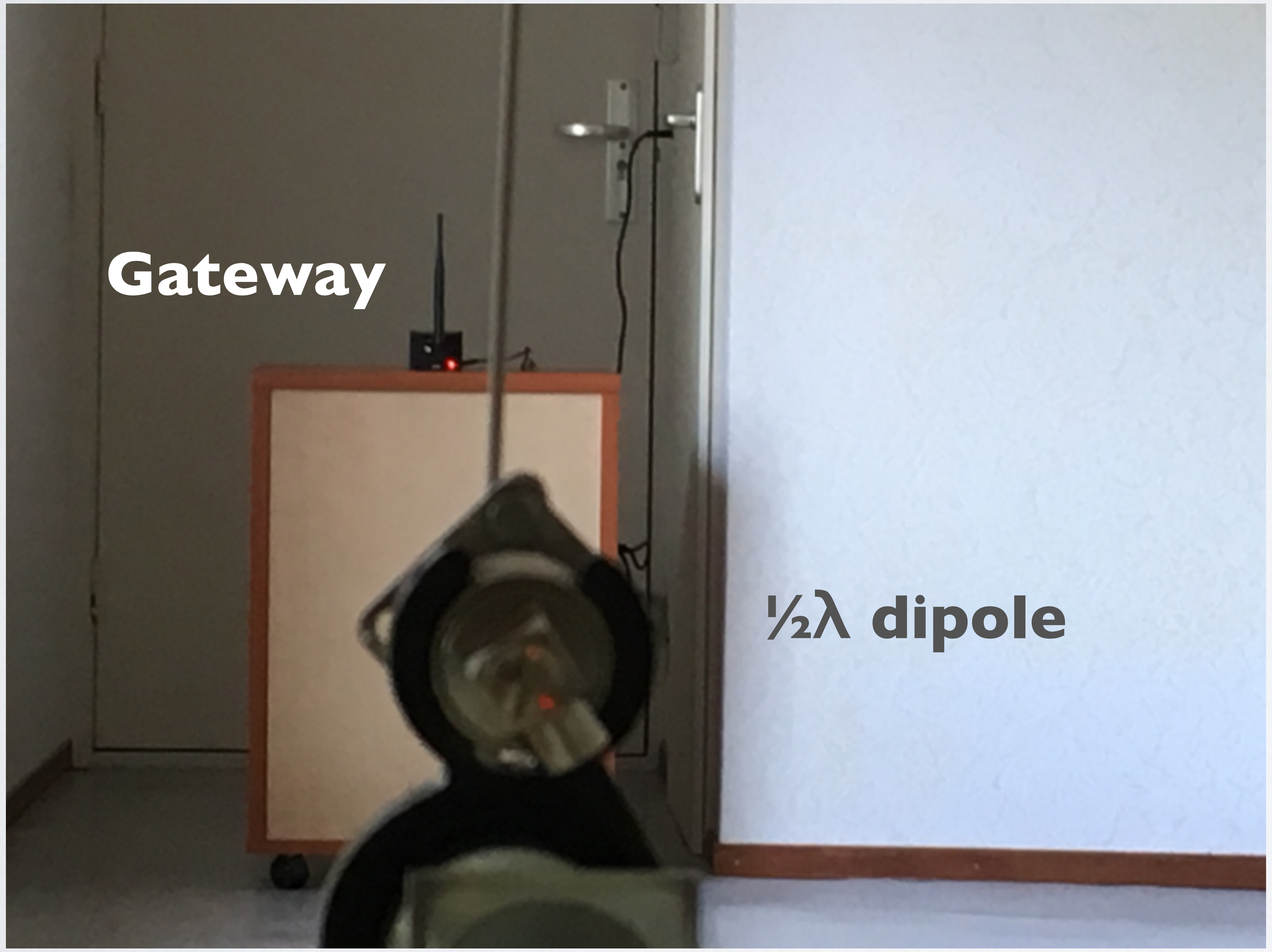
COLLINEAR ANTENNA I PERFORMANCE TEST B

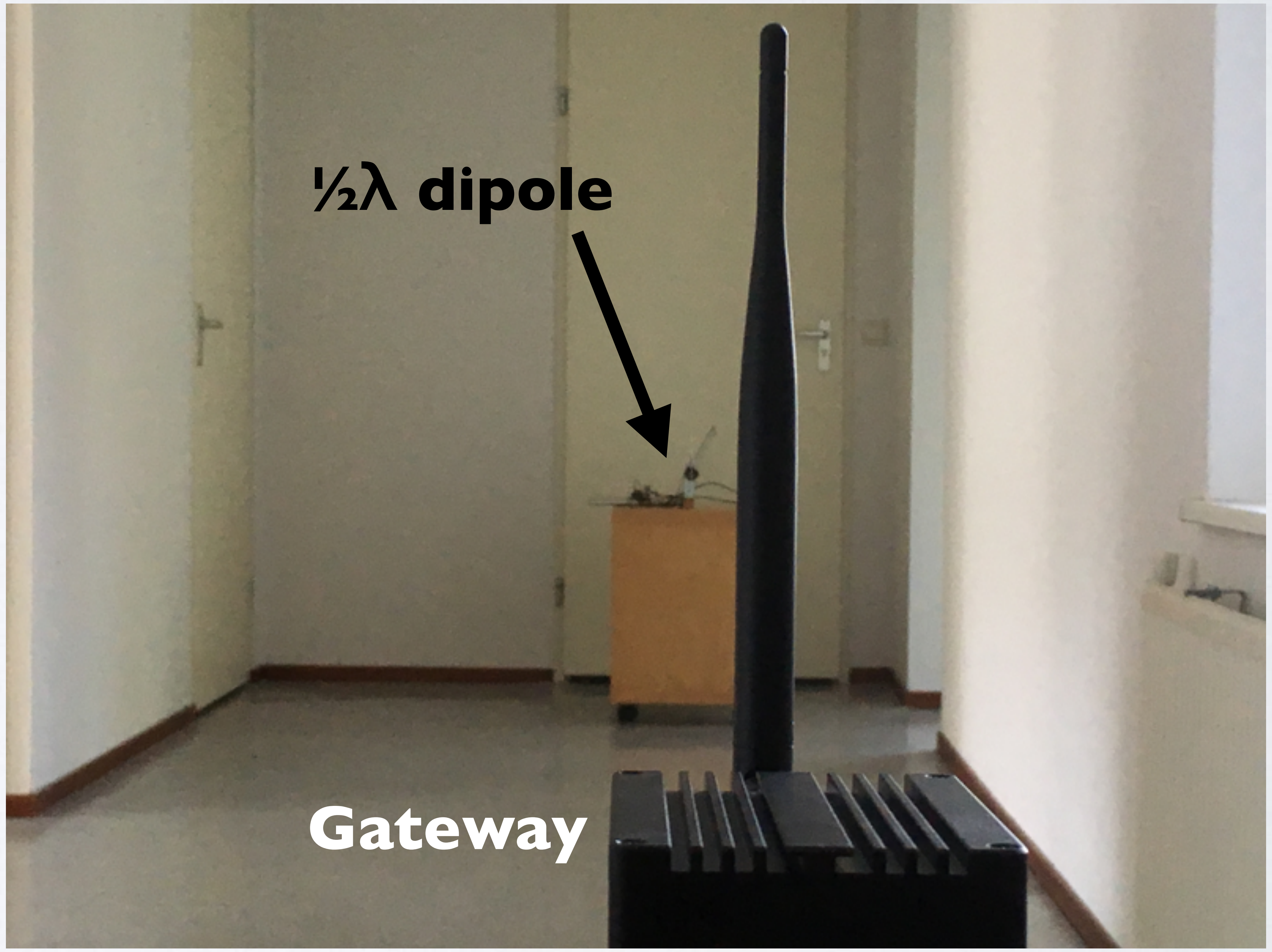




COLLINEAR ANTENNA | PERFORMANCE TEST B

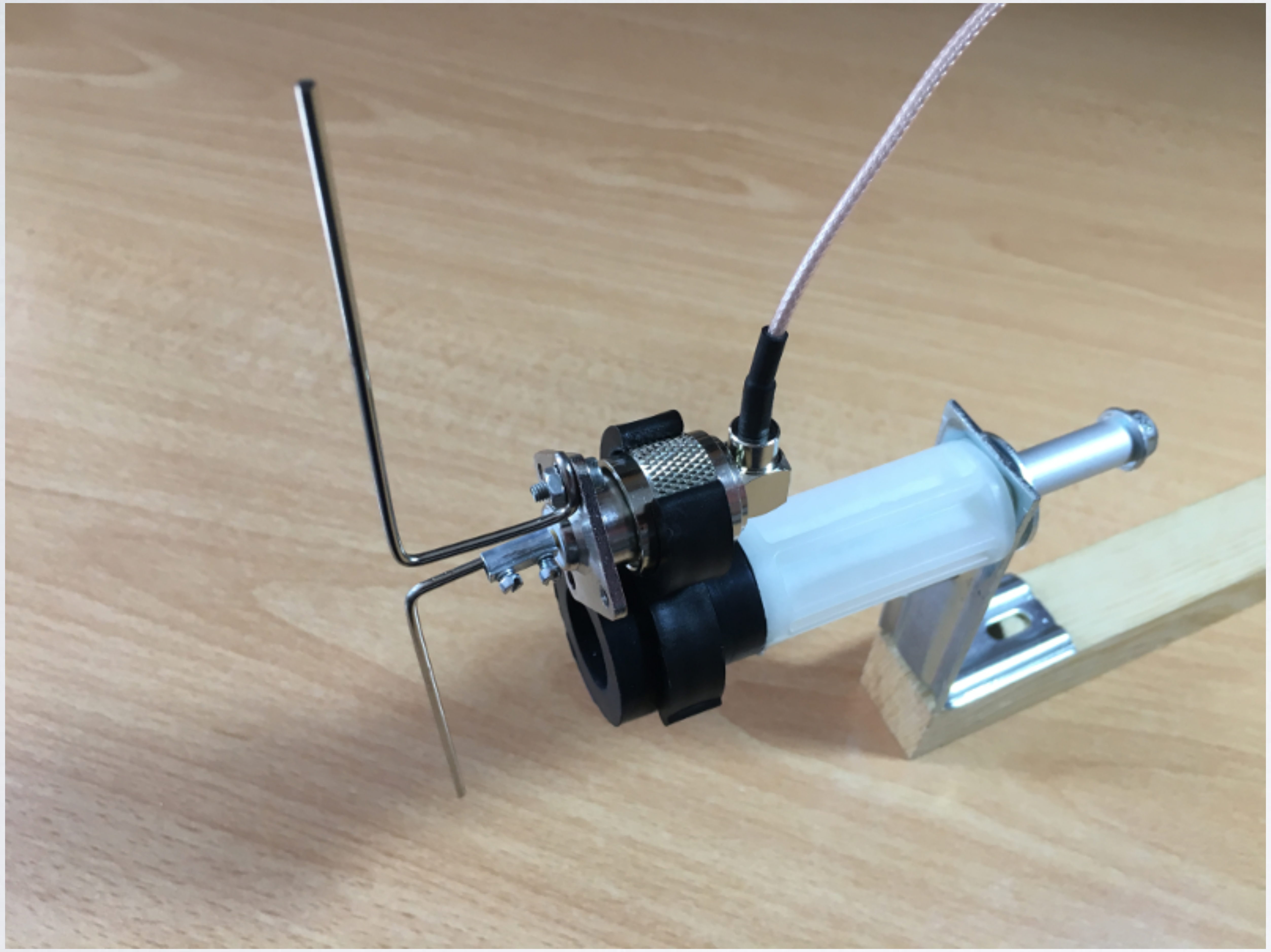






COLLINEAR ANTENNA | PERFORMANCE TEST B

- This ½λ dipole antenna is used in this setup, see tutorial 41.



VSWR ≈ 1.1
Z ≈ 54Ω
S11 ≈ -27 dB

COLLINEAR ANTENNA 1 PERFORMANCE TEST B

- The logged data can be found at:
  https://www.mobilefish.com/download/lora/collinear_antenna_gain.txt

- The average RSSI when using the ½λ dipole antenna: -26.8 dBm
  The average RSSI when using collinear antenna 1: -29.5 dBm

COLLINEAR ANTENNA 1 PERFORMANCE TEST B

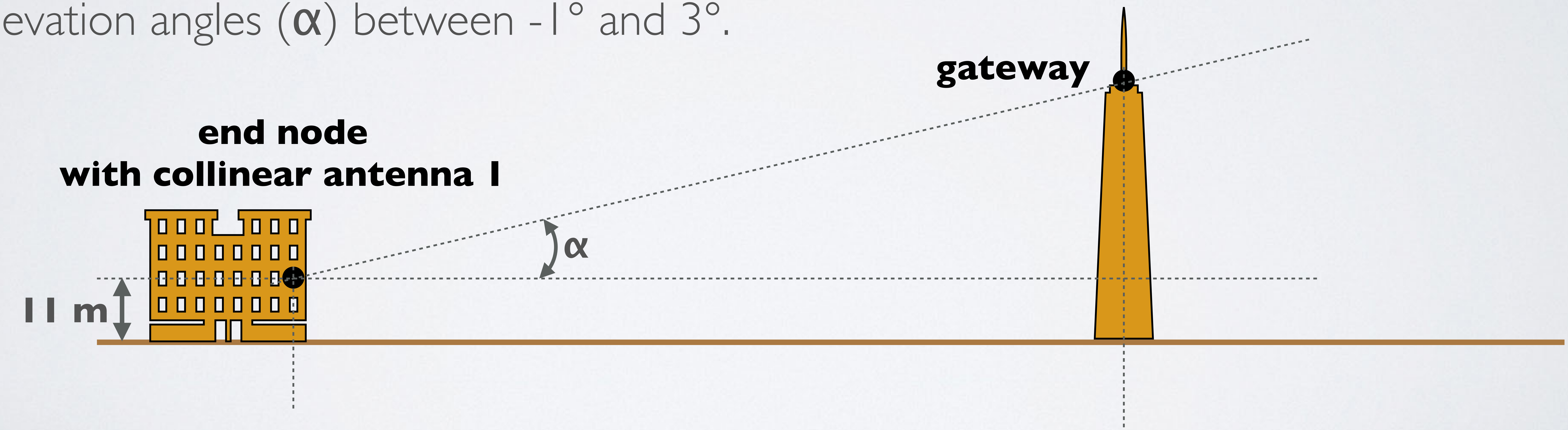
- The time it took for the gateway to receive the 15 messages from the end node:
  Using the ½λ dipole antenna: 15 minutes
  Using collinear antenna 1: 16 minutes

- The Arduino sketch is configured to transmit 2 message per minute. In a perfect situation it should take 7.5 to 8 minutes to transmit these 15 messages.

COLLINEAR ANTENNA 1 CONCLUSION

- Based on the results of performance test A and B, I conclude that the collinear antenna 1 performance is quite similar to the ½λ dipole antenna. If I ONLY look at elevation angles (α) between -1° and 3°.

- This assumption is supported by comparing the 4NEC2 radiation pattern in the vertical plane between the ½λ dipole antenna and the collinear antenna 1 at elevation angles (α) between -1° and 3°.



Collinear Antenna 2

COLLINEAR ANTENNA 2

- As mentioned in the beginning of this presentation there are two collinear designs.

- Let's try the other design, collinear antenna 2:
  https://github.com/IRNAS/ttn-irnas-gw/
  Attention: I have made some modifications to this design.

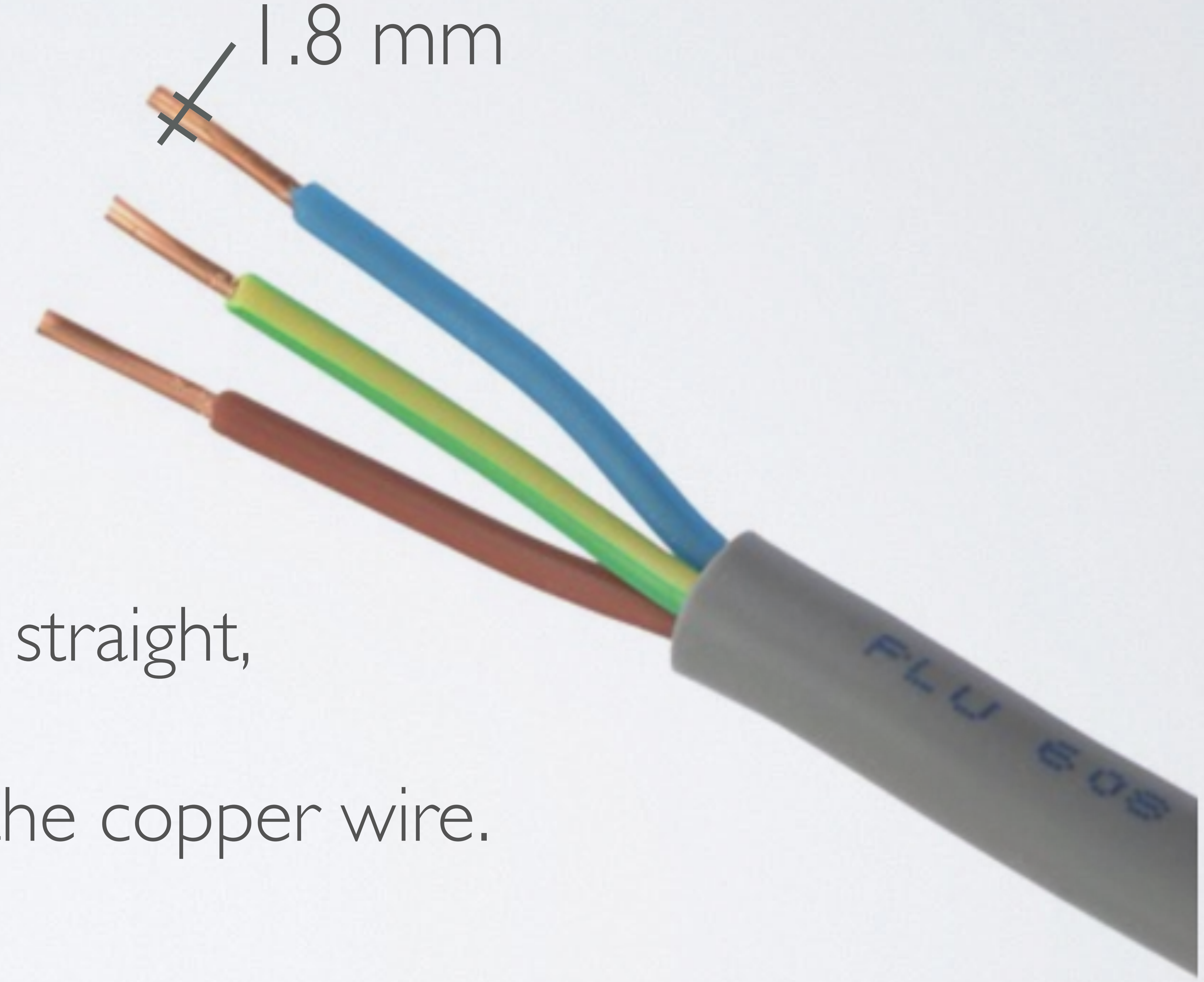
- 4NEC2 card deck:
  https://www.mobilefish.com/download/lora/collinear2_868mhz_4nec2.nec.txt

BUILD COLLINEAR ANTENNA 2

- Bill of materials
  - Type N female chassis mount 4-hole connector
    LxW: 2.5 x 2.5 cm / 1" x 1"
    Hole diameter: 3.5 mm / 0.137"
    Impedance: 50Ω
    Material: Metal alloy
    Cost: € 0.96

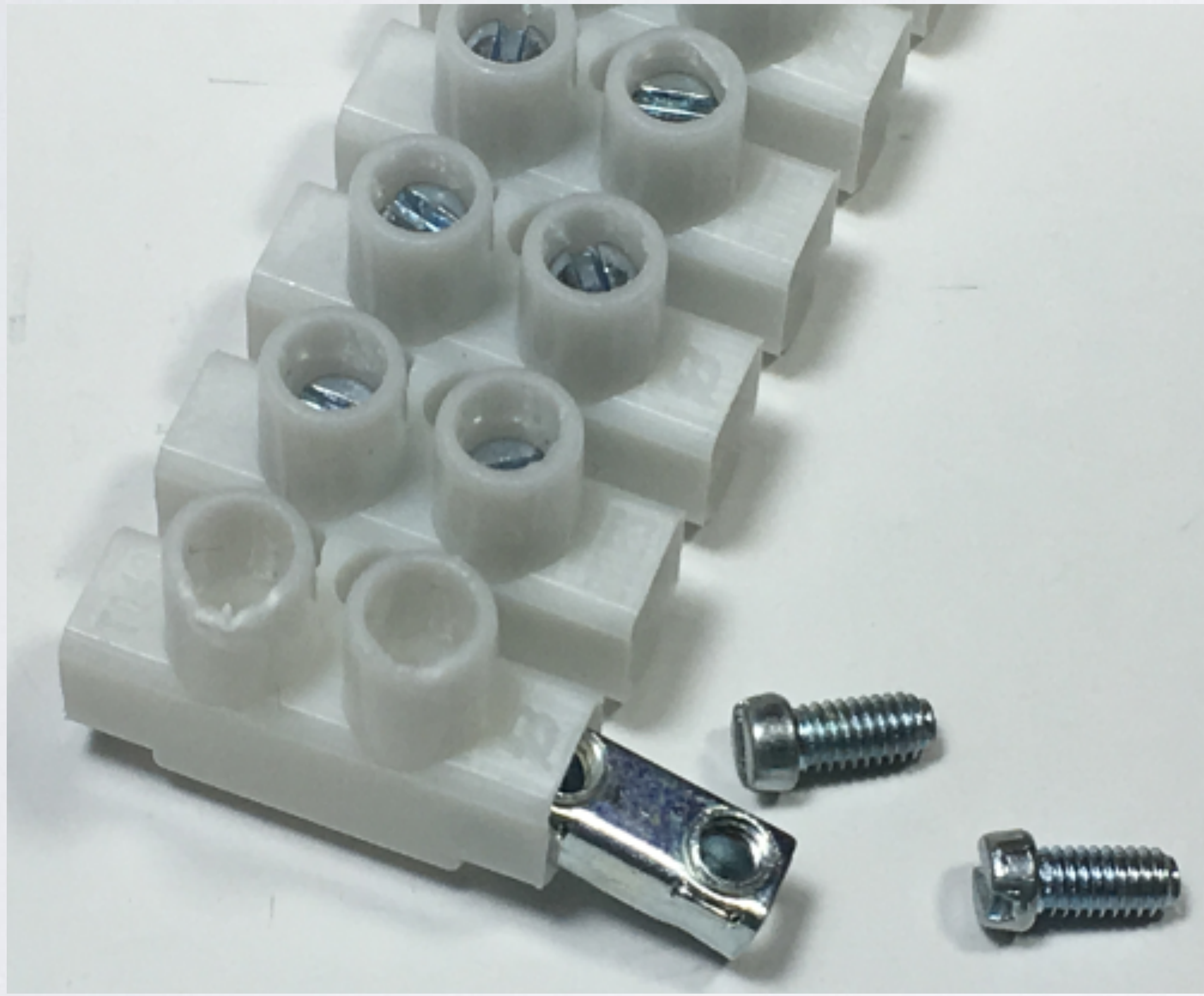
BUILD COLLINEAR ANTENNA 2

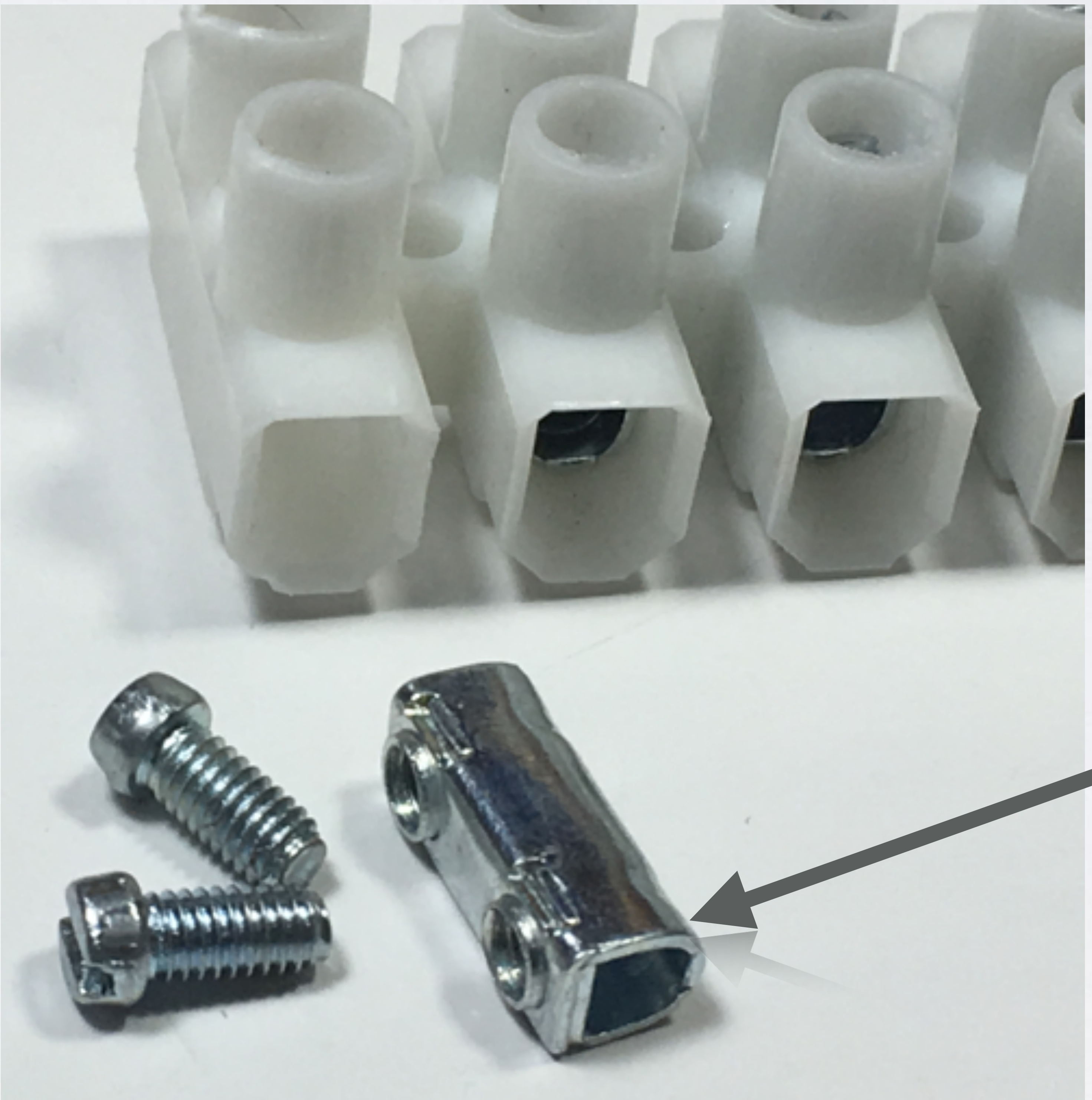
- Outdoor cable XMVK 3x2.5 mm^2 grey.
  The copper wire has a diameter of 1.8 mm.
  Only 1 meter is needed.
  Cost: € 1.75 per meter
- The electrical insulator can be easily removed using a Stanley knife.
- The copper wire can be stretched out.
  The stretched out wire will be stiffer, more straight, and the wire diameter will decrease.
  In this tutorial I have **NOT** stretched out the copper wire.

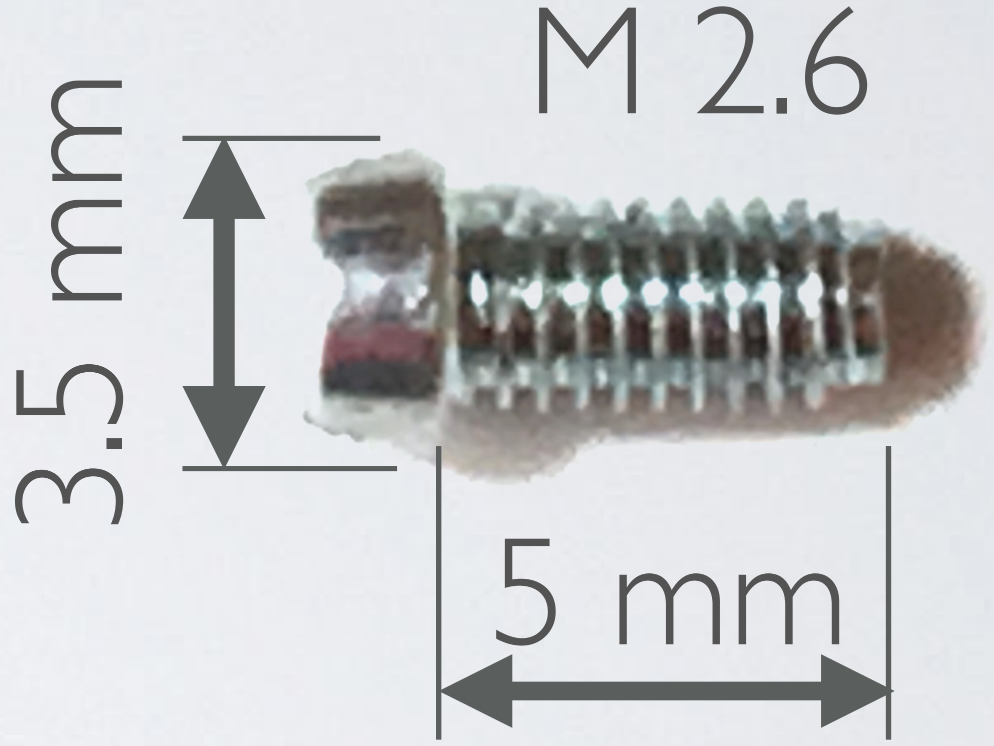


BUILD COLLINEAR ANTENNA 2

- Terminal strip block 1.5-4.0 mm^2
  To be used for wires with a diameter of 1.38 mm - 2.26 mm
  Cost: € 1.98 (2 strips, each strip has 12 terminals)

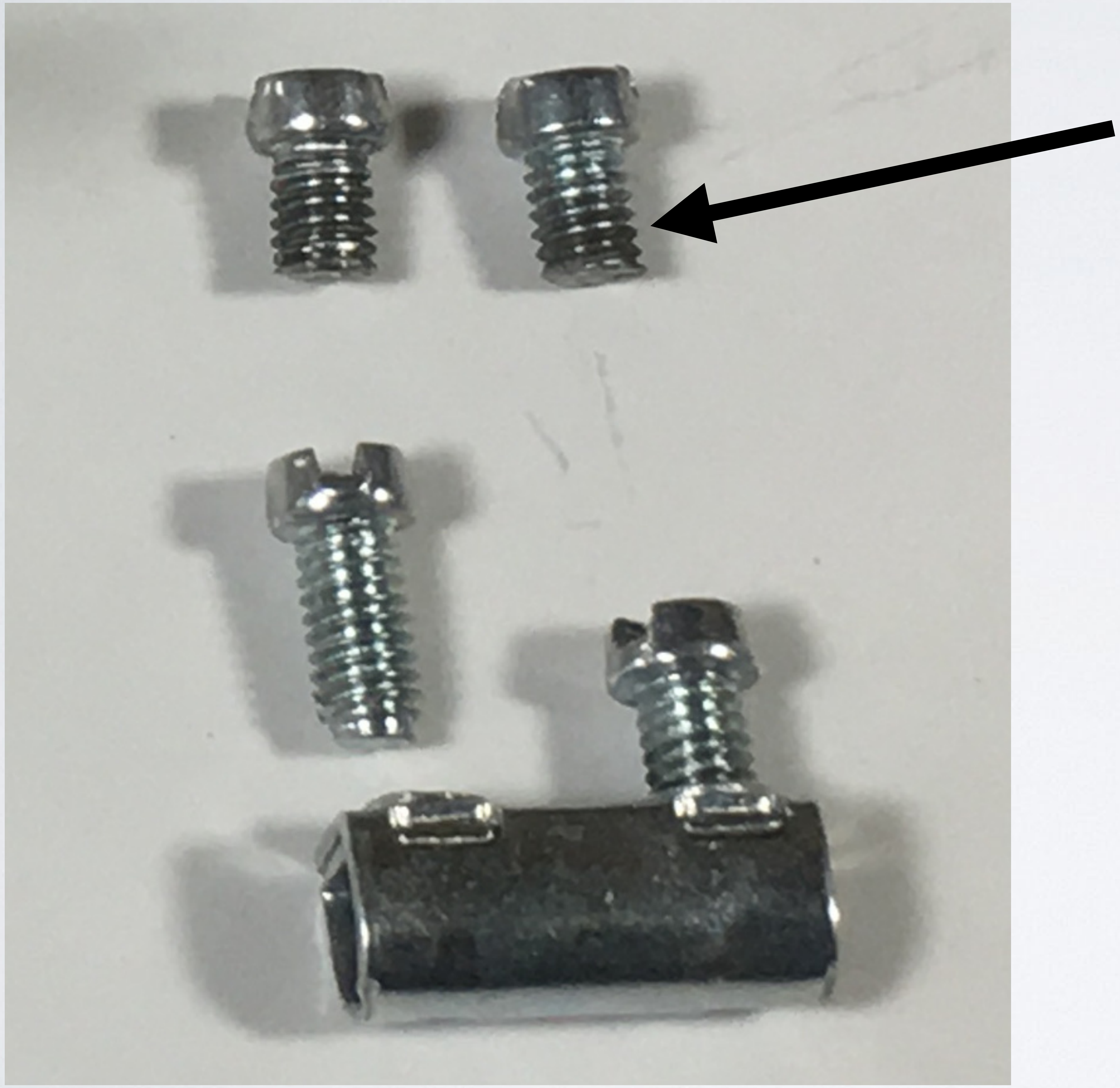




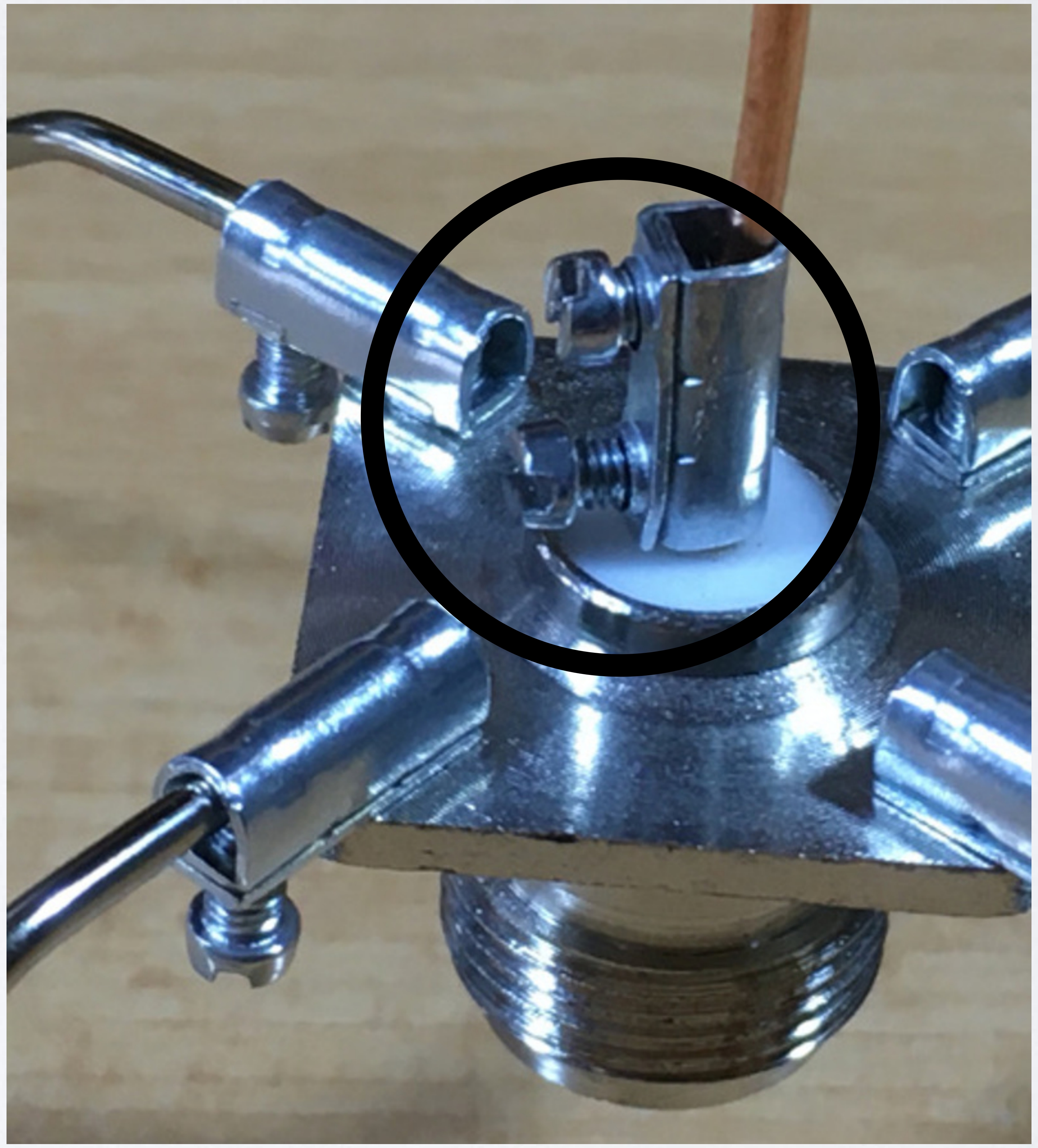


The terminals and screws are tiny. Will not withstand harsh weather conditions.

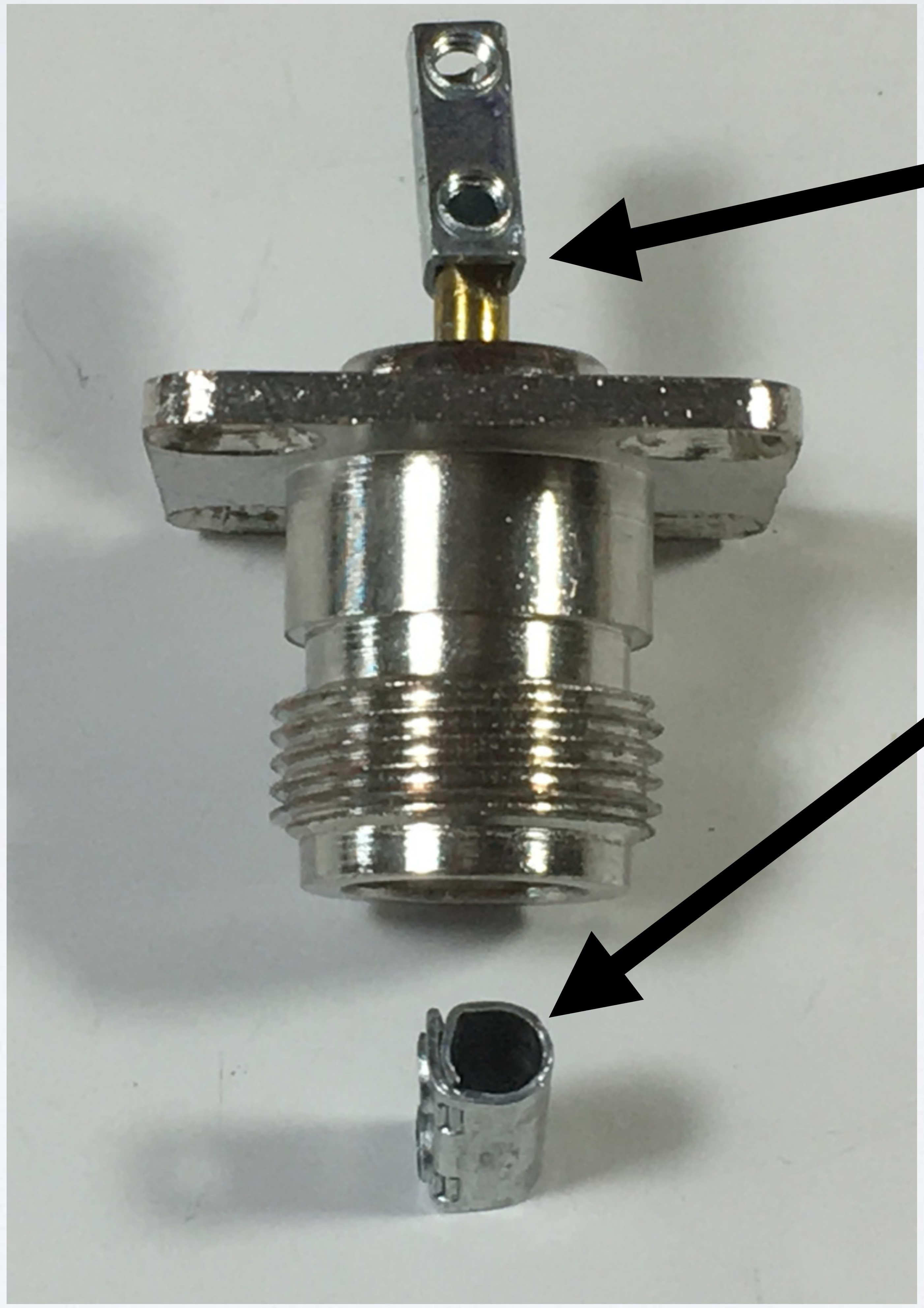
BUILD COLLINEAR ANTENNA 2



Cut the screws in half, so they will not stick out too much. Explained in tutorial 44.



BUILD COLLINEAR ANTENNA 2



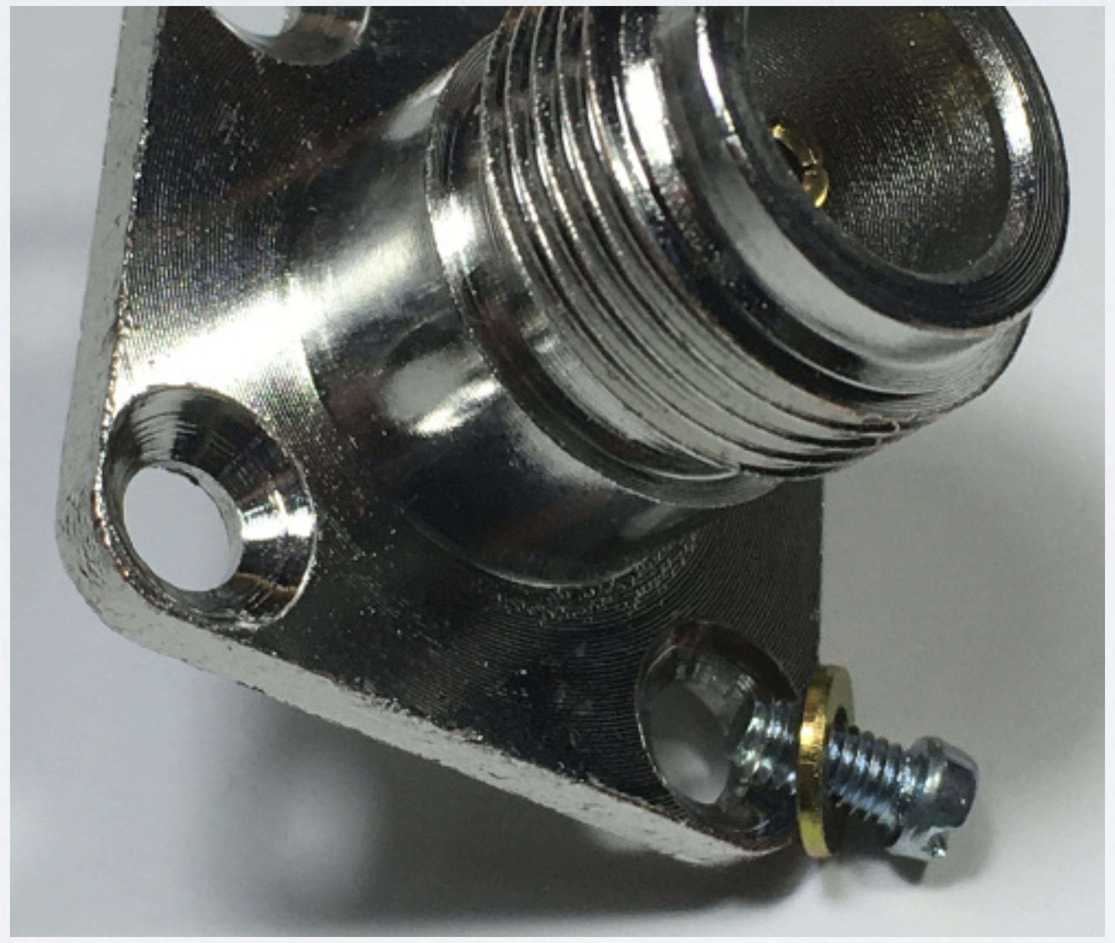
Terminal does not fit.

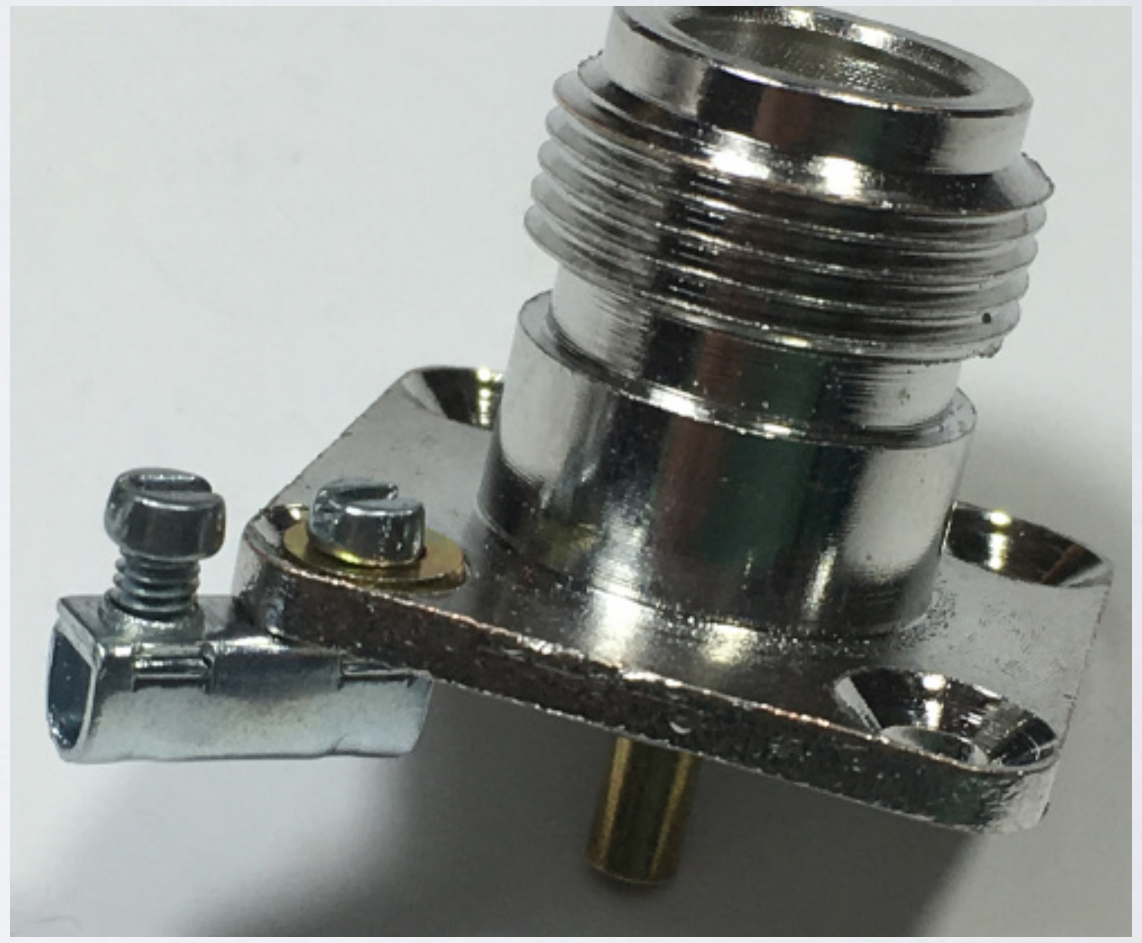
Enlarge the hole of a terminal.

Explained in tutorial 44.

BUILD COLLINEAR ANTENNA 2

- Metal washer M2.5 (DIN 125: 6.0 x 2.7 x 0.5 mm, outer diameter, inner diameter, thickness)
  Cost: € 0.89

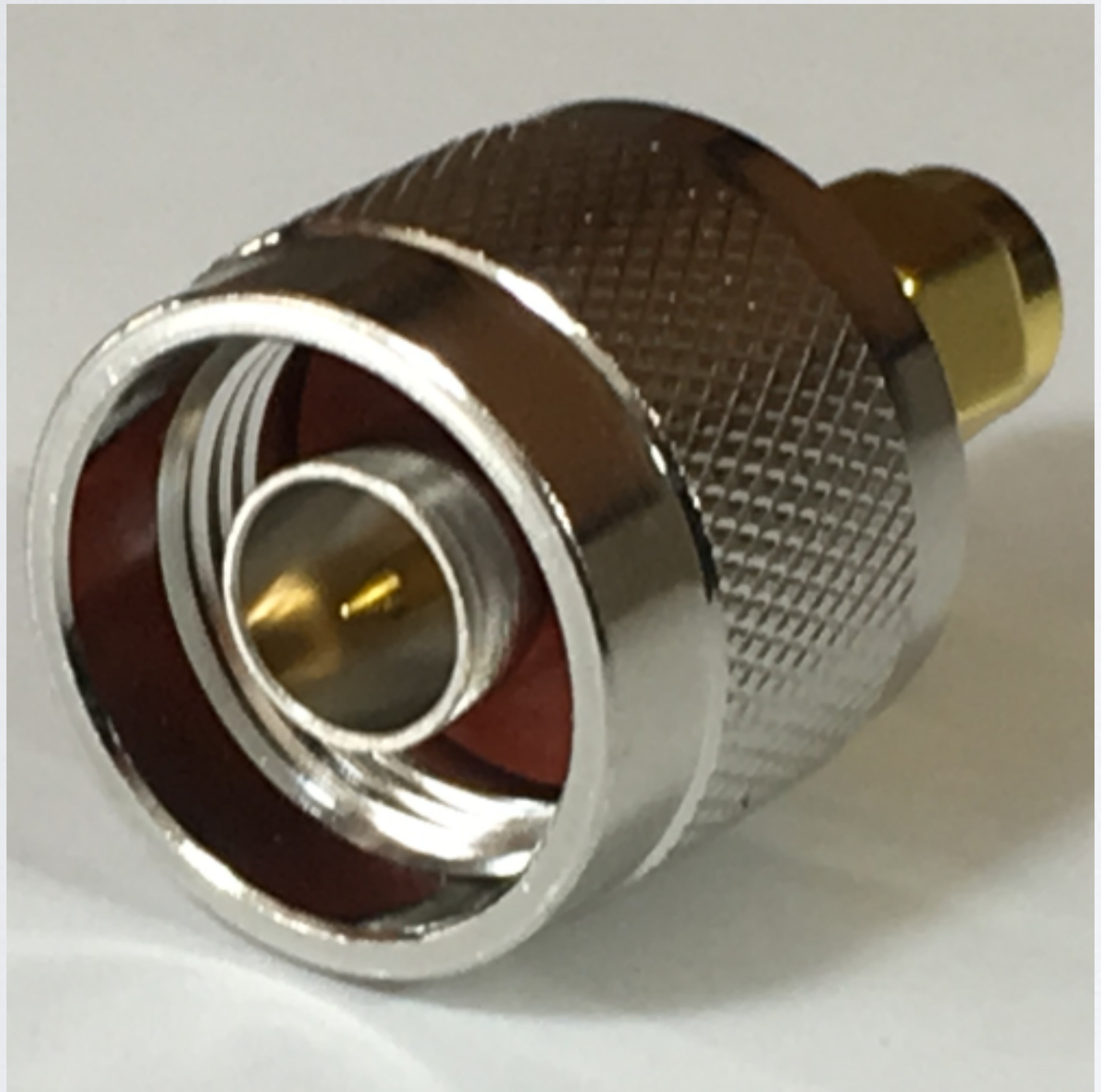


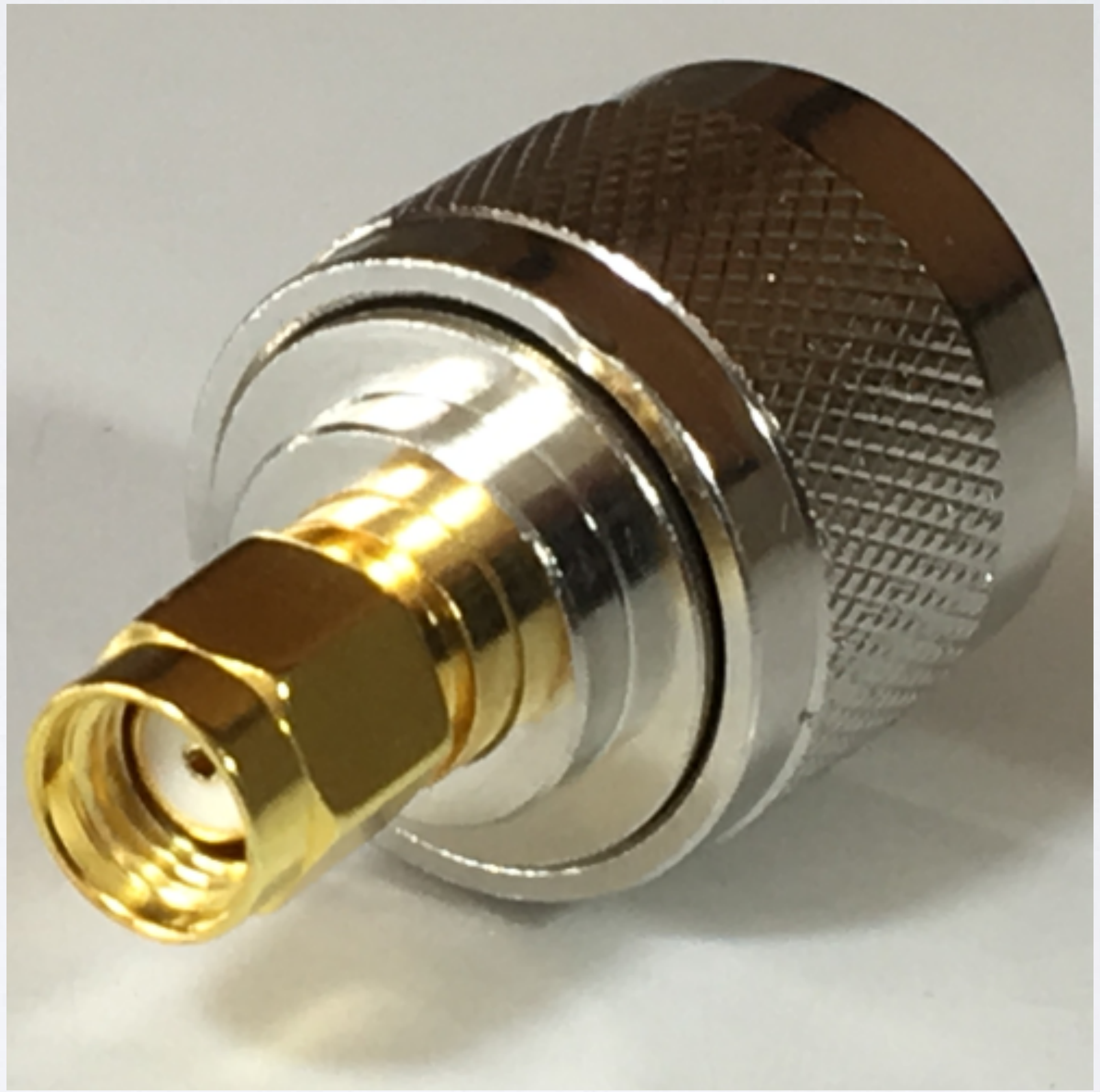


- The terminal screw head diameter (3.5 mm) is the same size as the type N connector hole diameter (3.5 mm) and that is why metal washers are needed.

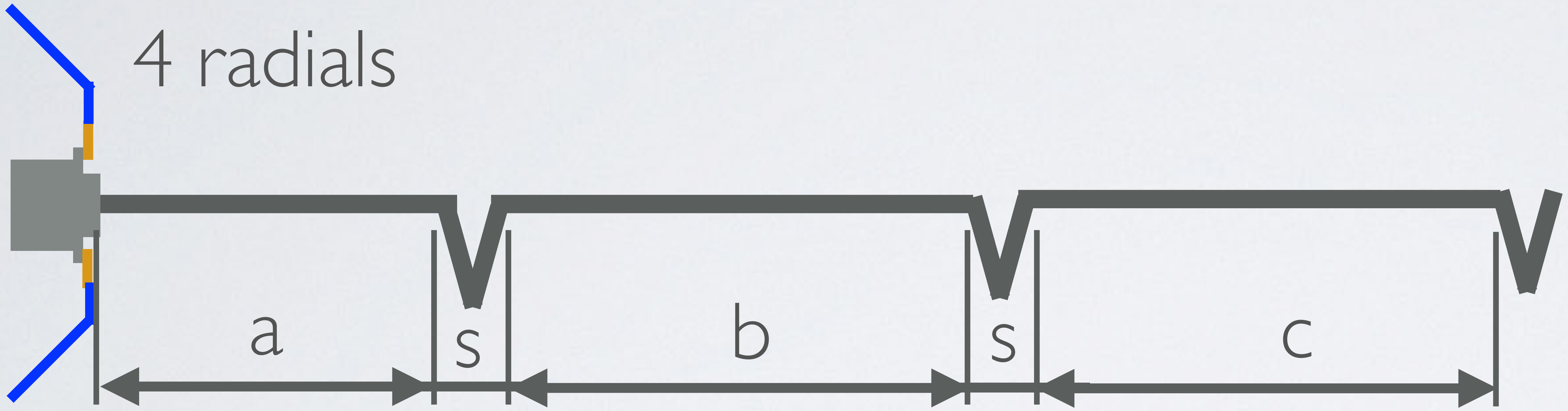
BUILD COLLINEAR ANTENNA 2

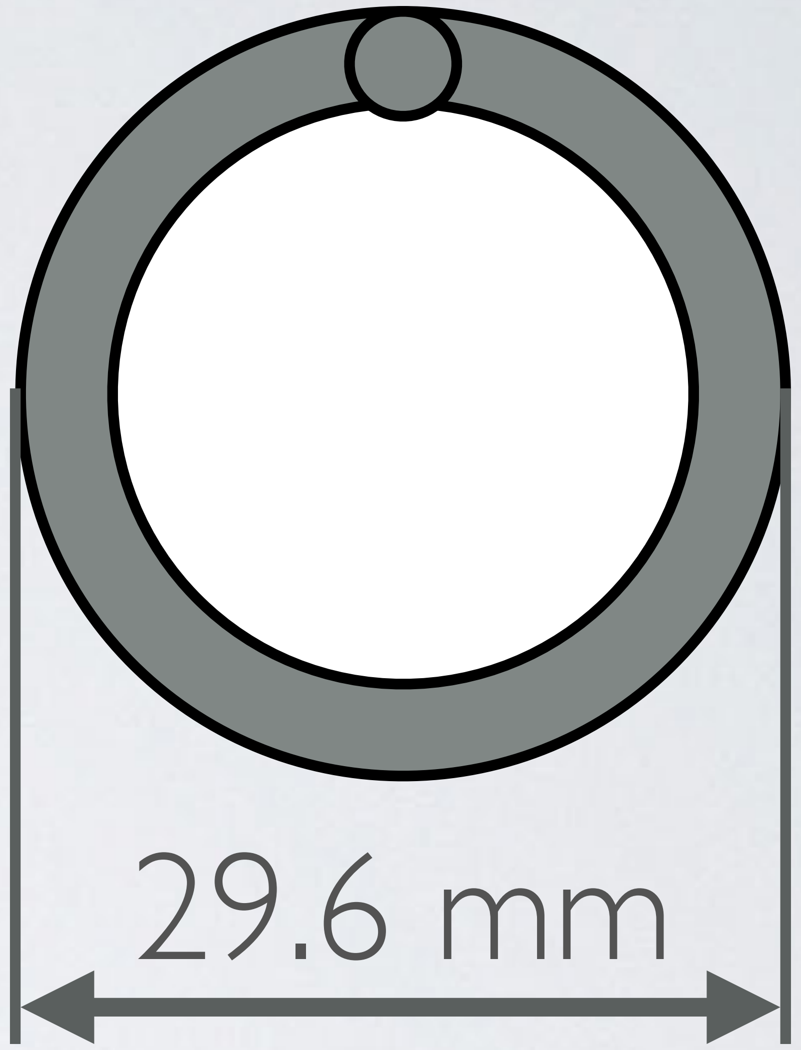
- Type N male to RP-SMA male plug adapter coaxial cable connector.
  Cost: € 1.44



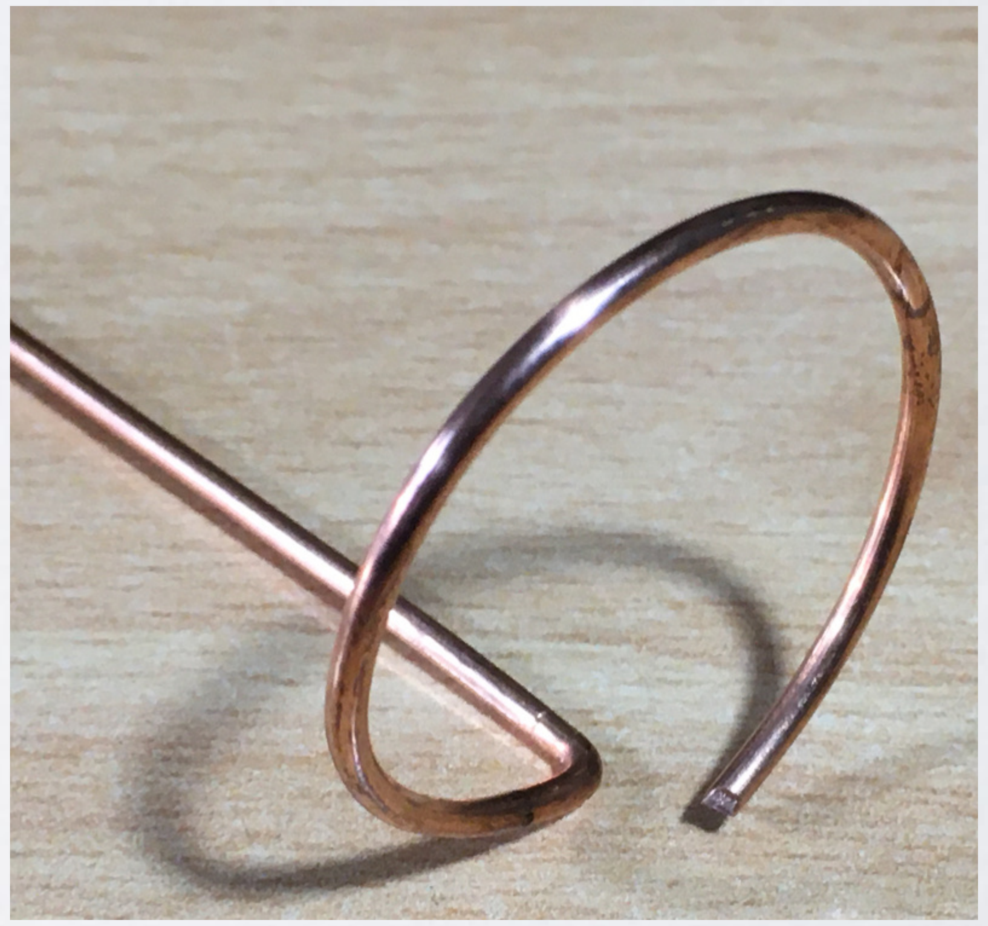


BUILD COLLINEAR ANTENNA 2

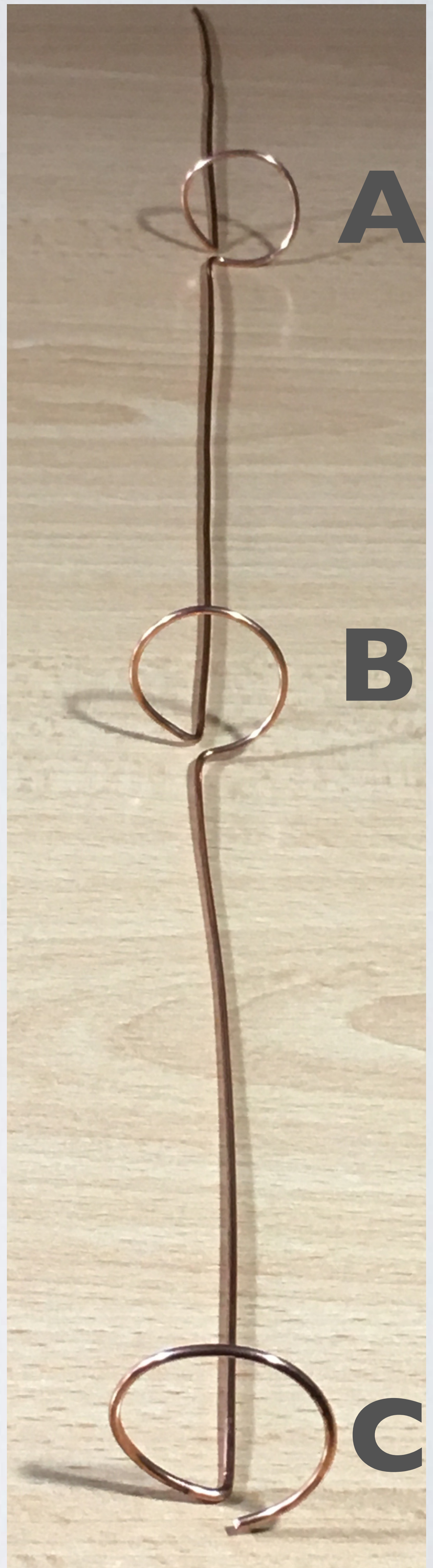




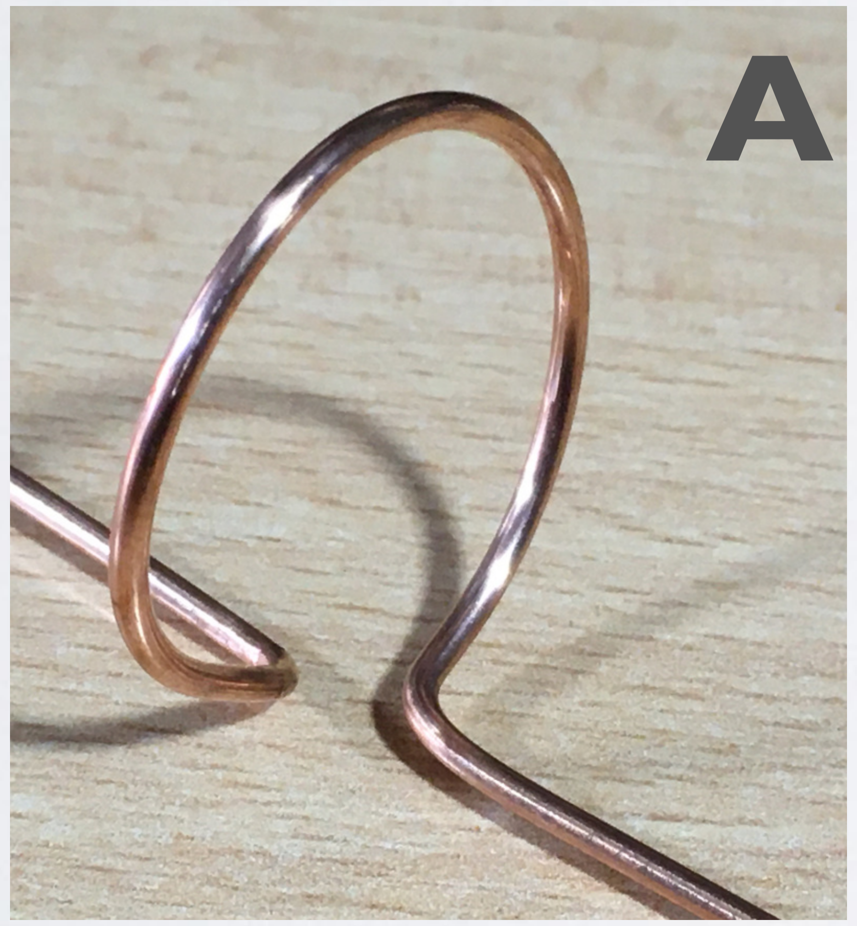
- Length a = 174 mm
  Length b = 221 mm
  Length c = 186 mm
  Spacing s = 4.5 mm
  diameter = 1.8 mm (radiator & radials)
  Material = copper (radiator), stainless steel (radials)

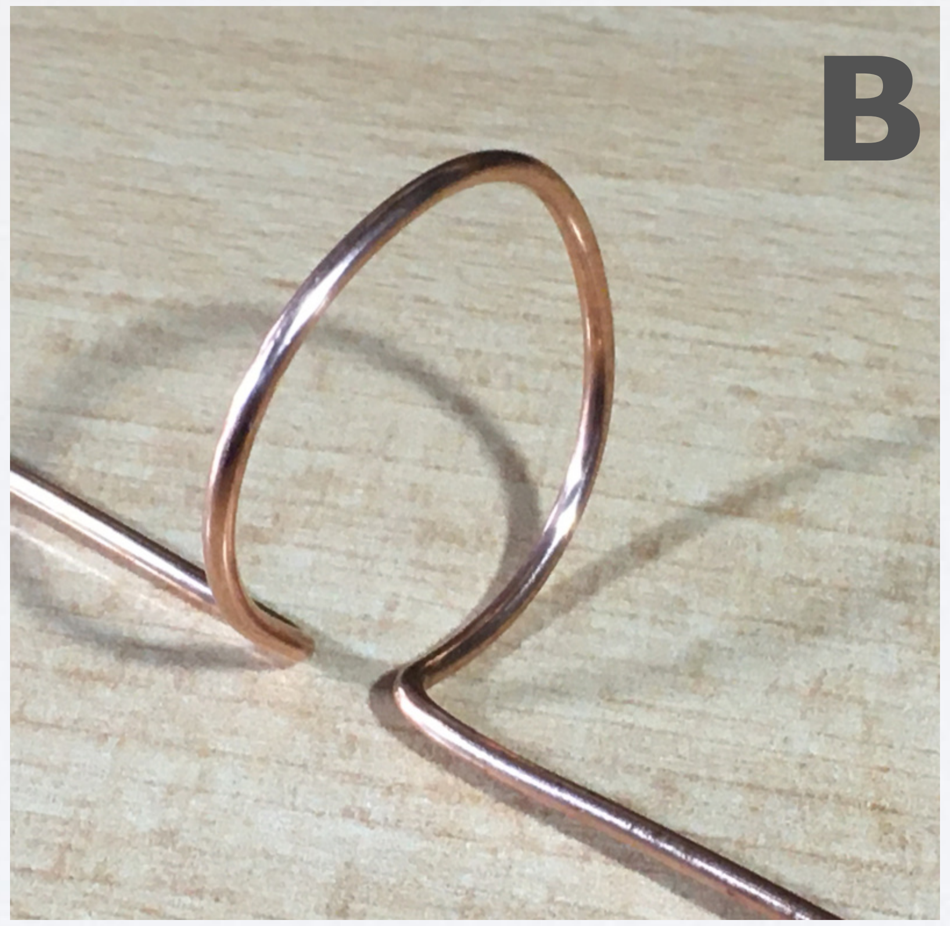


BUILD COLLINEAR ANTENNA 2

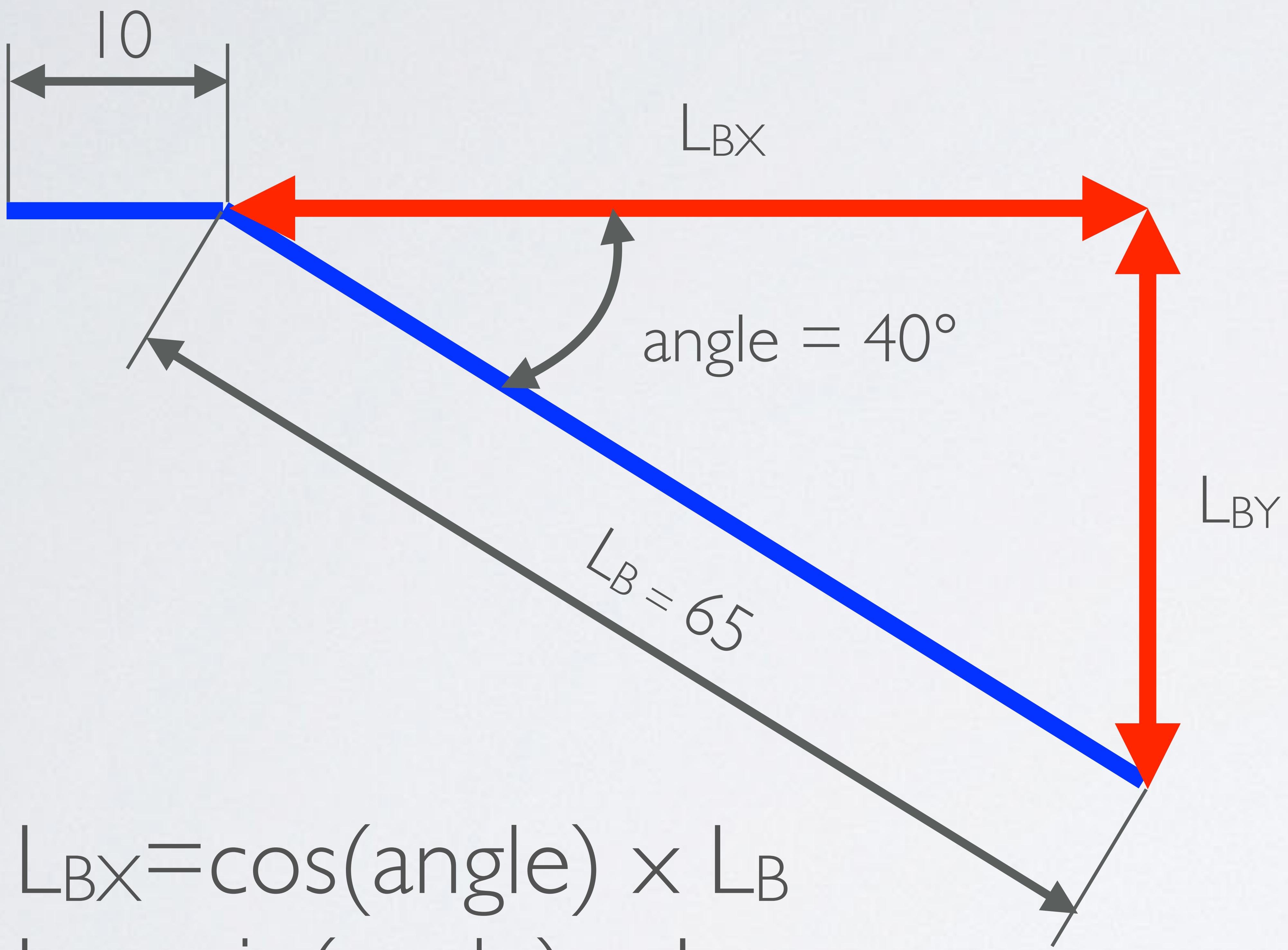


The three loops MUST all be wound in the **same** direction (clockwise or anti-clockwise).





BUILD COLLINEAR ANTENNA 2

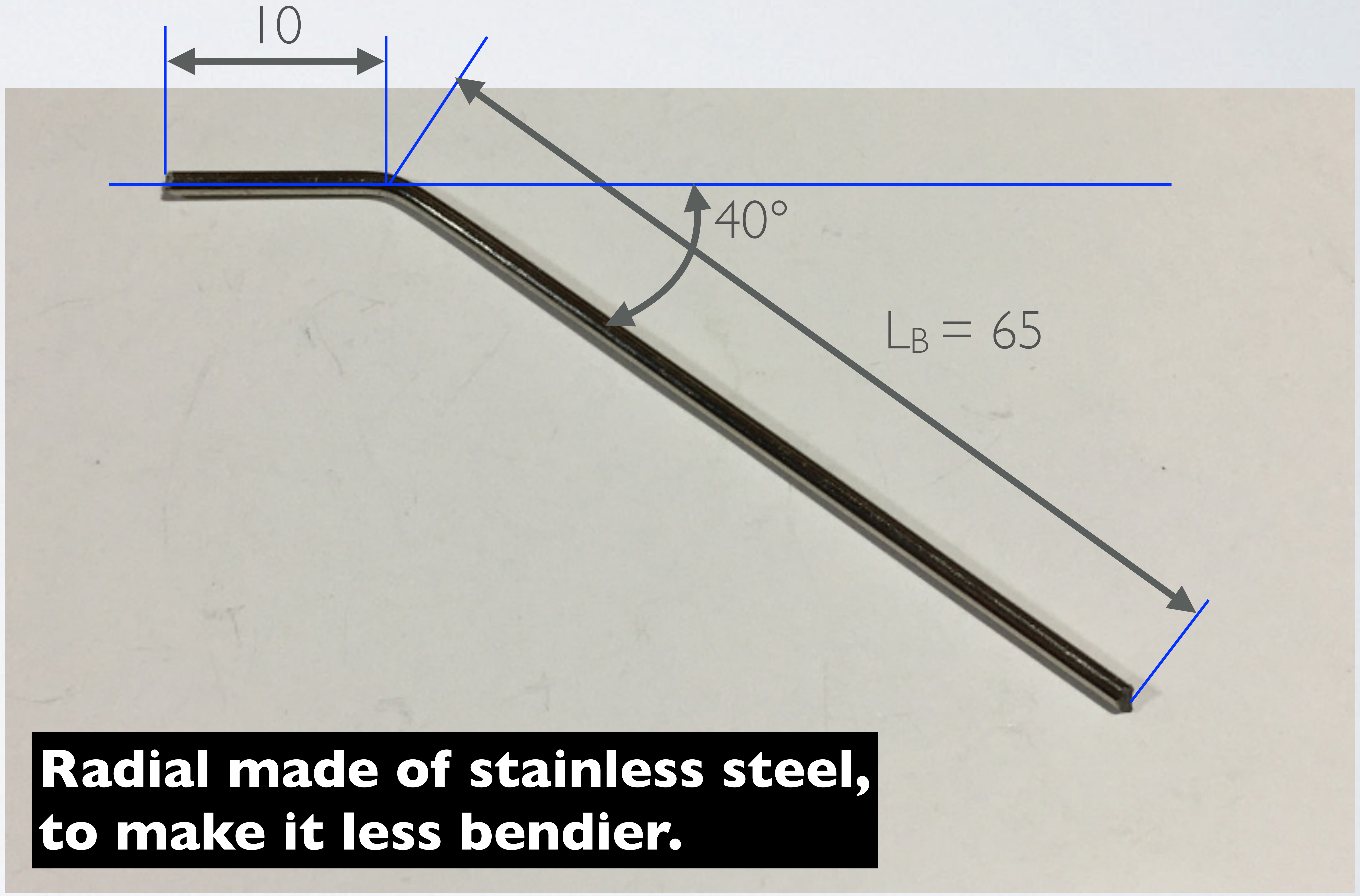


$L_{BX} = \cos(angle) \times L_B$

$L_{BY} = \sin(angle) \times L_B$

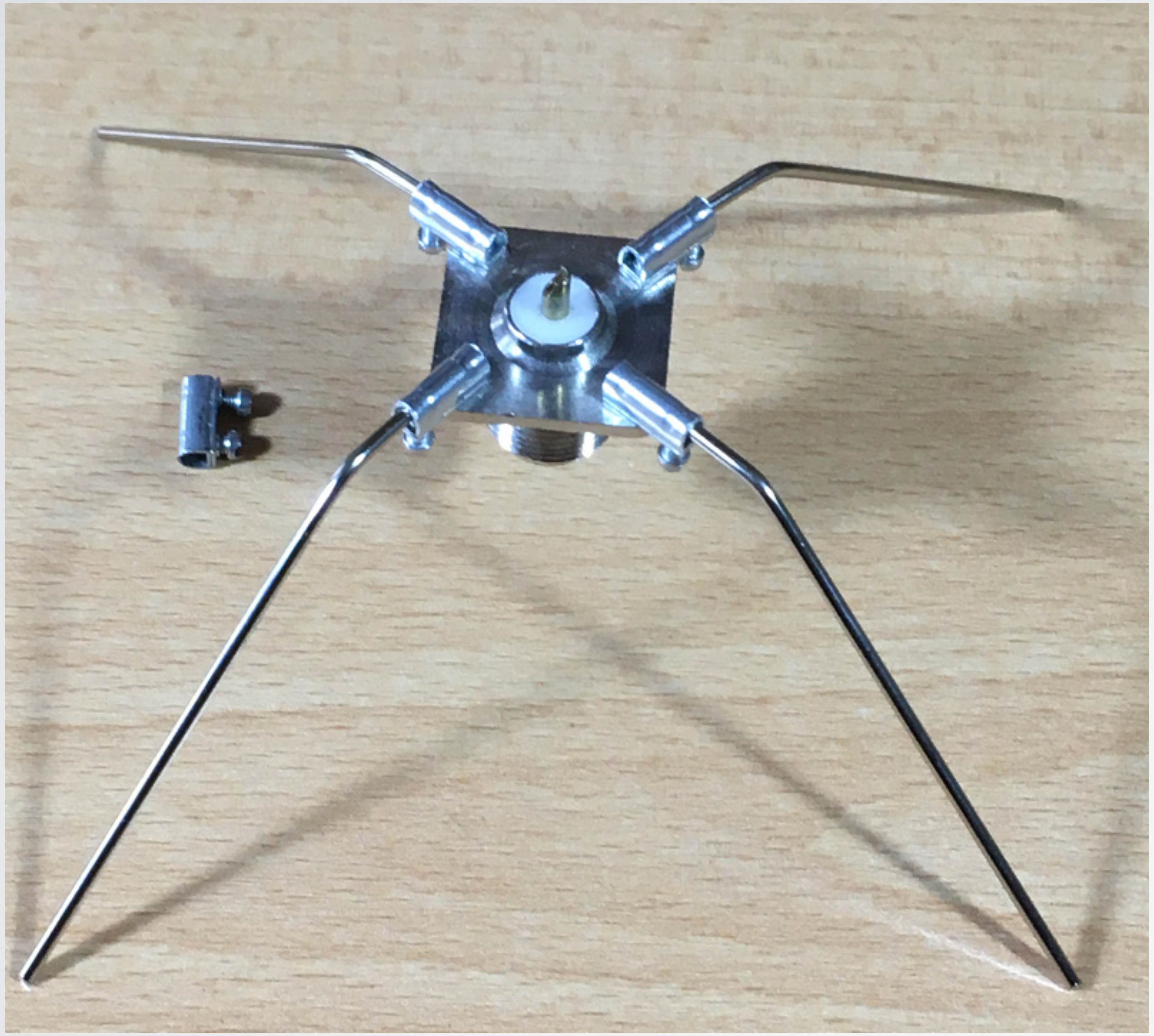
All units in mm

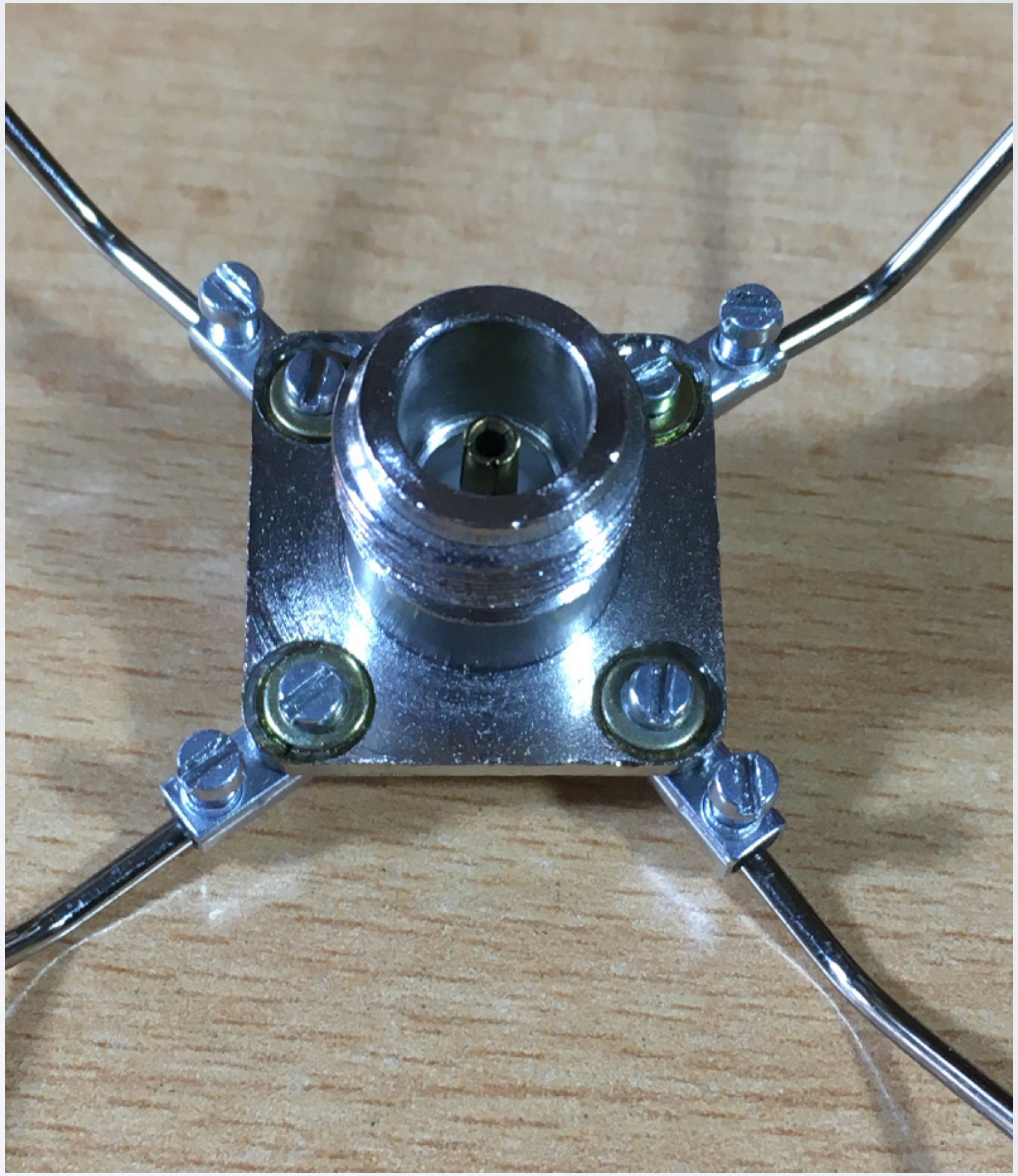
Drawing not to scale



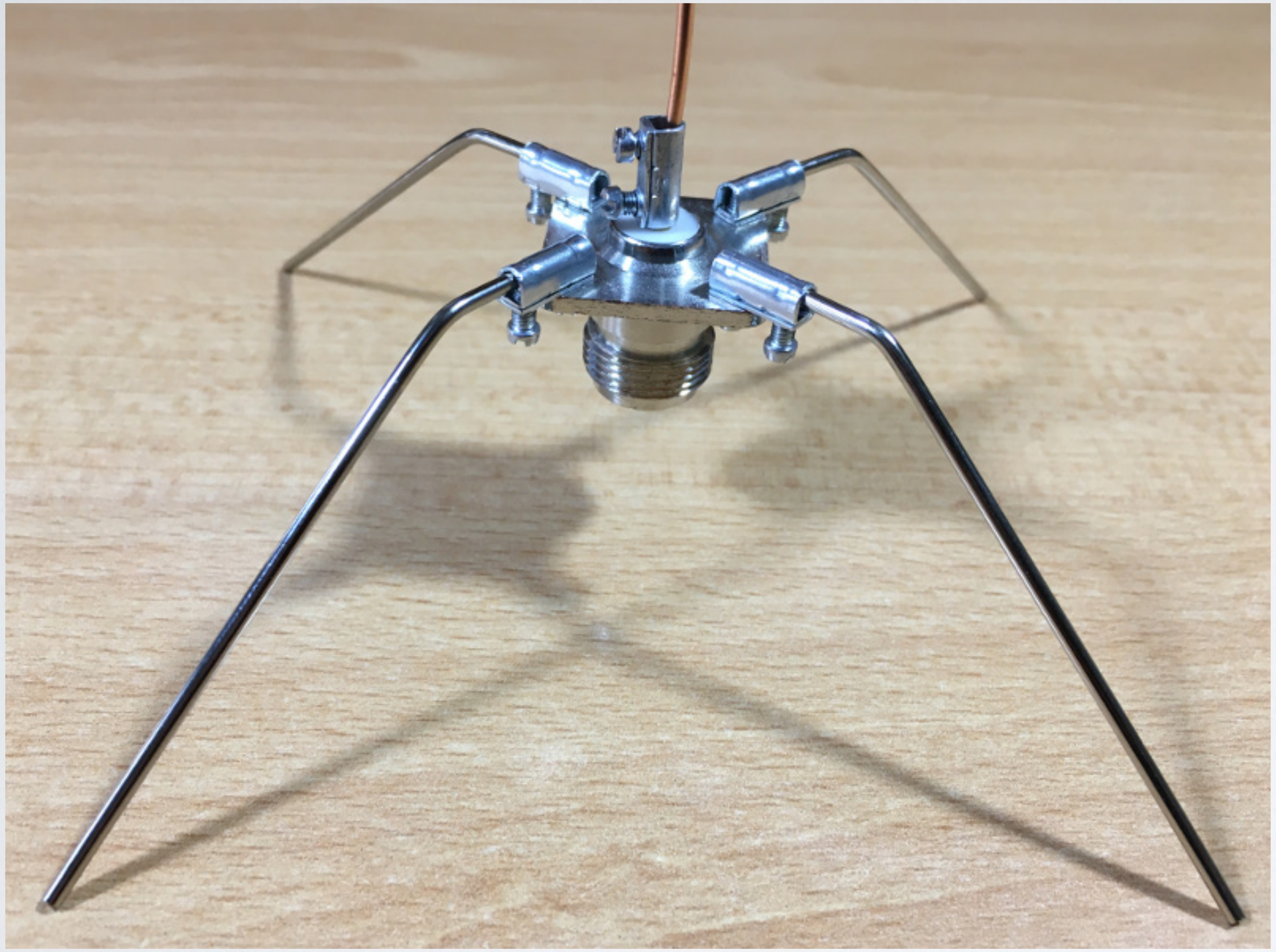
Radial made of stainless steel, to make it less bendier.

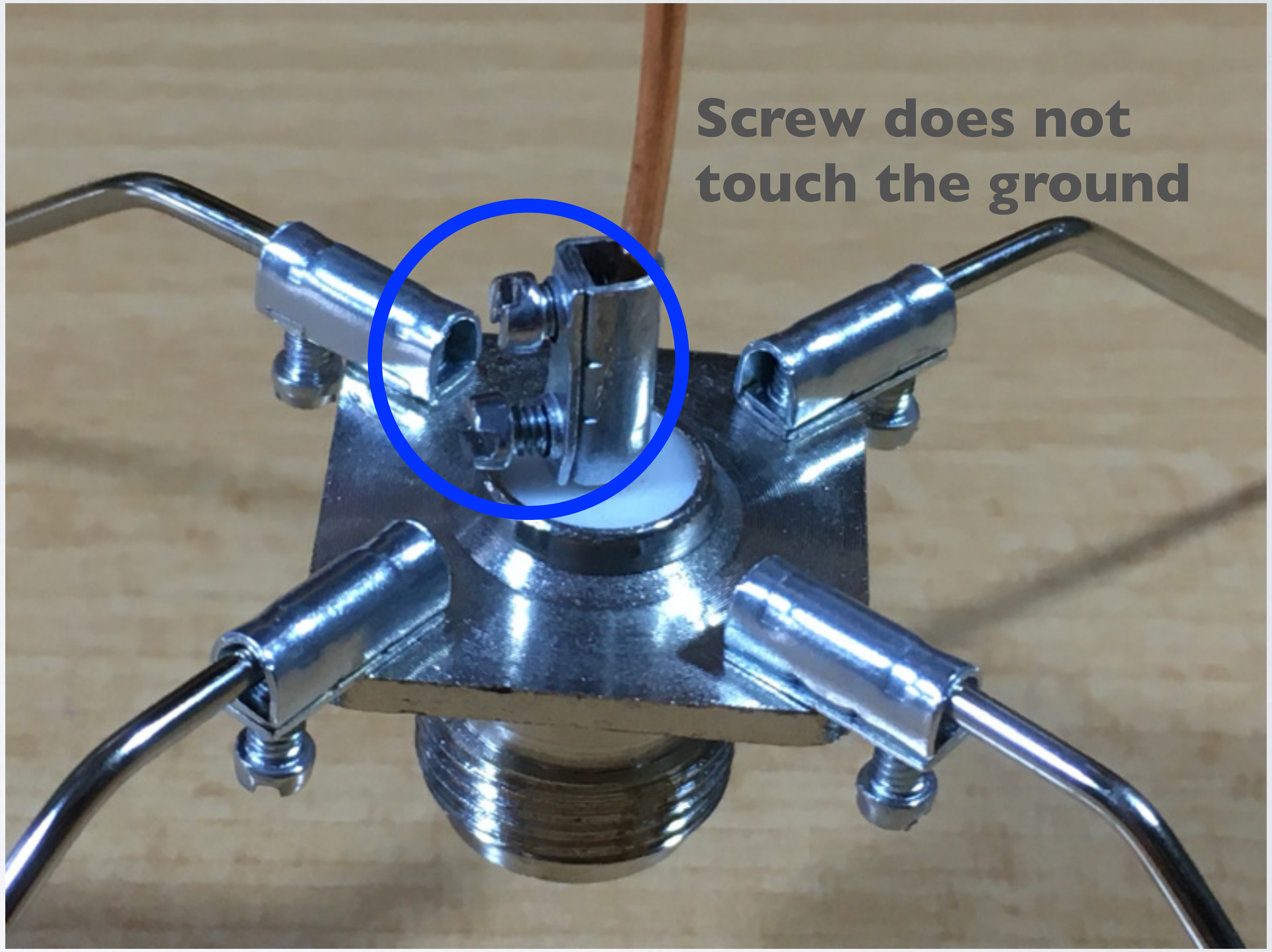
BUILD COLLINEAR ANTENNA 2



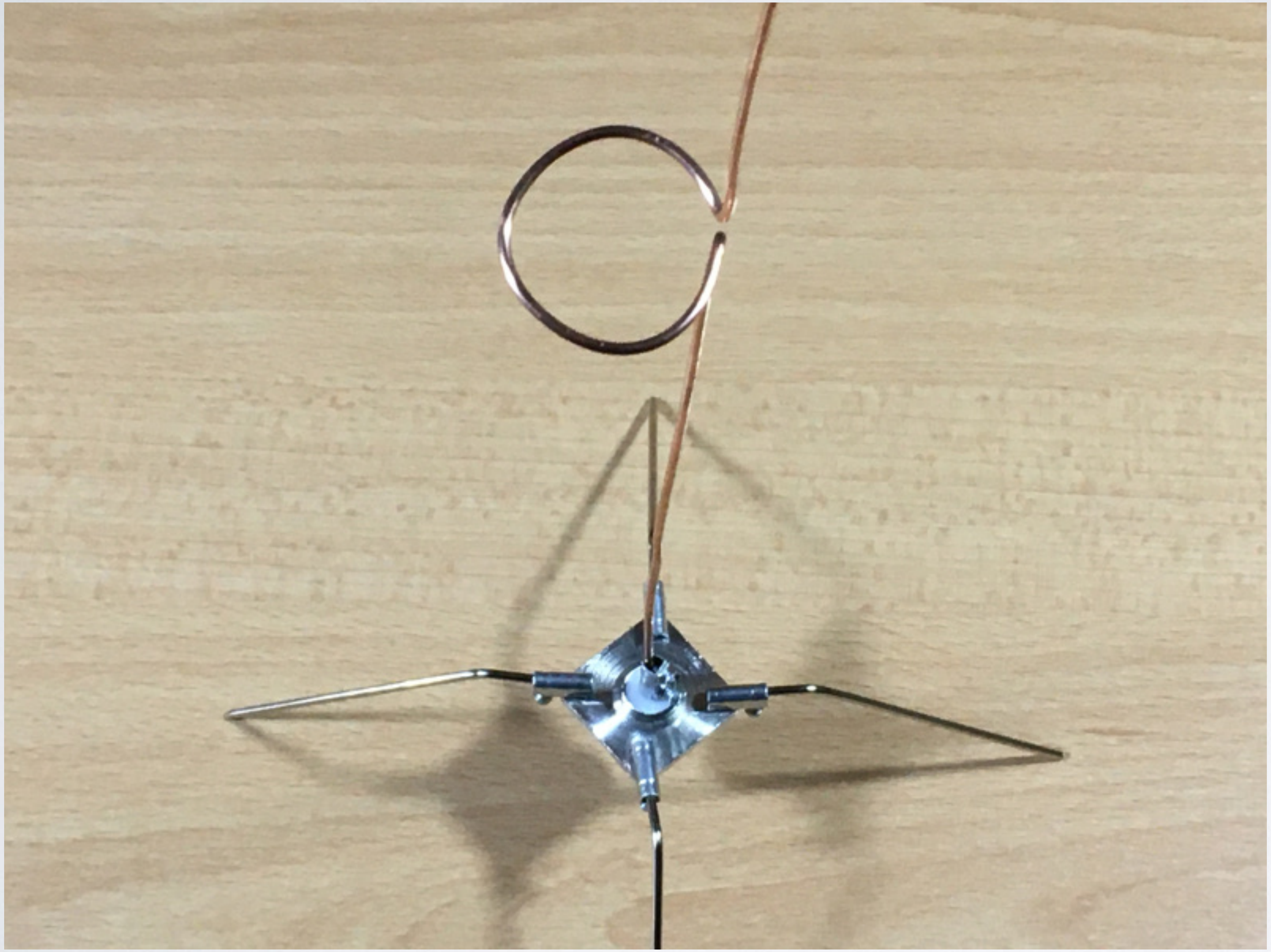


BUILD COLLINEAR ANTENNA 2

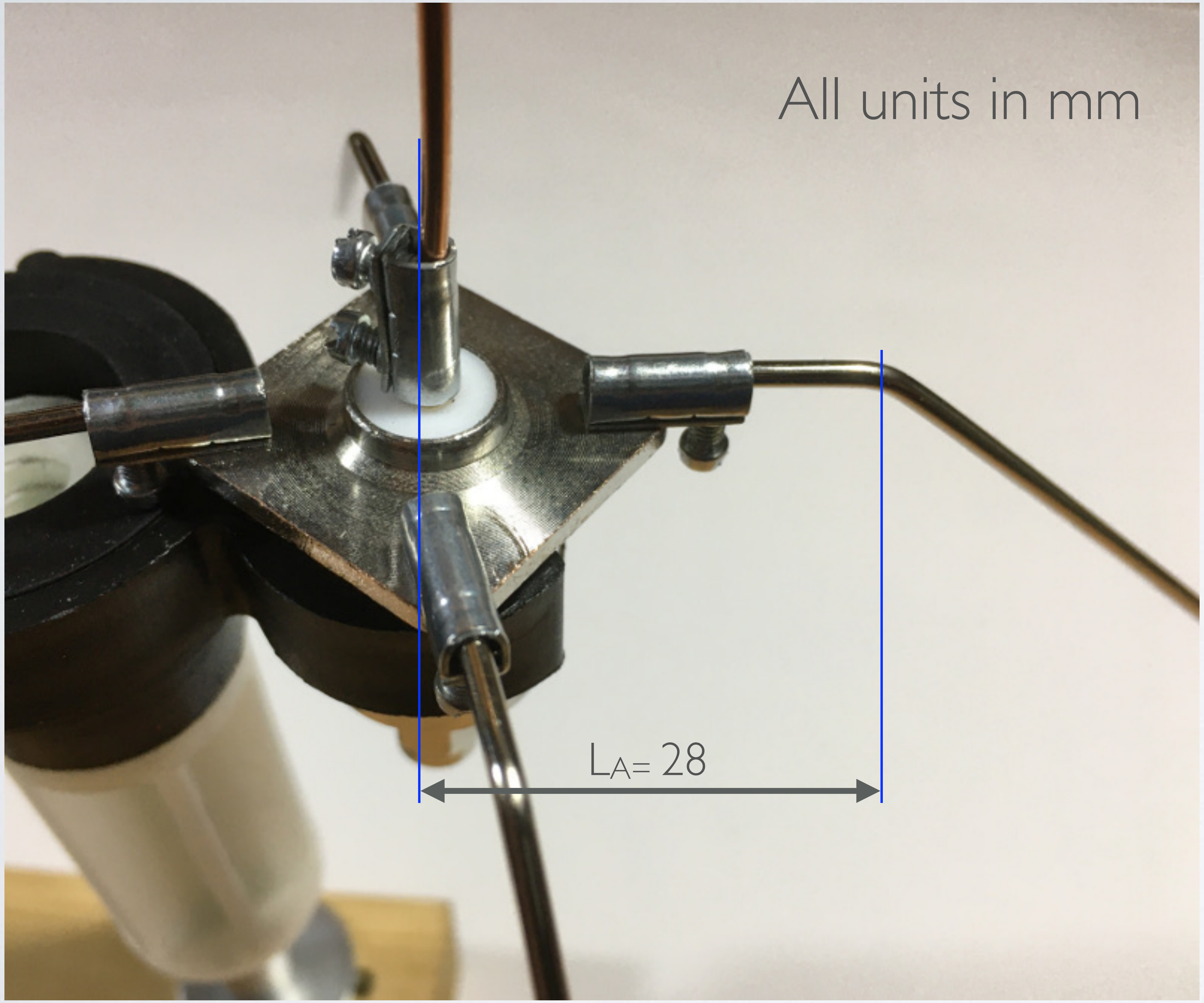


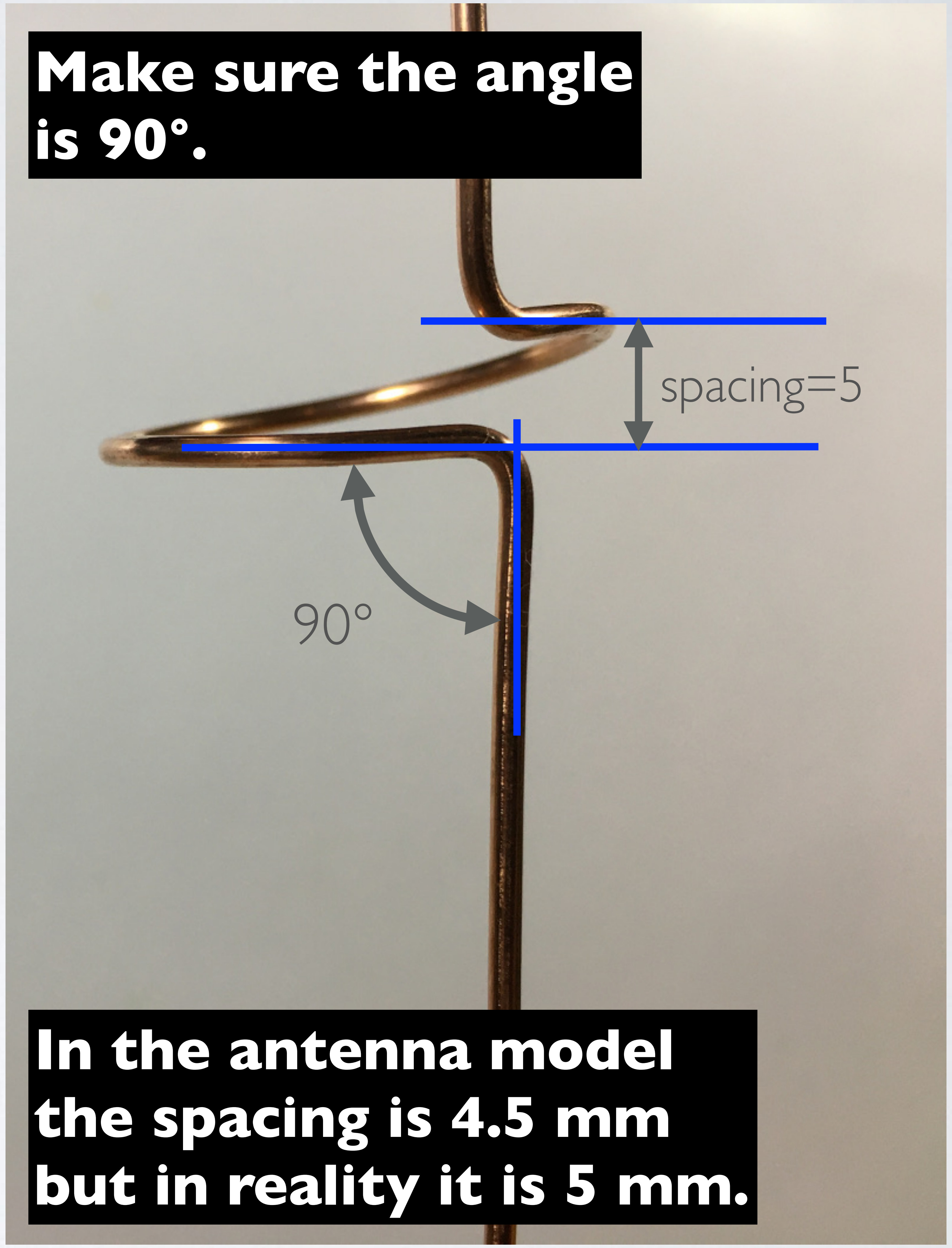


BUILD COLLINEAR ANTENNA 2



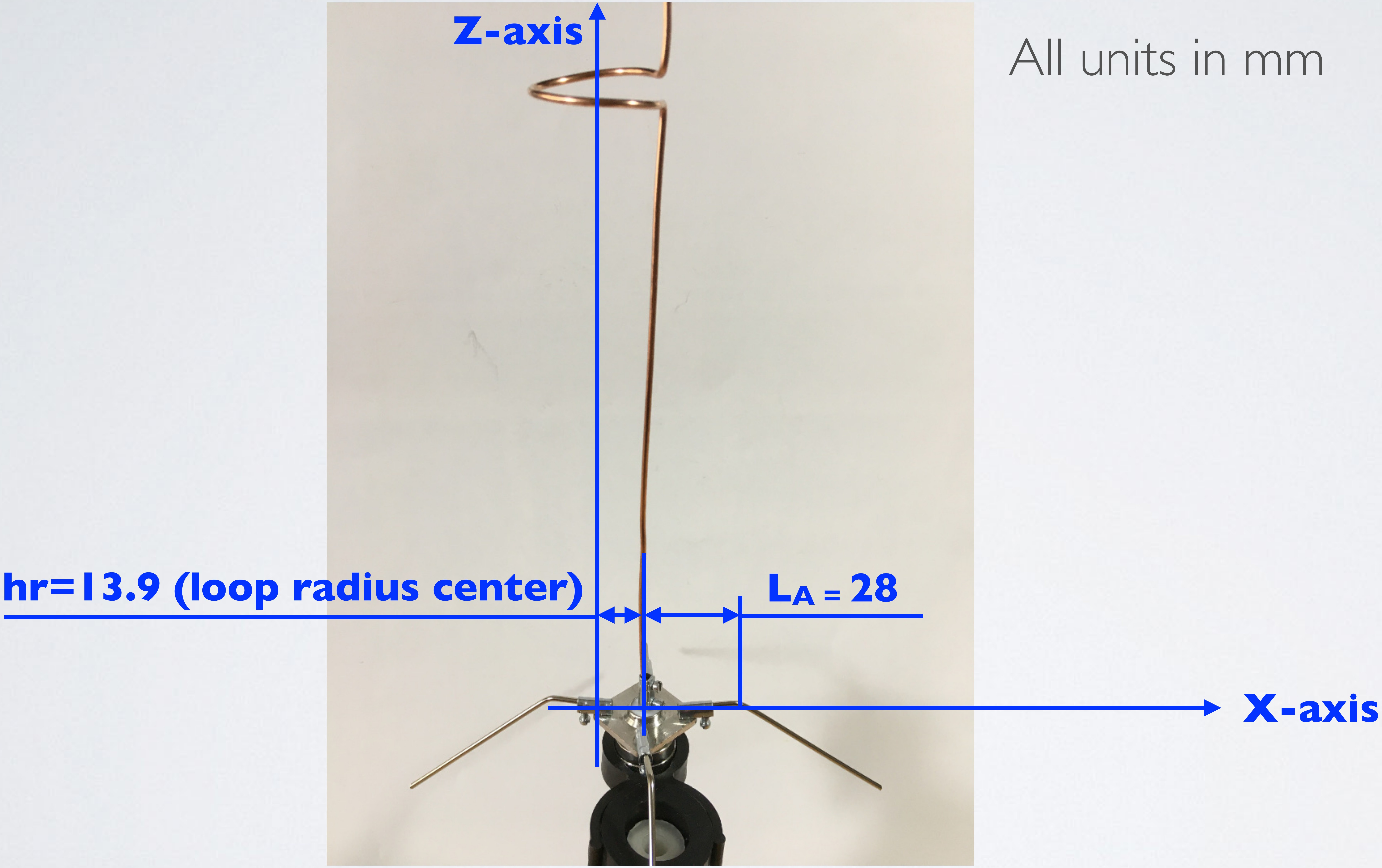
BUILD COLLINEAR ANTENNA 2



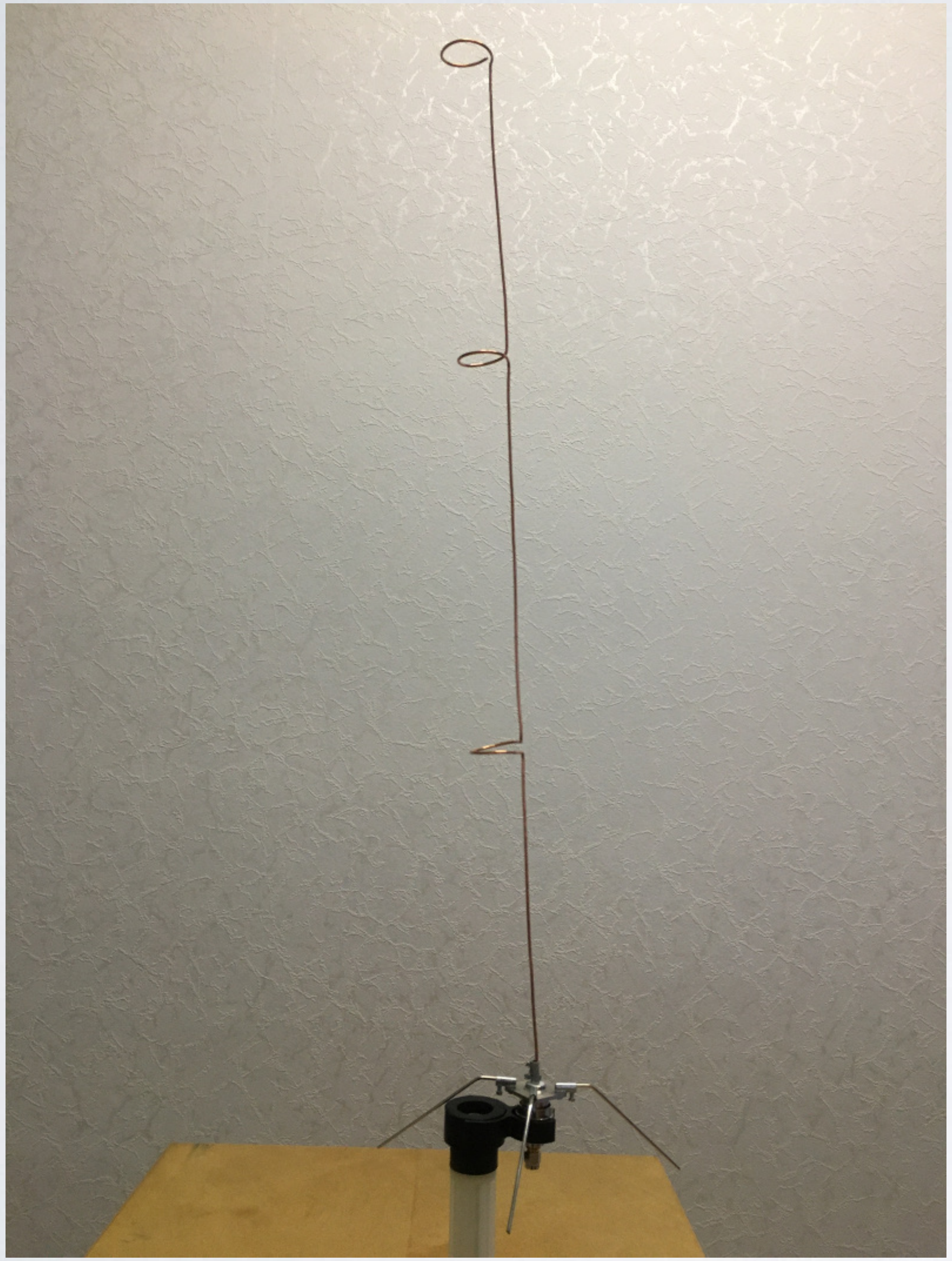


BUILD COLLINEAR ANTENNA 2

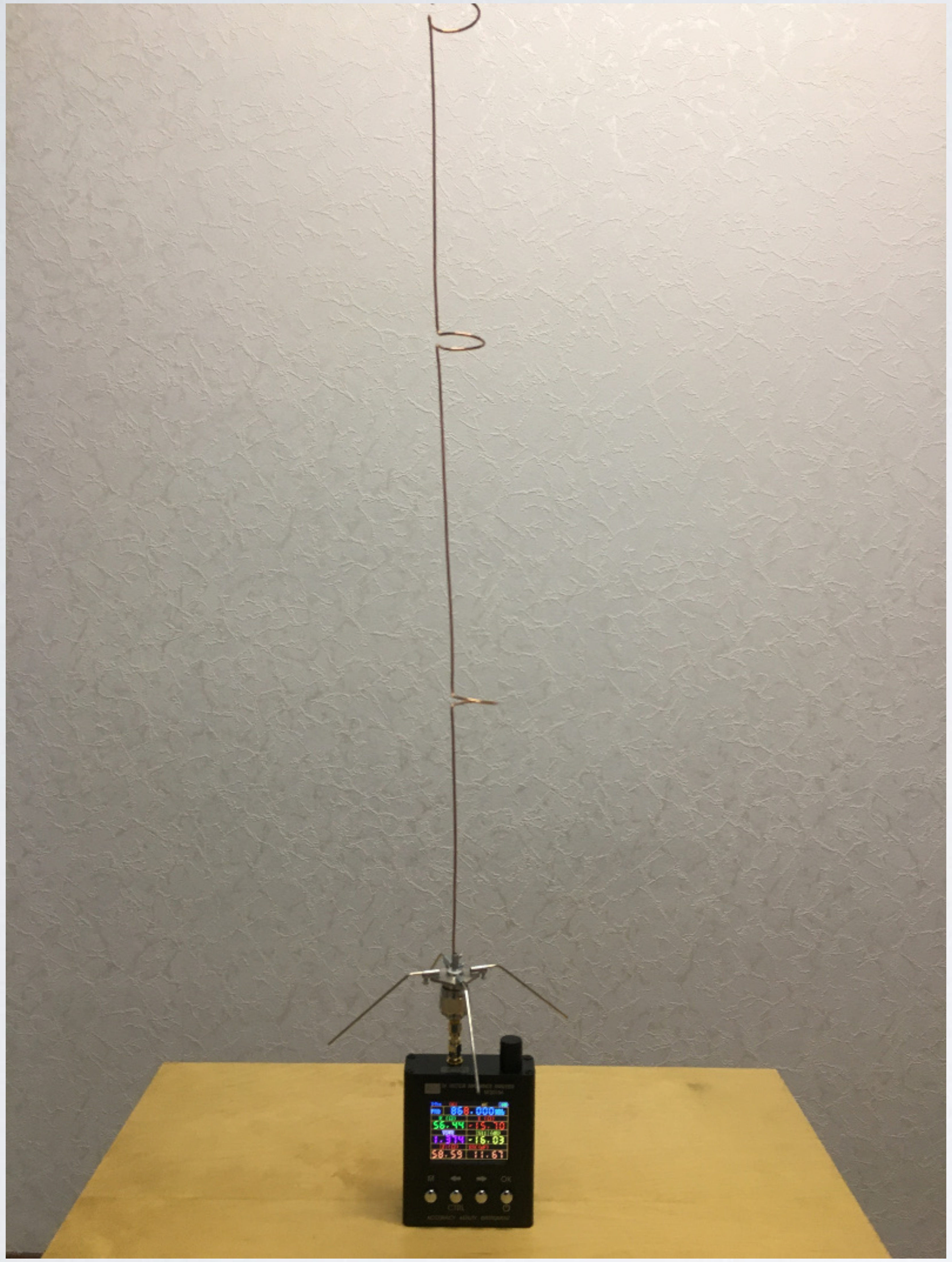
All units in mm



BUILD COLLINEAR ANTENNA 2



COLLINEAR ANTENNA 2

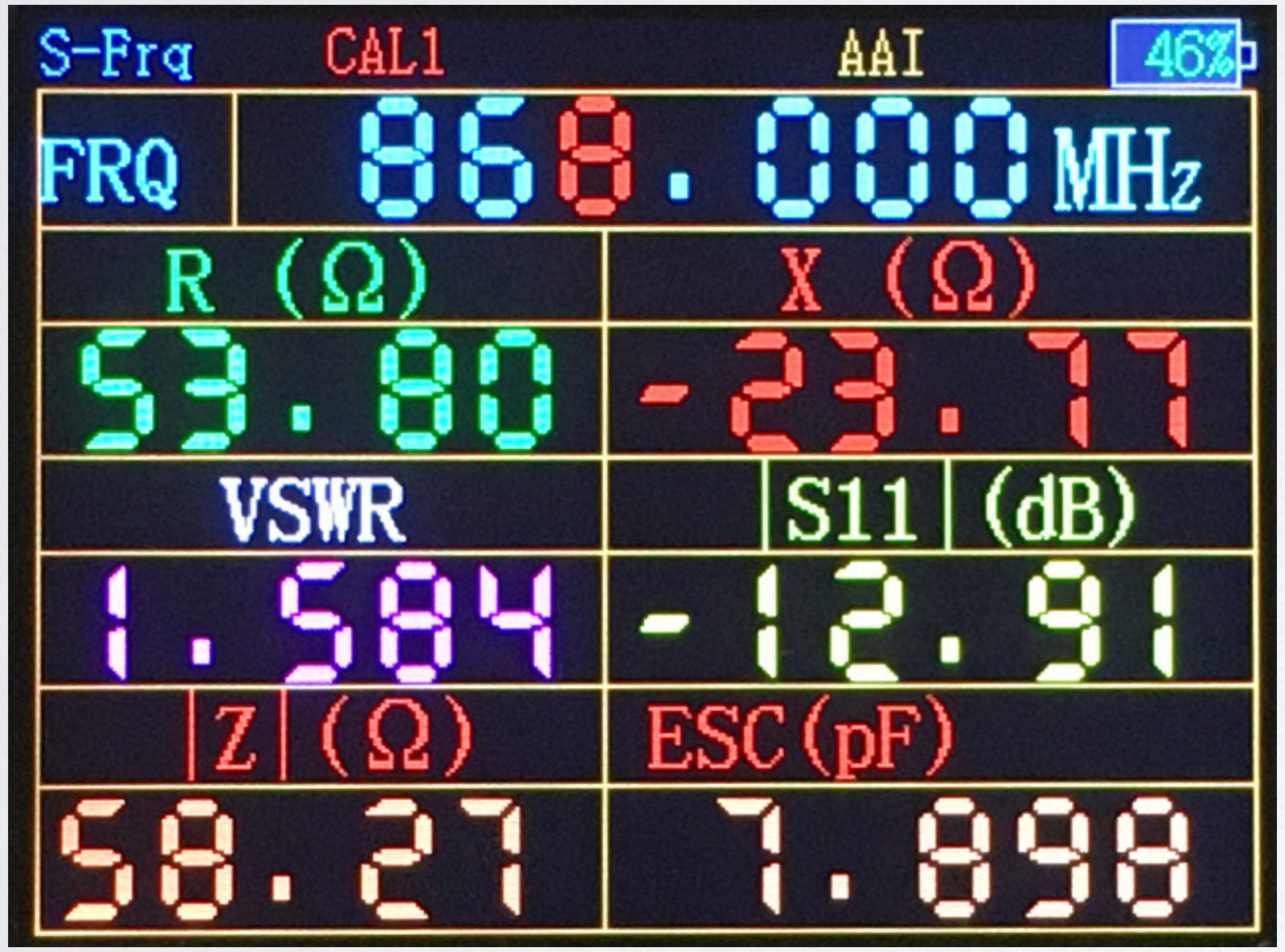


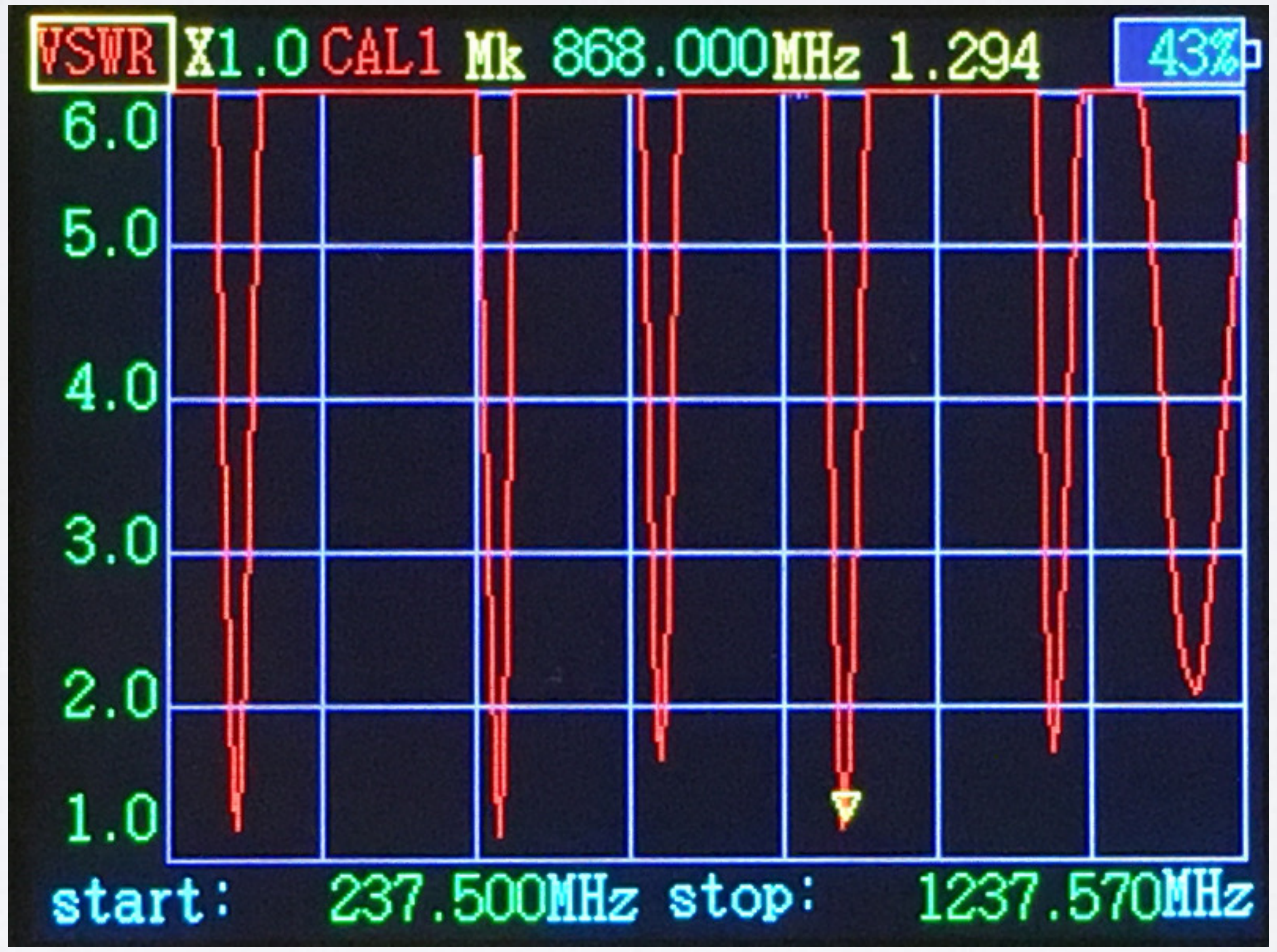
The antenna analyser with the collinear antenna and bend radials (= ground plane).

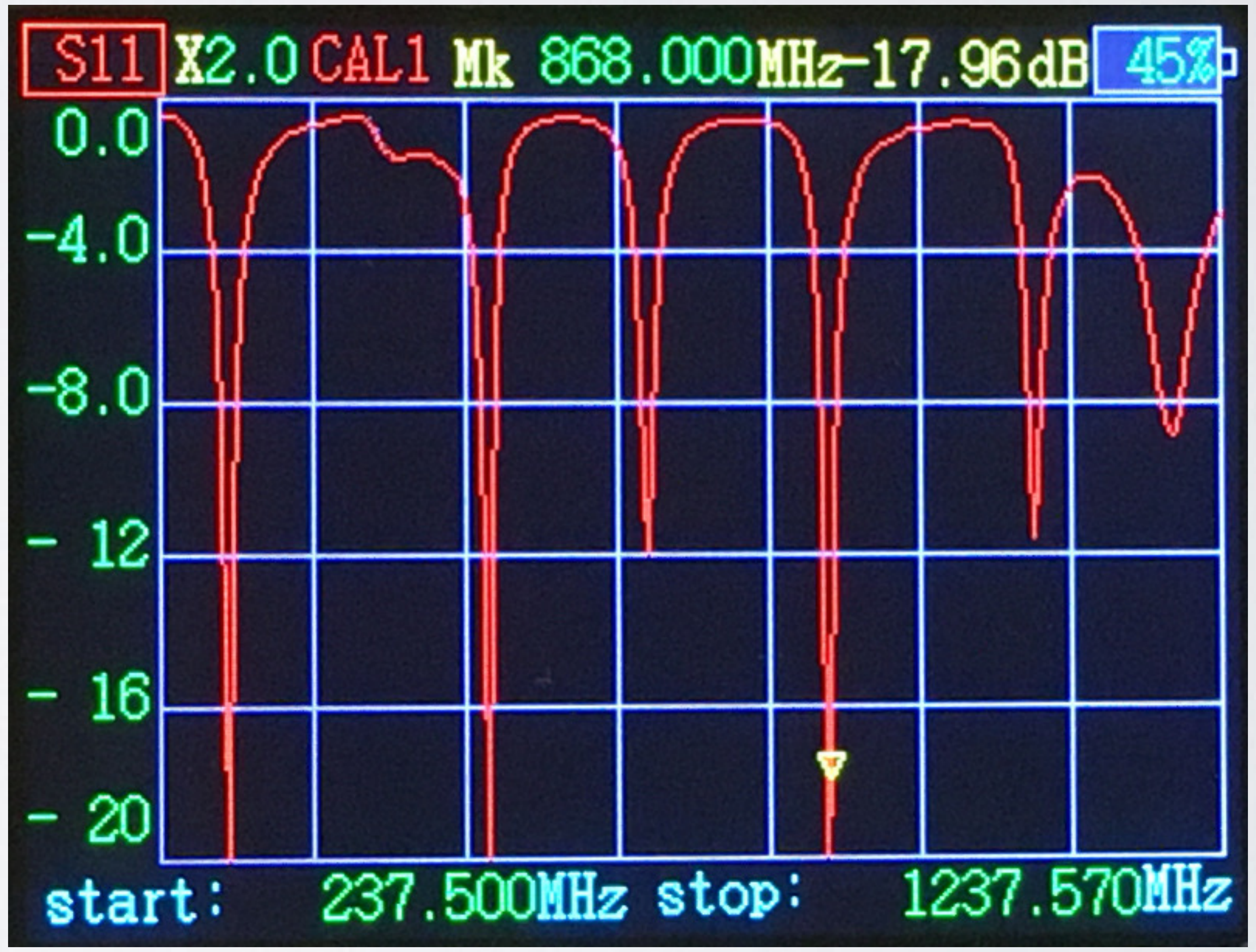
Measuring antenna parameters

MEASURED ANTENNA PARAMETERS

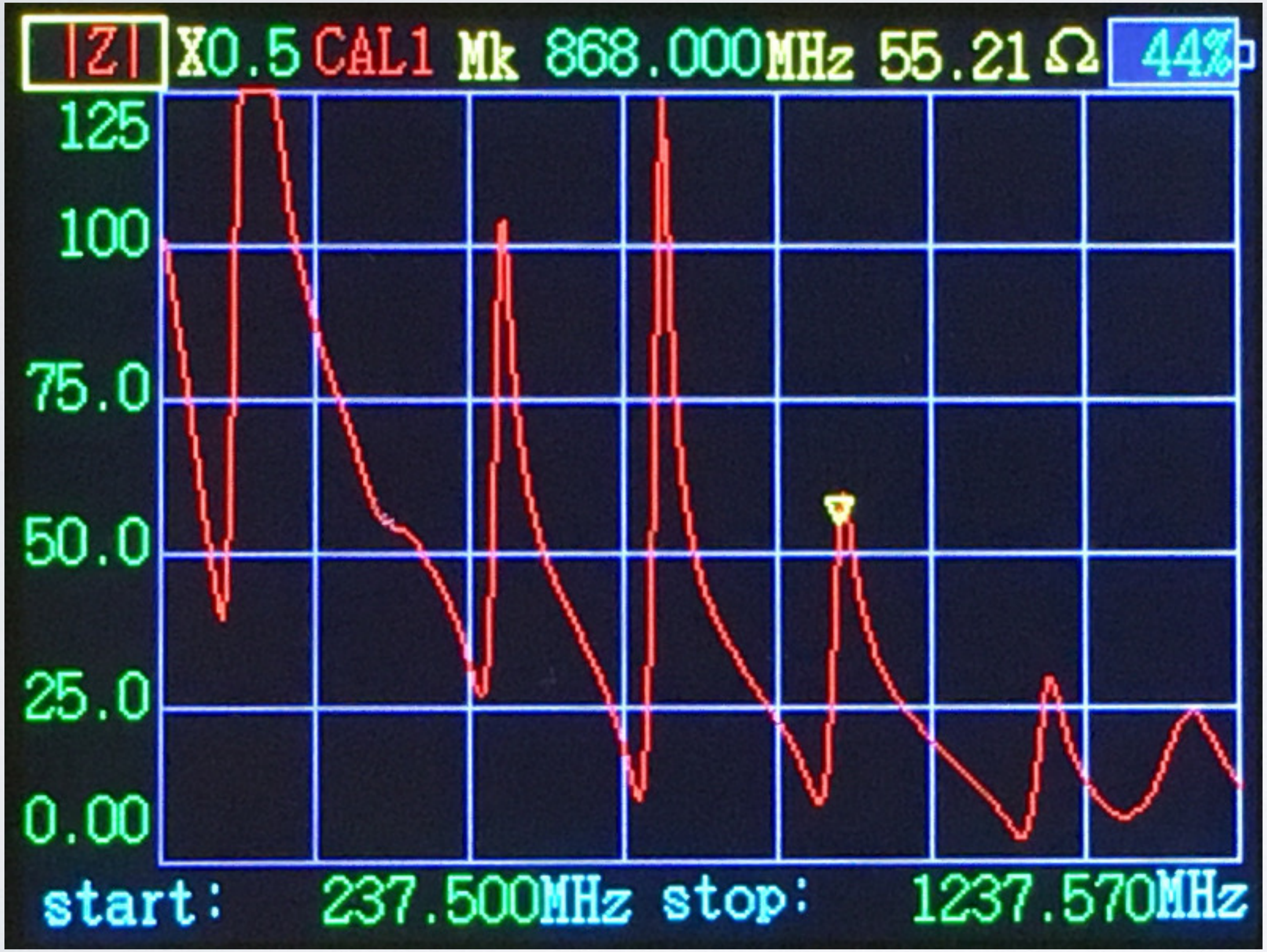
- Based on the collinear antenna 2 design (see previous slide) and using 4 bend radials:
  VSWR ≈ 1.6 ← Good. It is < 2
  Z ≈ 58Ω ← Good. Should be approx. 50Ω
  S11 ≈ -13 dB







MEASURED ANTENNA PARAMETERS

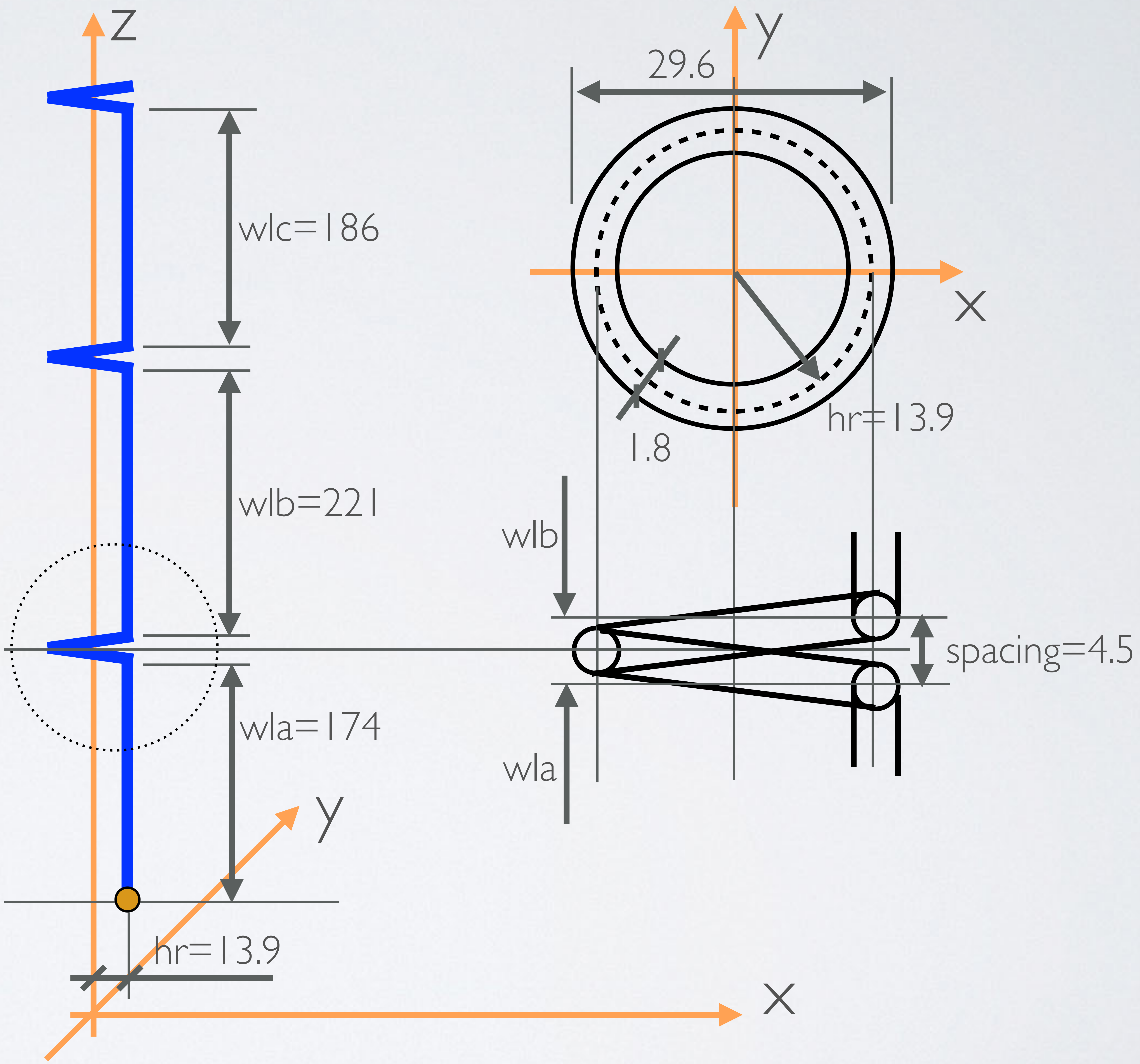


ANTENNA MODELLING NEC-2

- **collinear antenna 2**
  f = 868 MHz

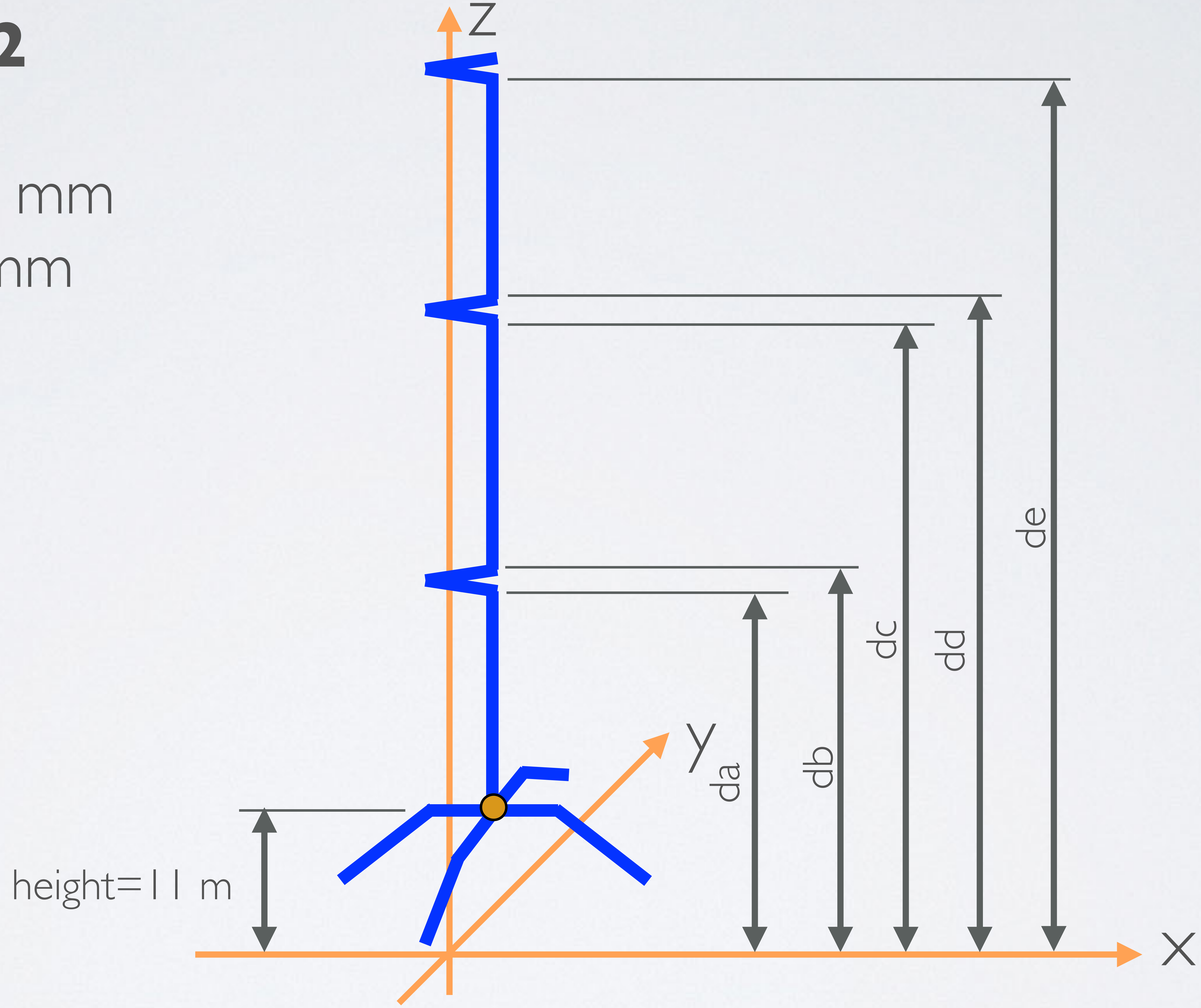
  Material antenna: copper
  Material radials: stainless steel

  All units in mm
  Drawing not to scale



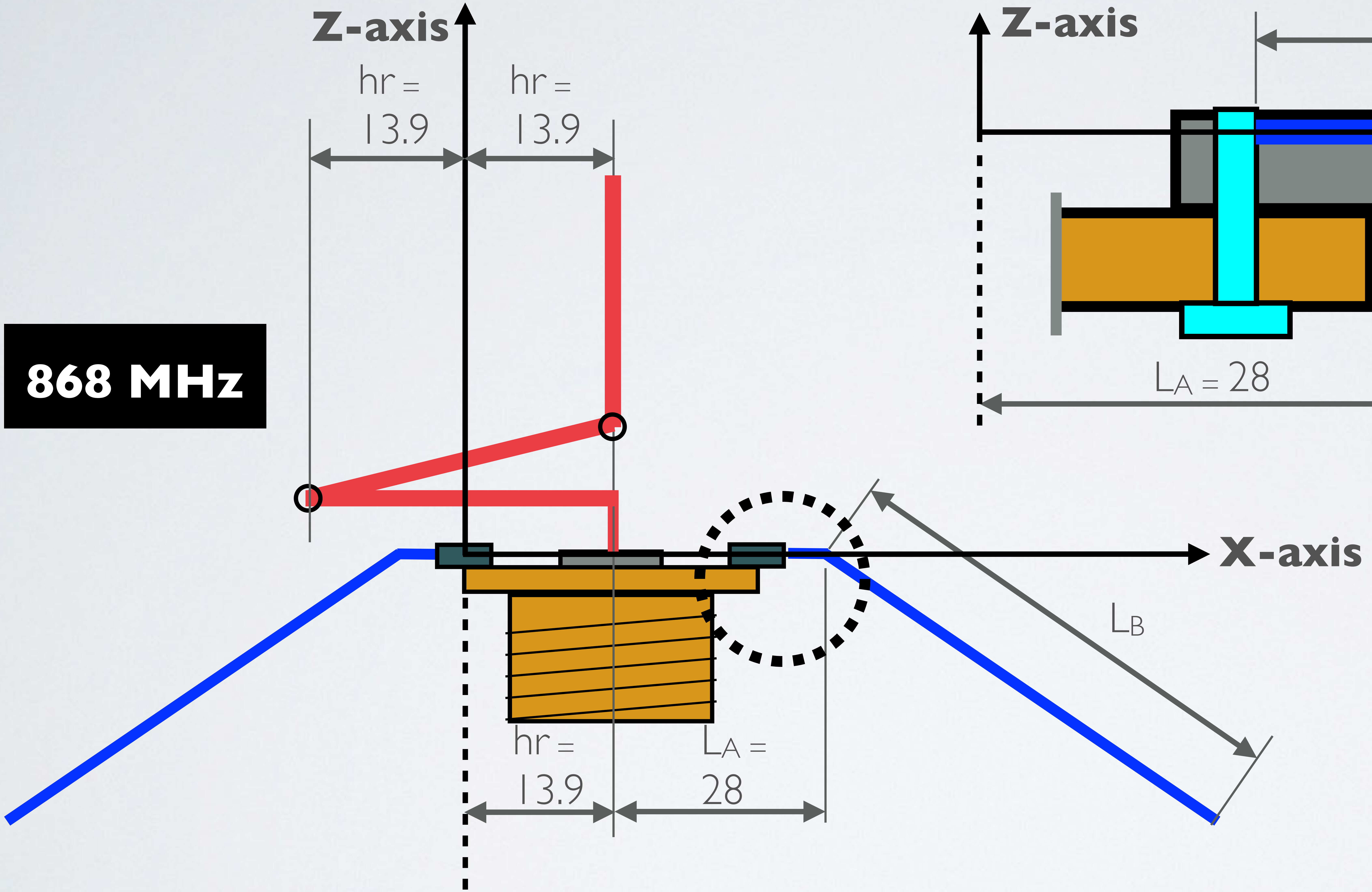
ANTENNA MODELLING NEC-2

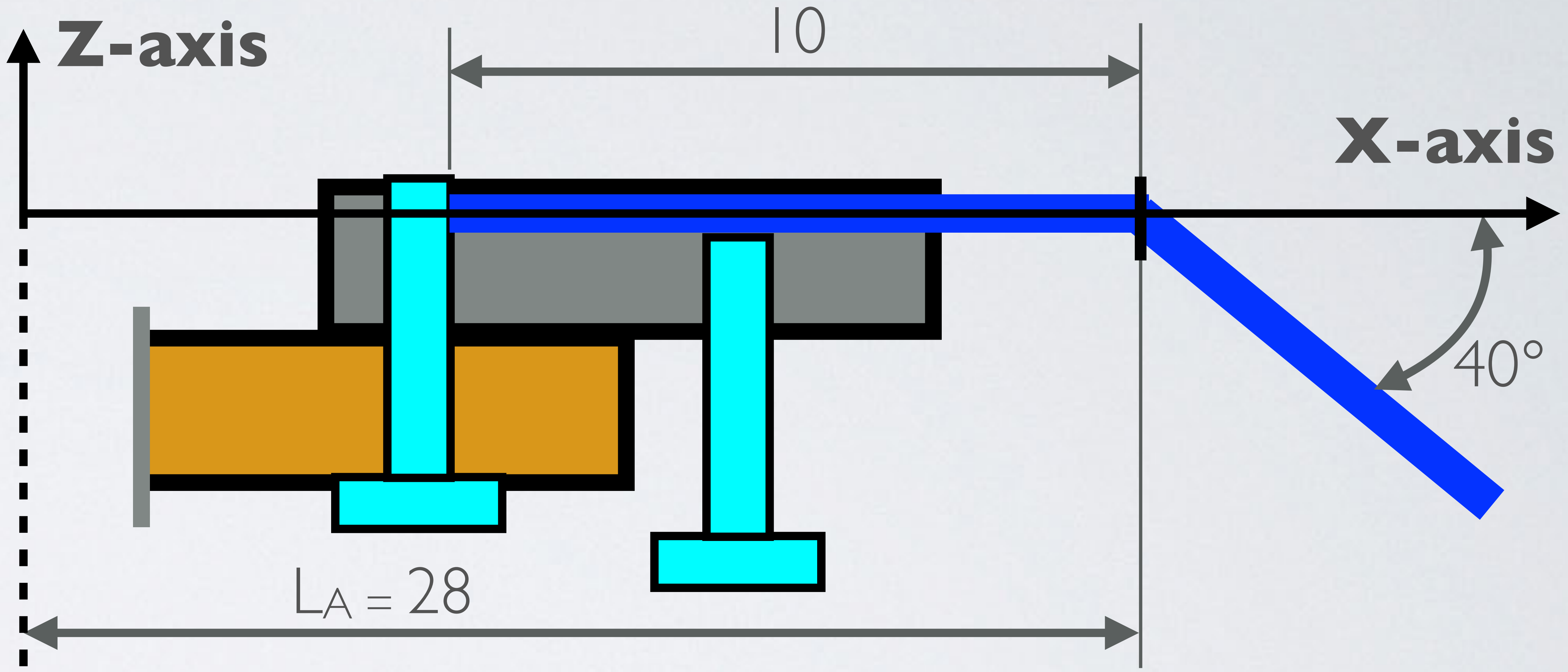
- **collinear antenna 2**
  f = 868 MHz
  radiator diameter = 1.8 mm
  radials diameter = 1.8 mm
  da = height+wla
  db = da+spacing
  dc = db+wlb
  dd = dc+spacing
  de = dd+wlc
  All units in mm
  Drawing not to scale



ANTENNA MODELLING NEC-2

868 MHz





$L_{Radial} = L_A + L_B$

$93 = 28 + L_B$

$L_B = 65$ mm

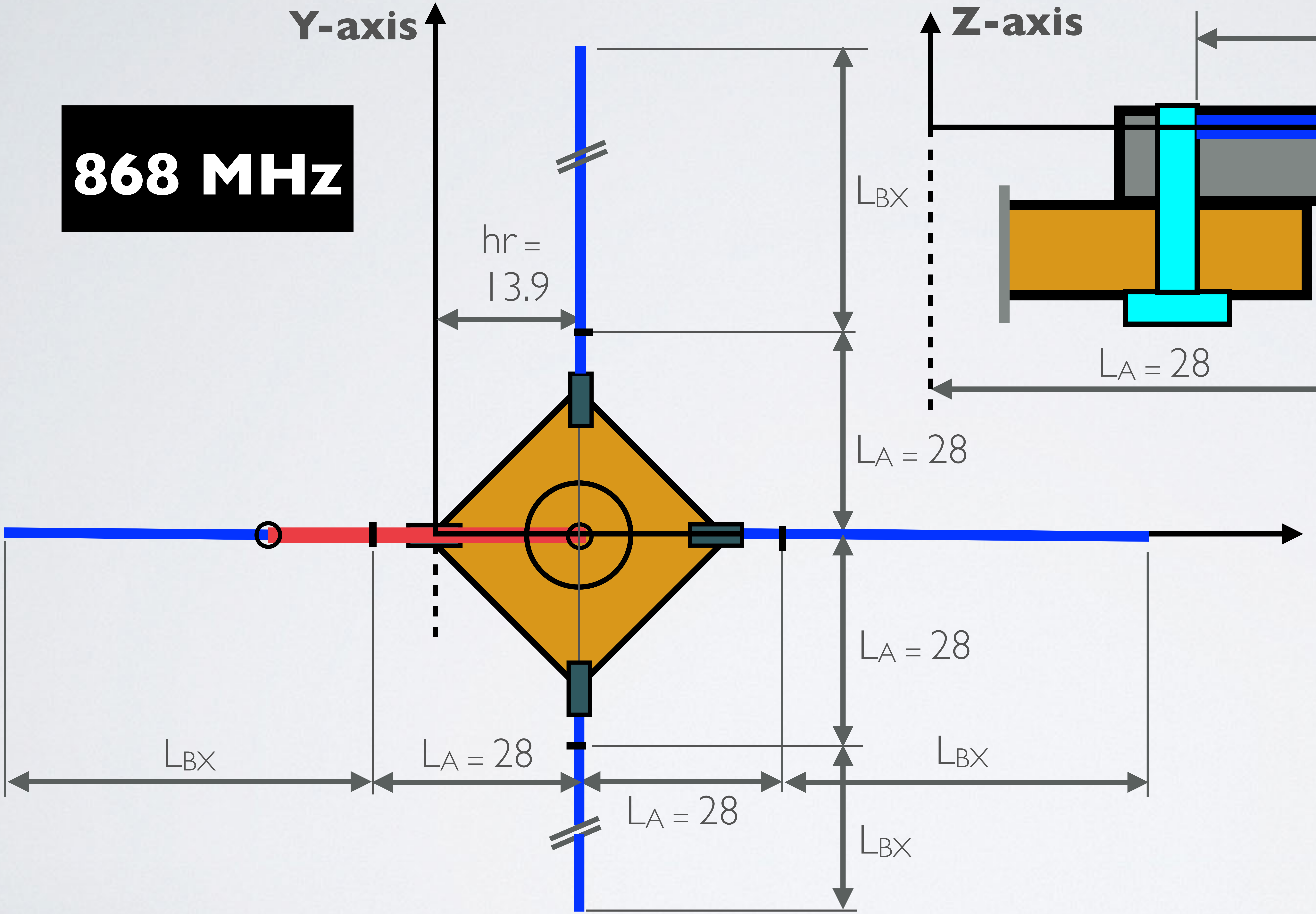
All units in mm

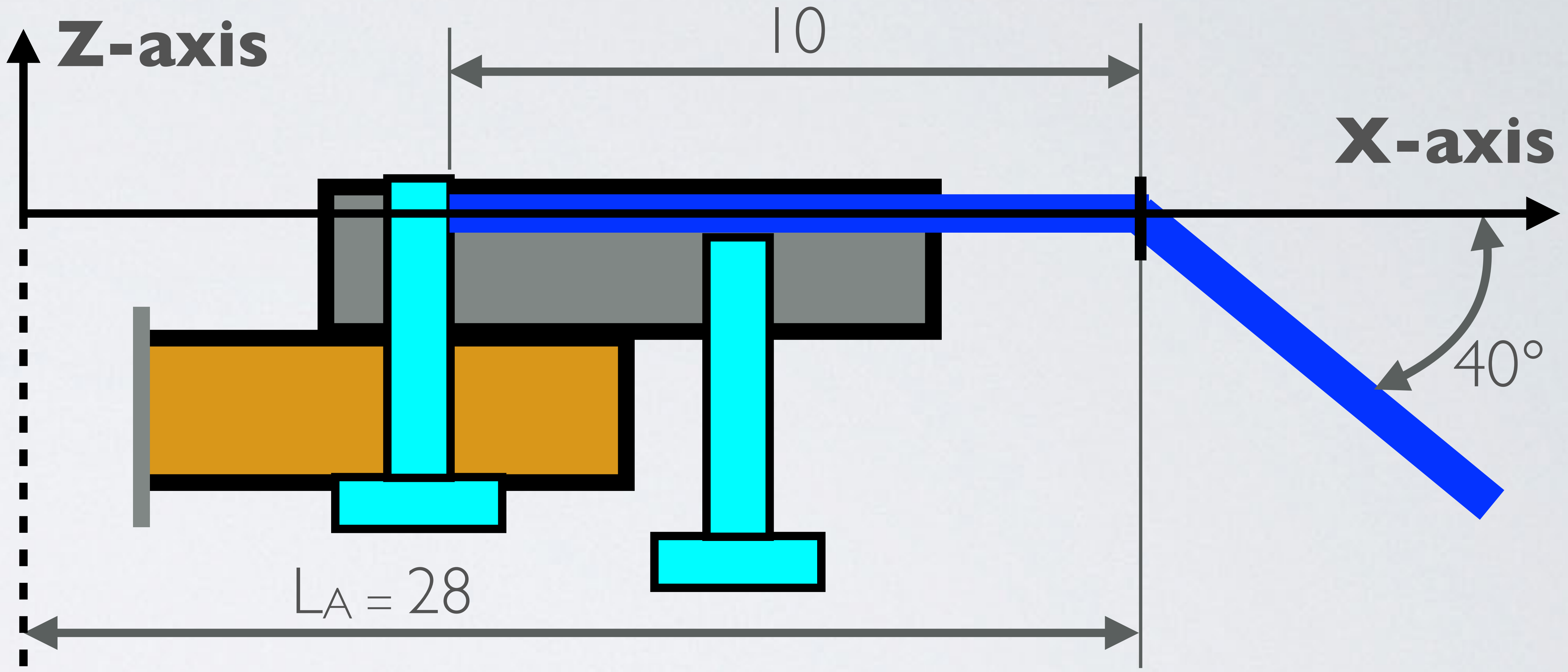
Drawing not to scale

mobilefish.com

ANTENNA MODELLING NEC-2

868 MHz

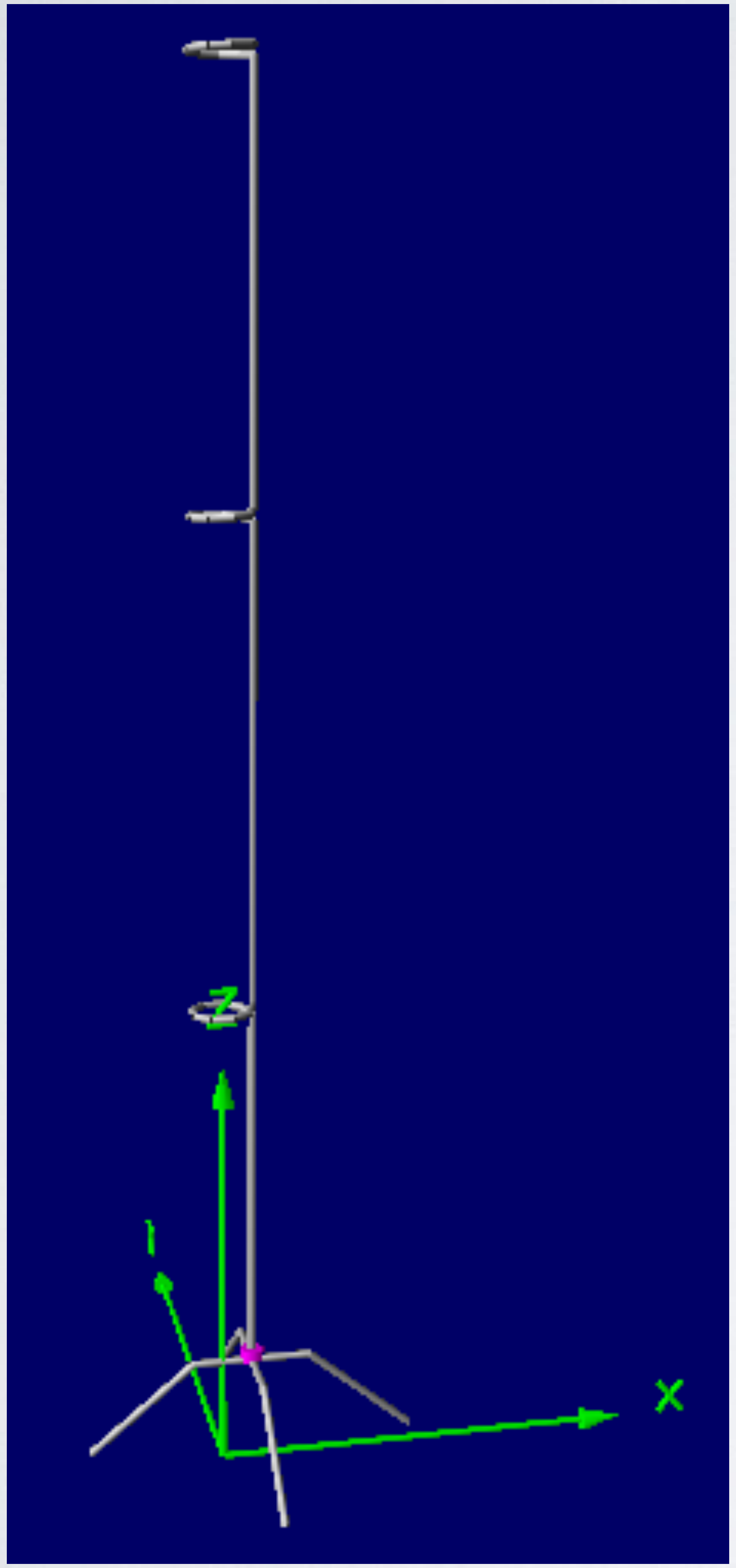


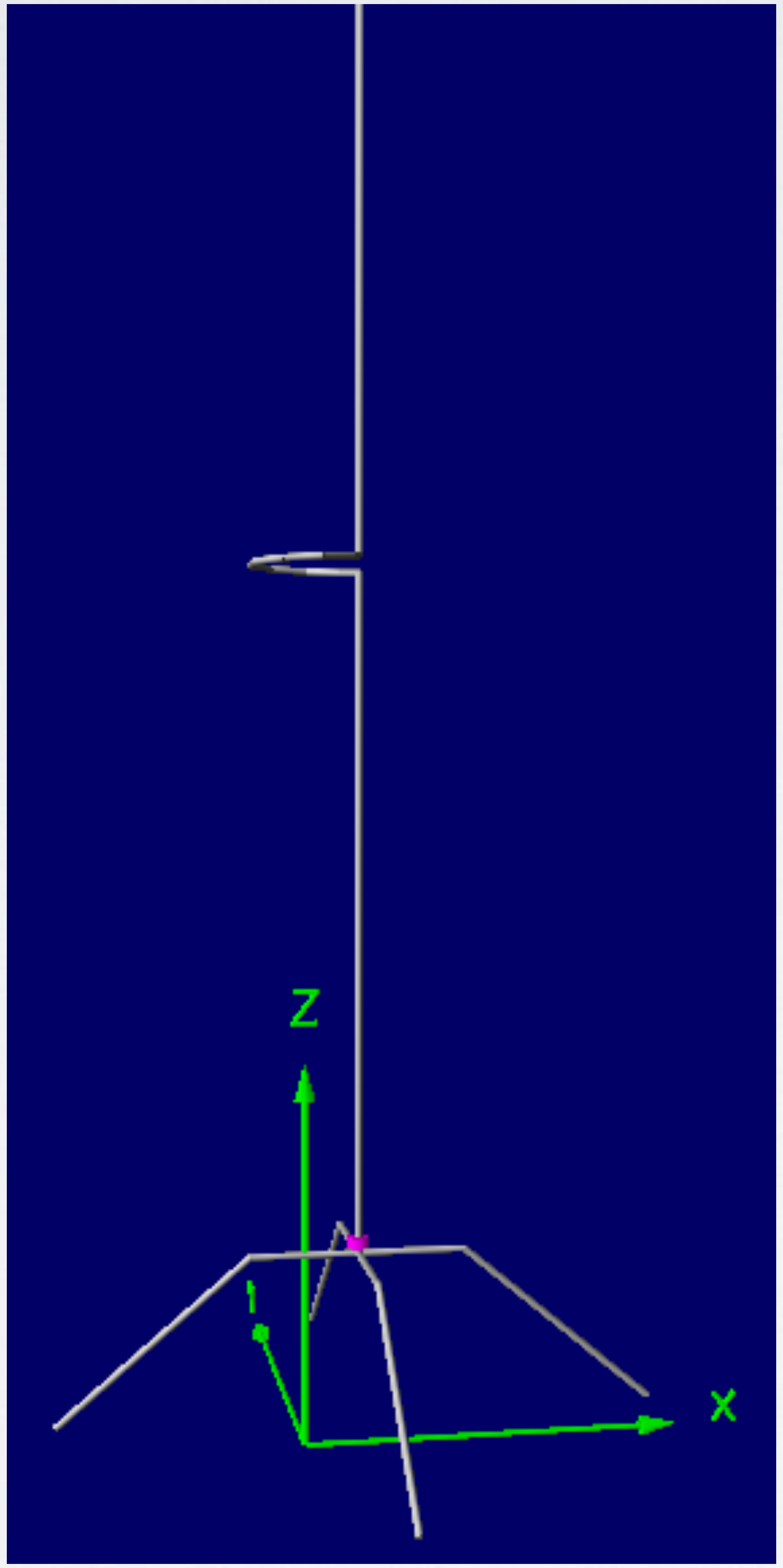


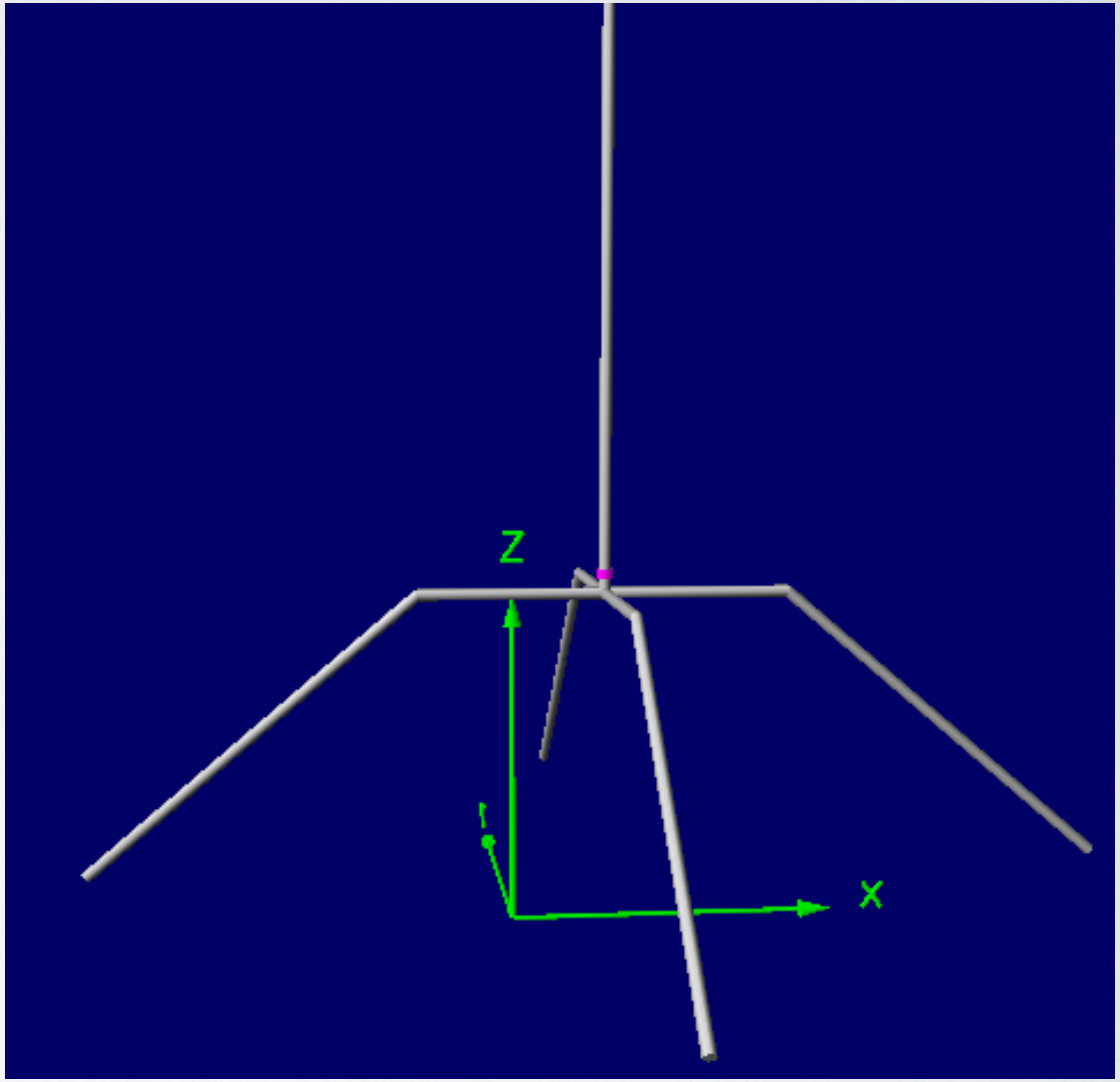
All units in mm
Drawing not to scale

ANTENNA MODELLING NEC-2

Created in 4NEC2

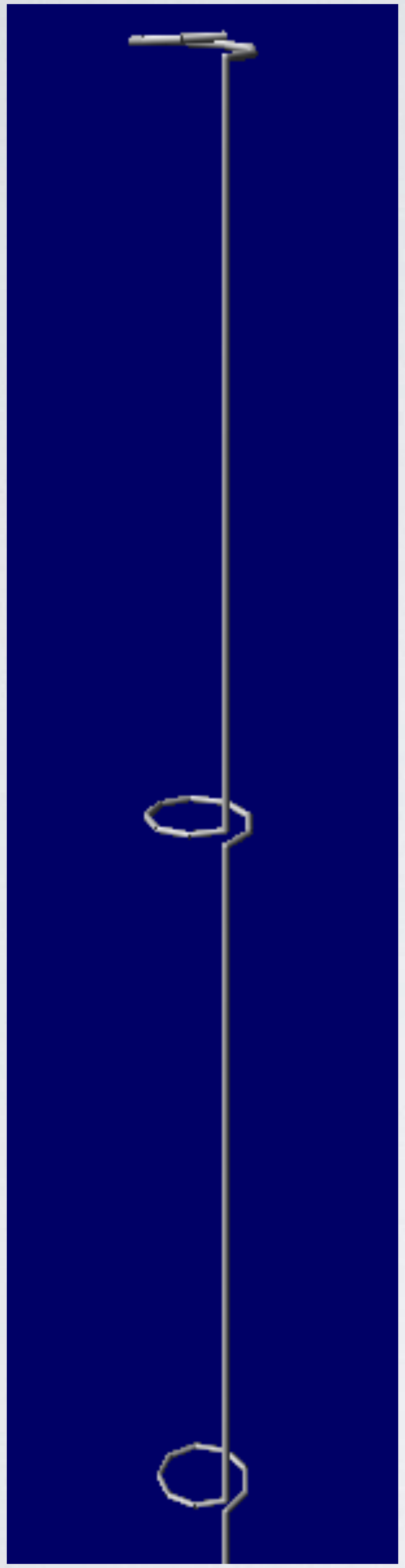


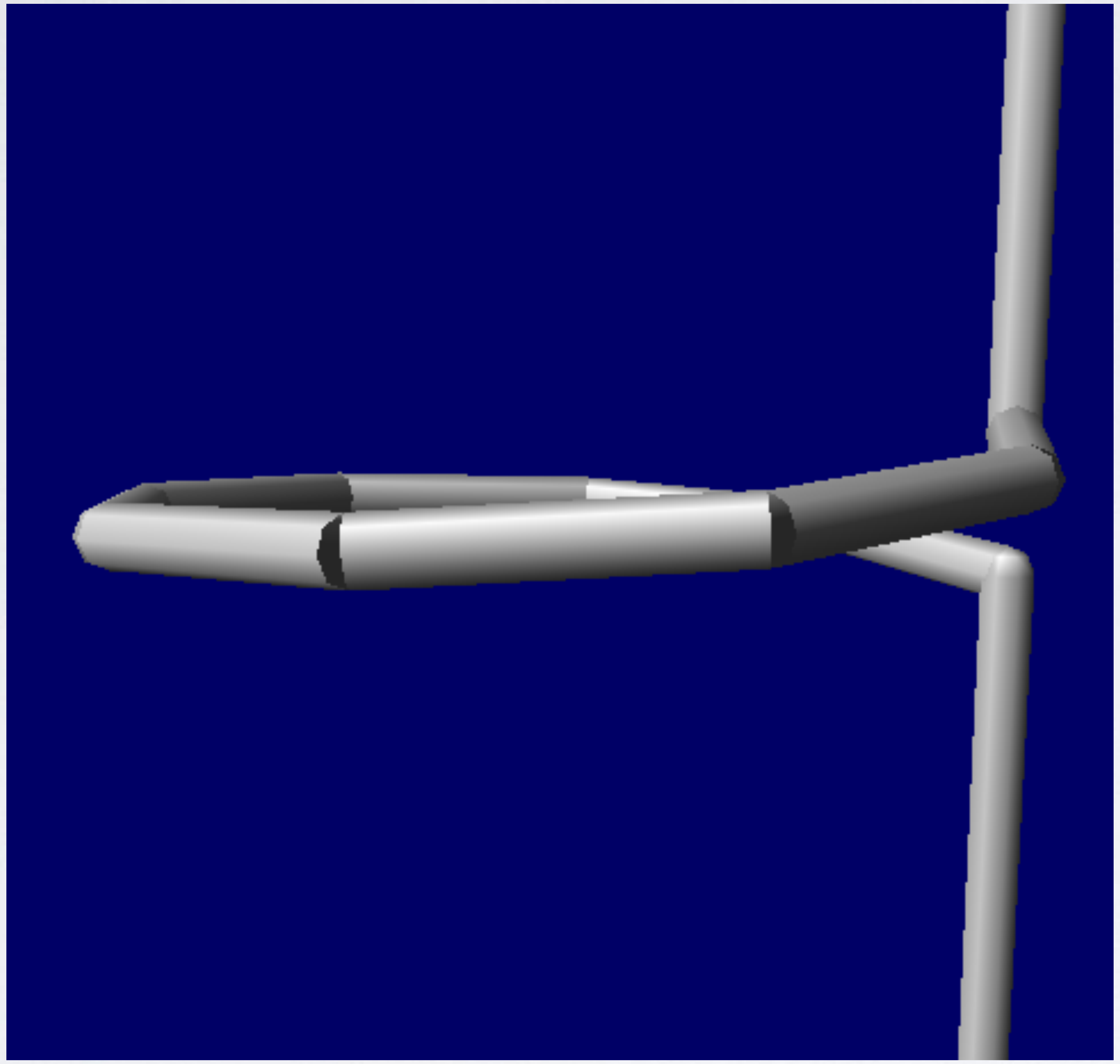


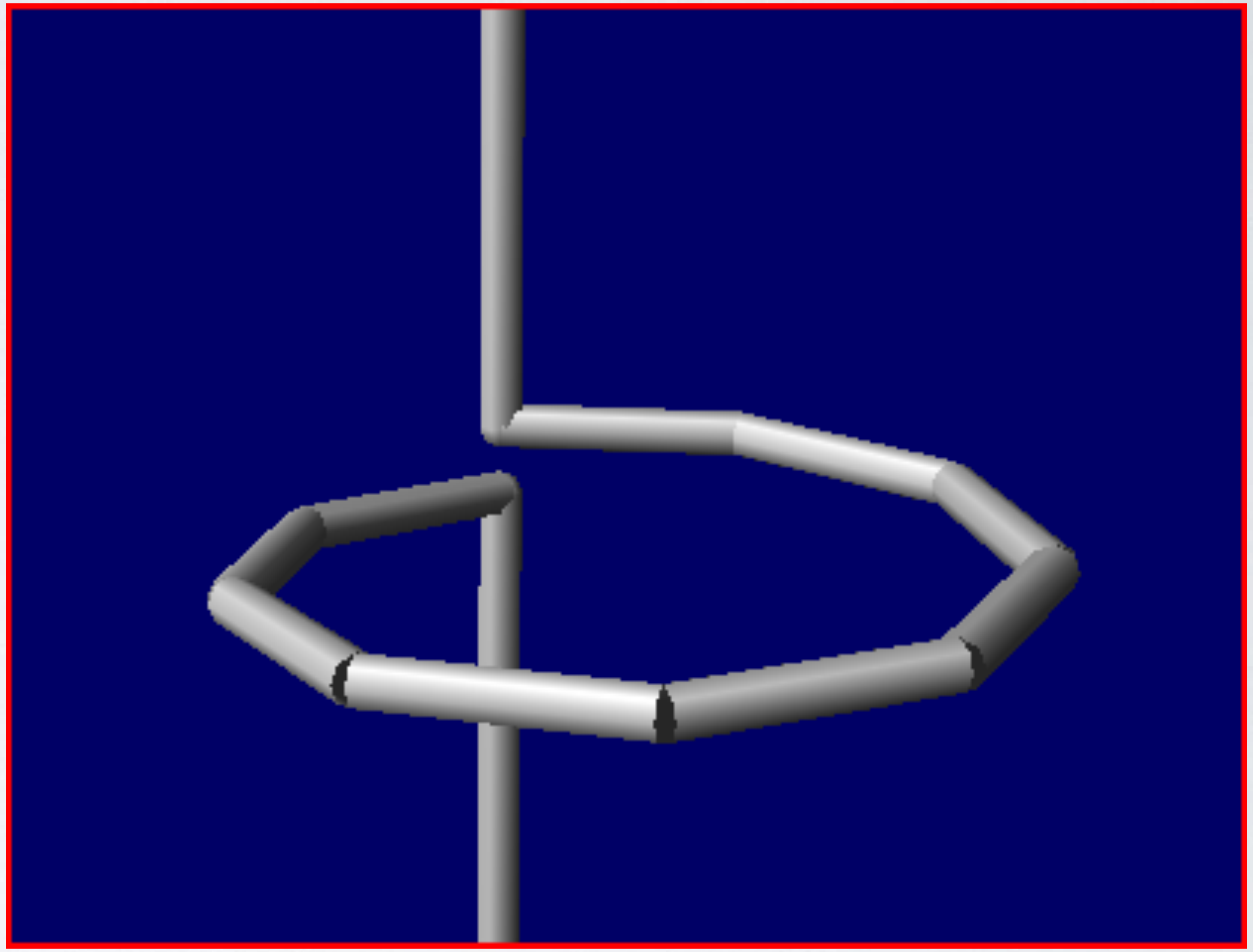


ANTENNA MODELLING NEC-2

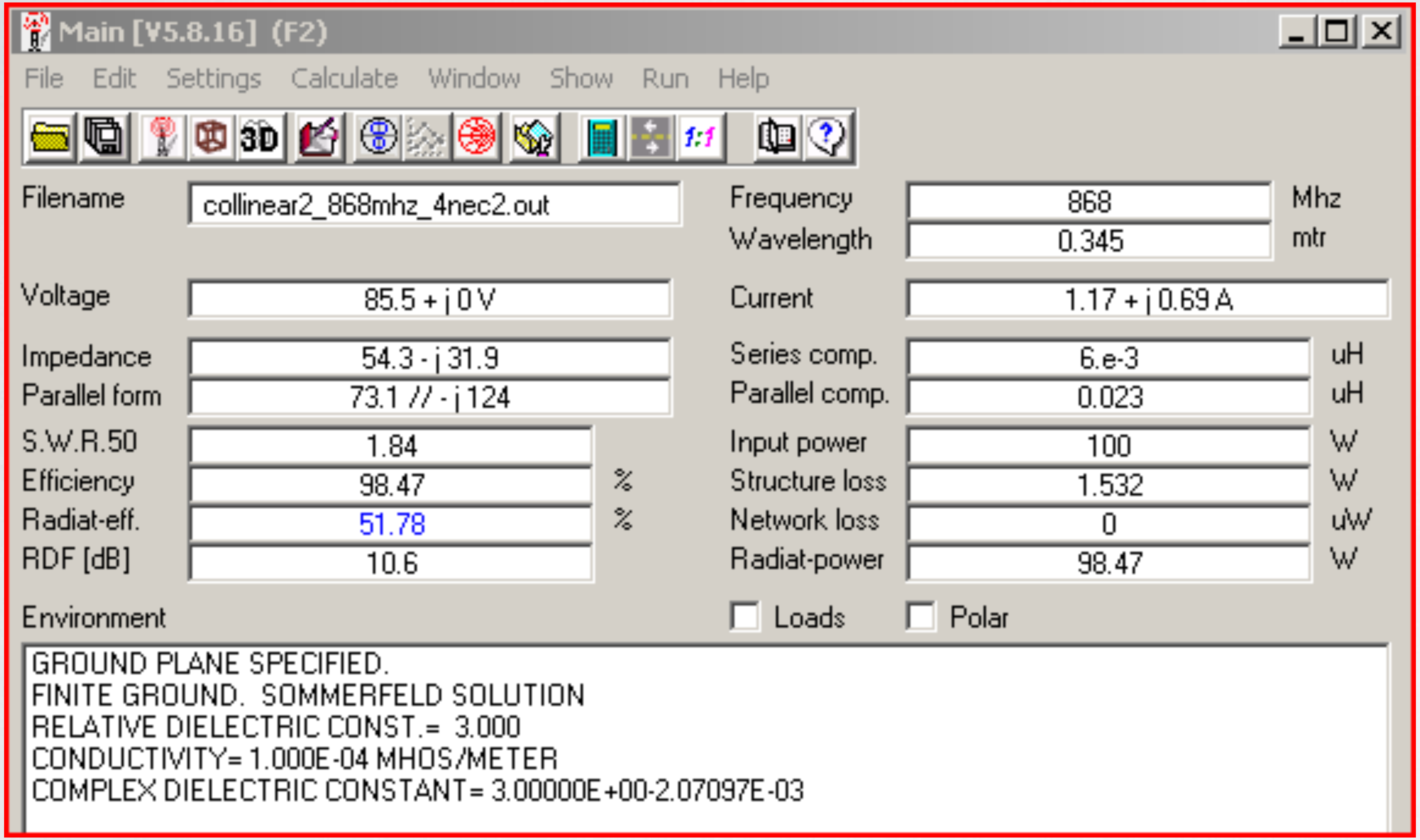
Created in 4NEC2







ANTENNA MODELLING NEC-2

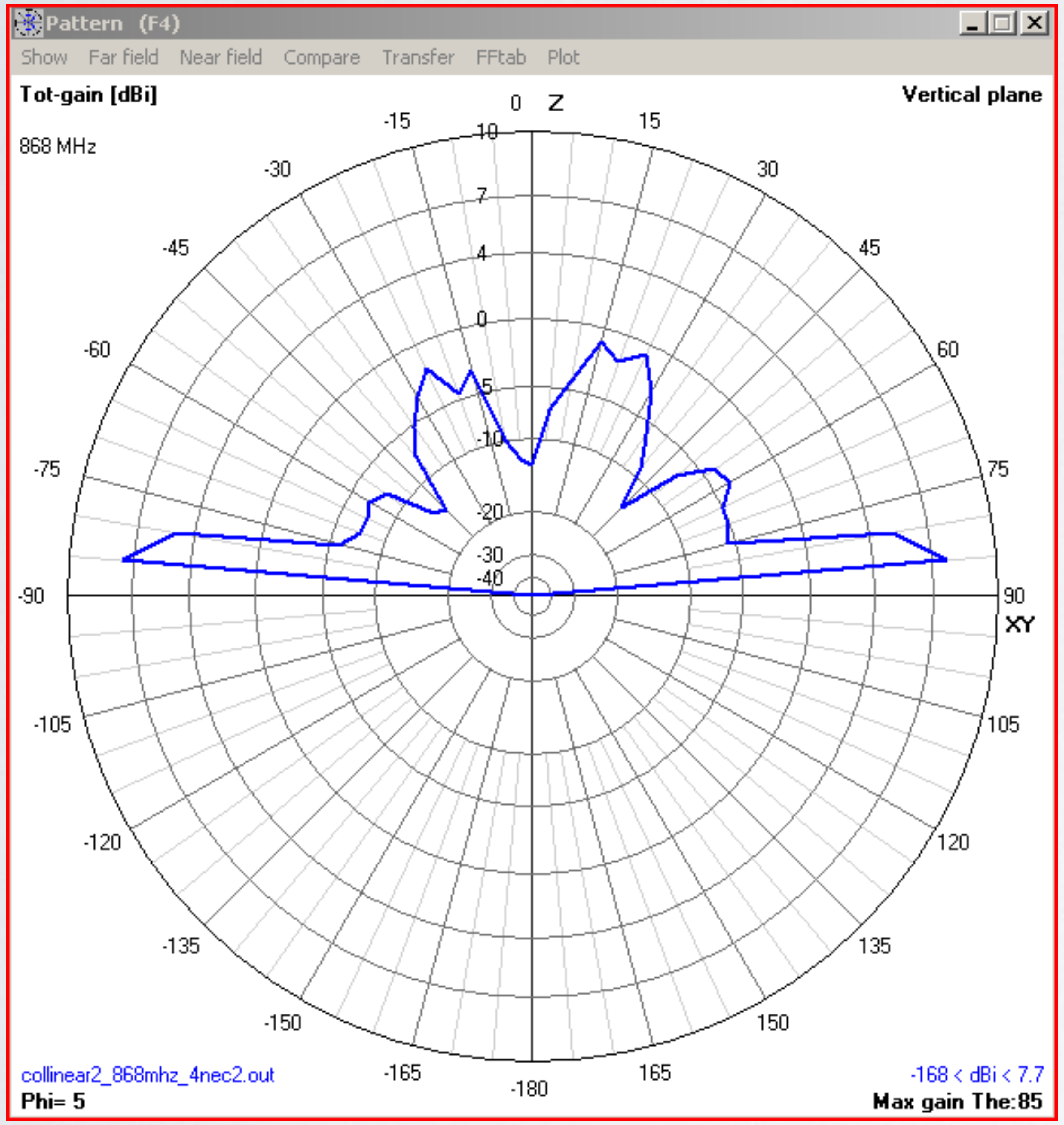


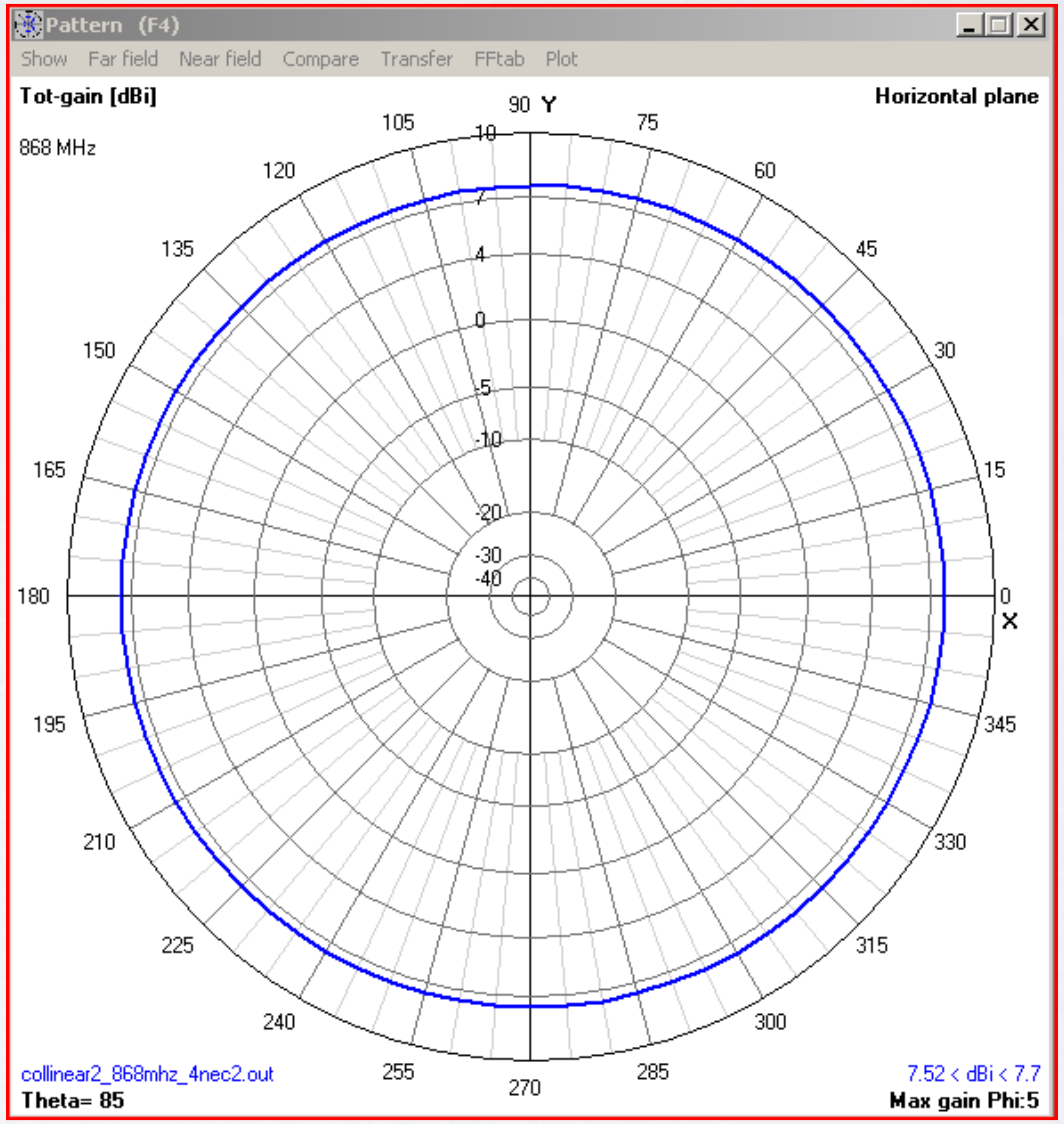
VSWR=1.84

Ground: **Real ground** Ground type: **City industrial area** Height: **11 m above ground**

ANTENNA MODELLING NEC-2

- Ground: **Real ground** Ground type: **City industrial area**



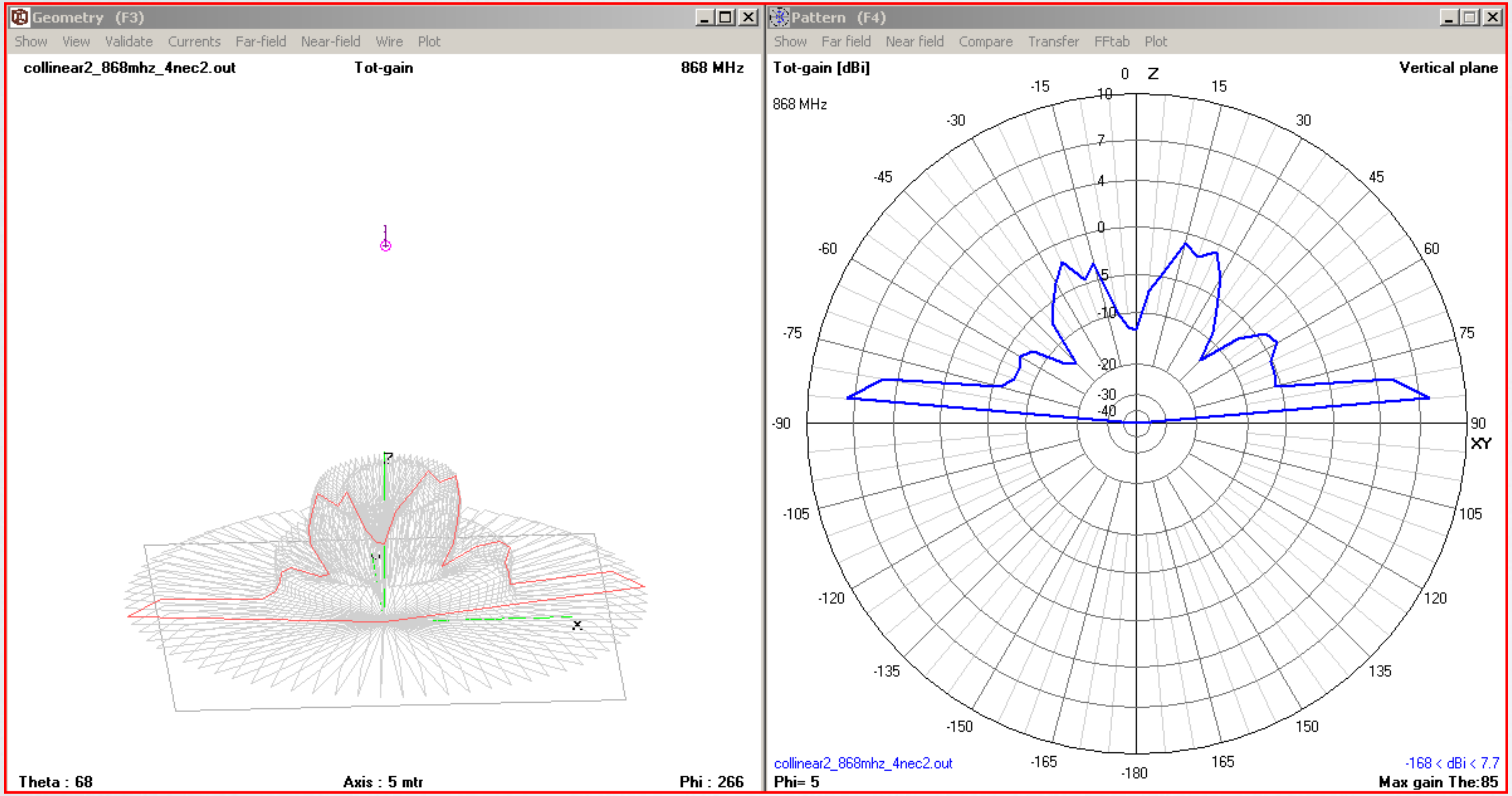


Height: 11 m above ground

Max gain: 7.7 dBi @ Θ=85°

ANTENNA MODELLING NEC-2

- Ground: **Real ground** Ground type: **City industrial area**

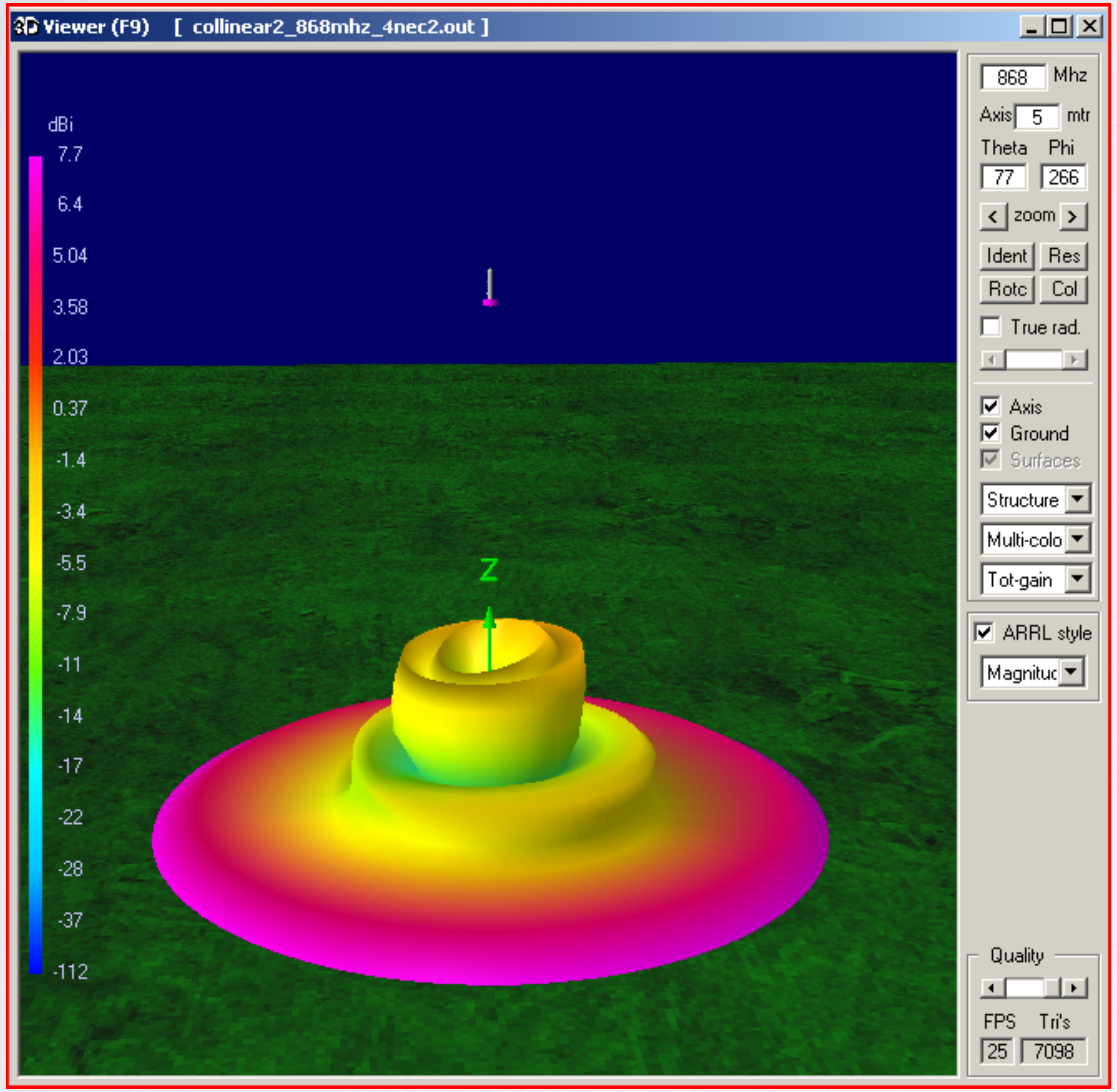


Height: 11 m above ground

Max gain: 7.7 dBi @ Θ=85°

ANTENNA MODELLING NEC-2

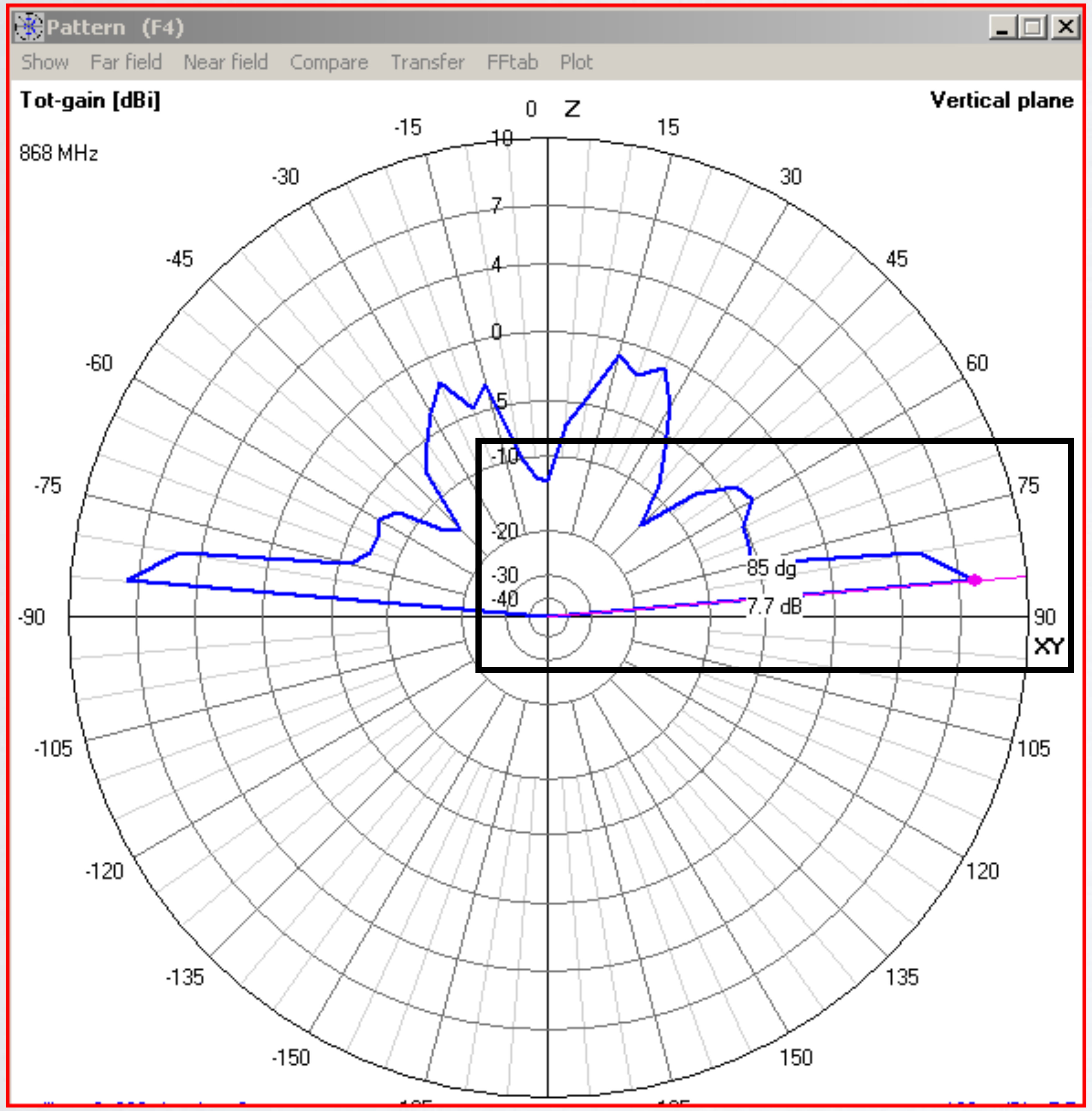
- Ground: **Real ground** Ground type: **City industrial area**



Height: 11 m above ground

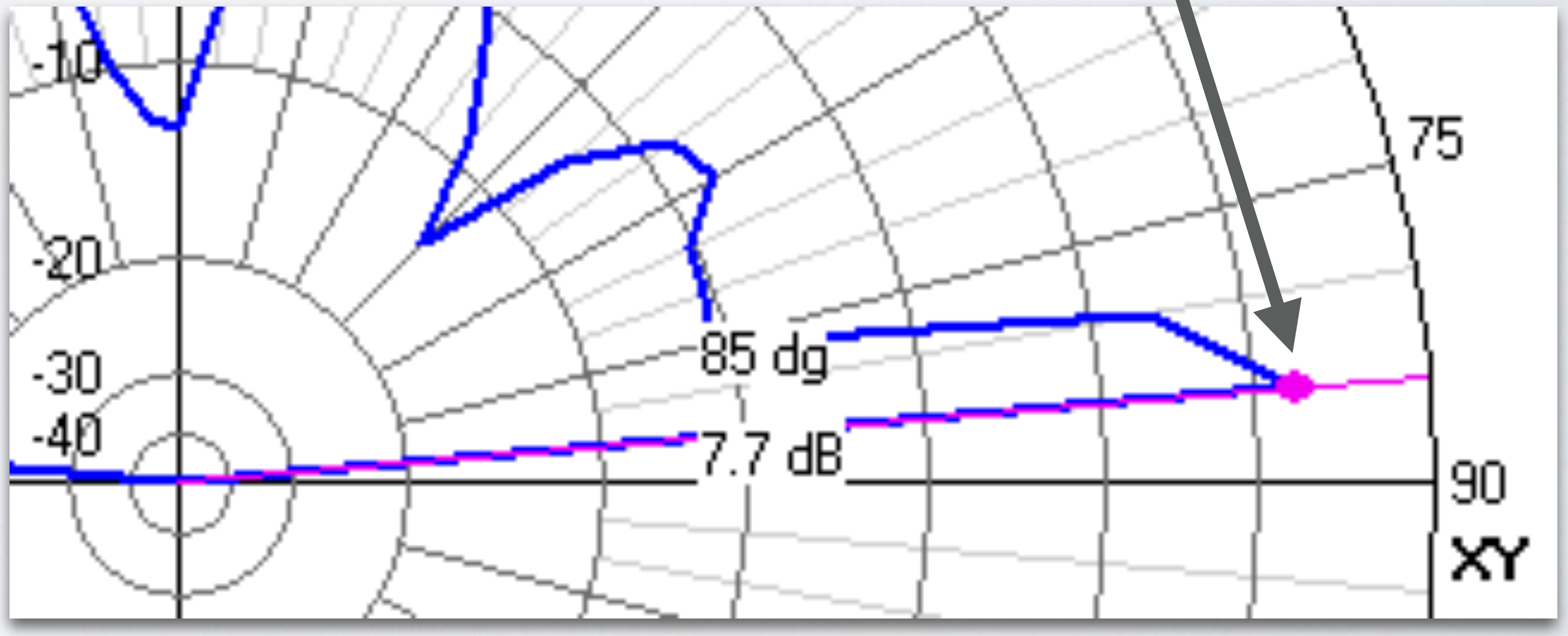
ANTENNA MODELLING NEC-2

- Ground: **Real ground** Ground type: **City industrial area**



Height: 11 m above ground

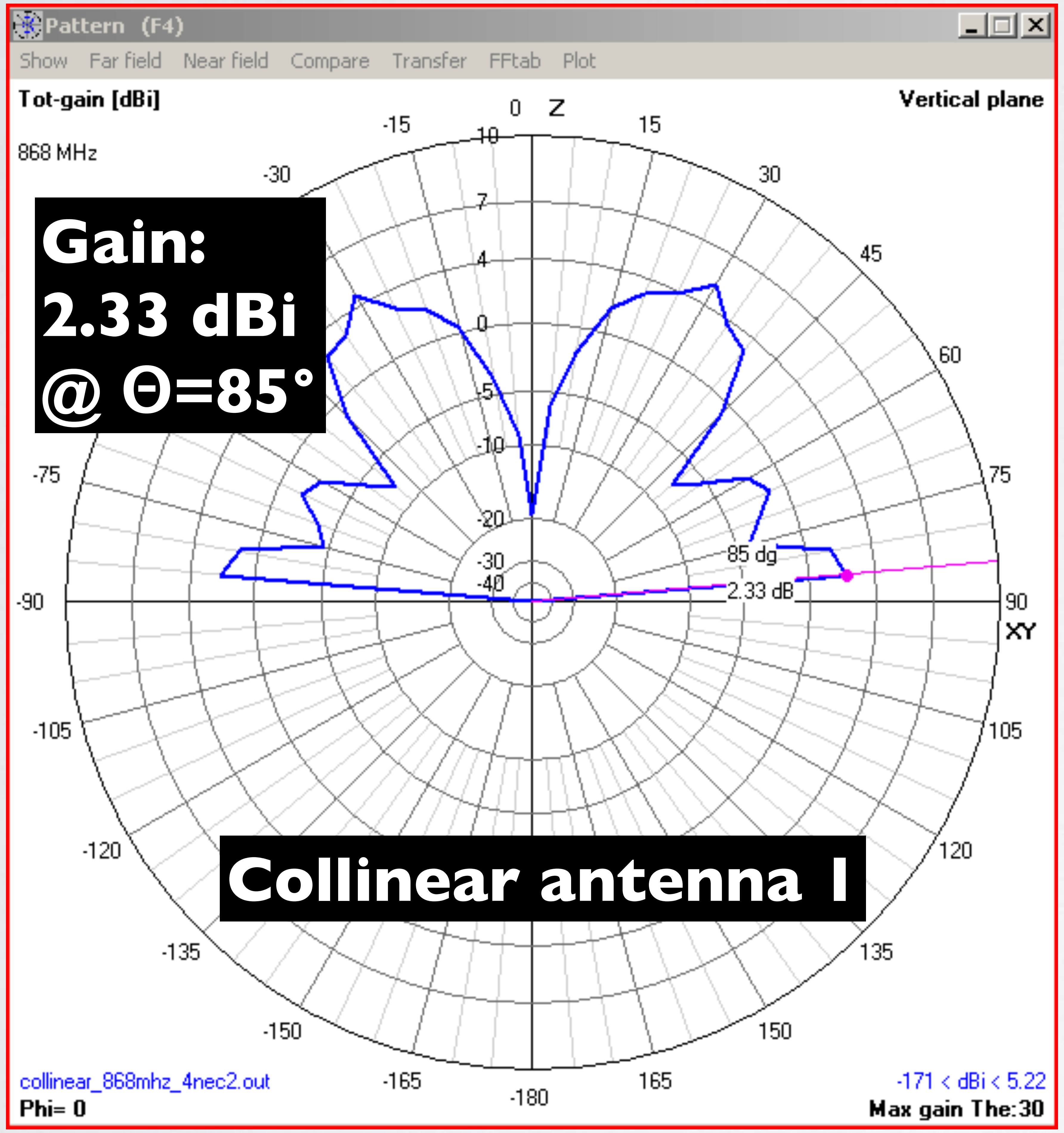
Gain:
7.7 dBi
@ Θ=85°

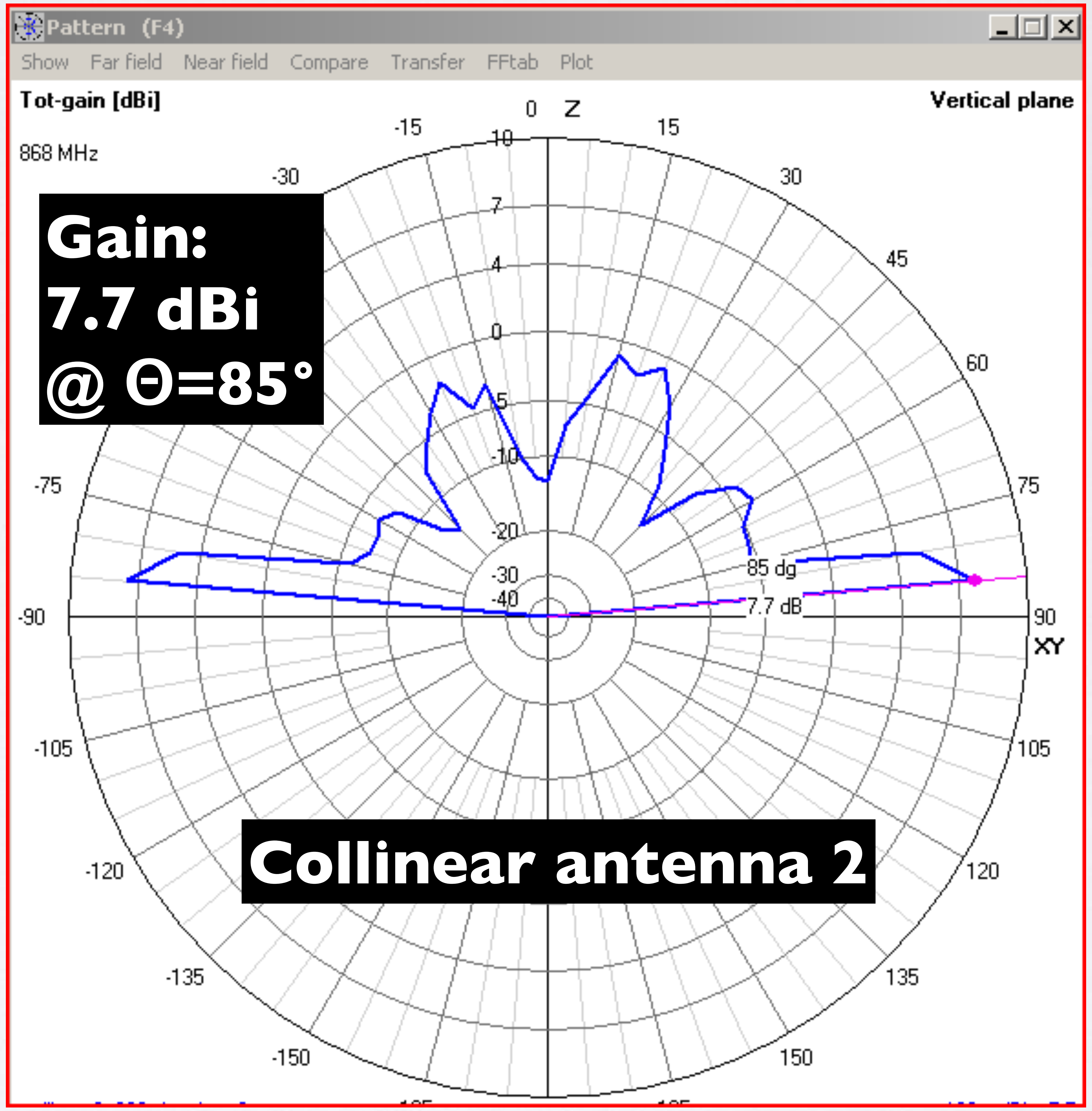


ANTENNA MODELLING NEC-2

- Ground: **Real ground** Ground type: **City industrial area**

Height: 11 m above ground



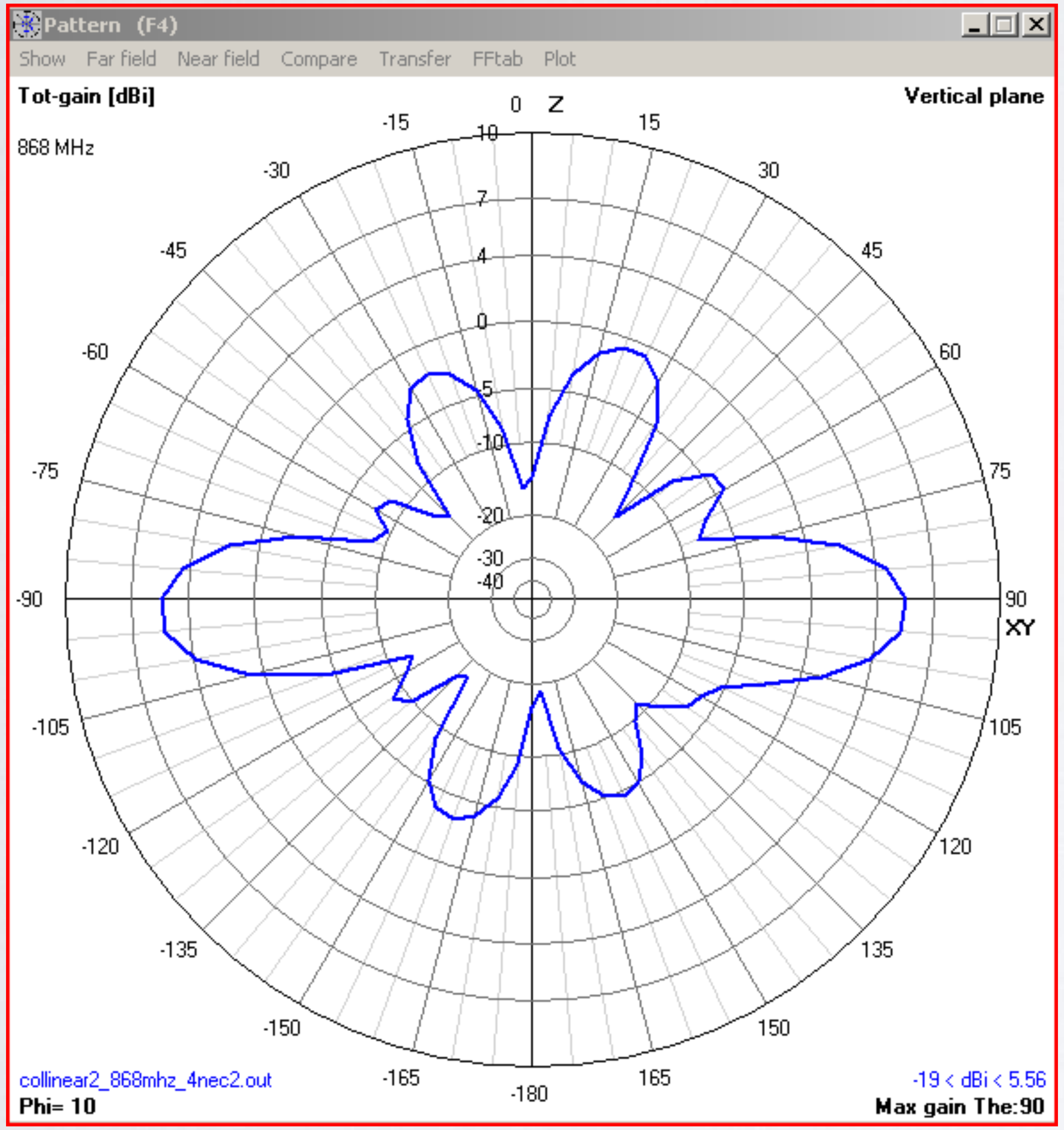


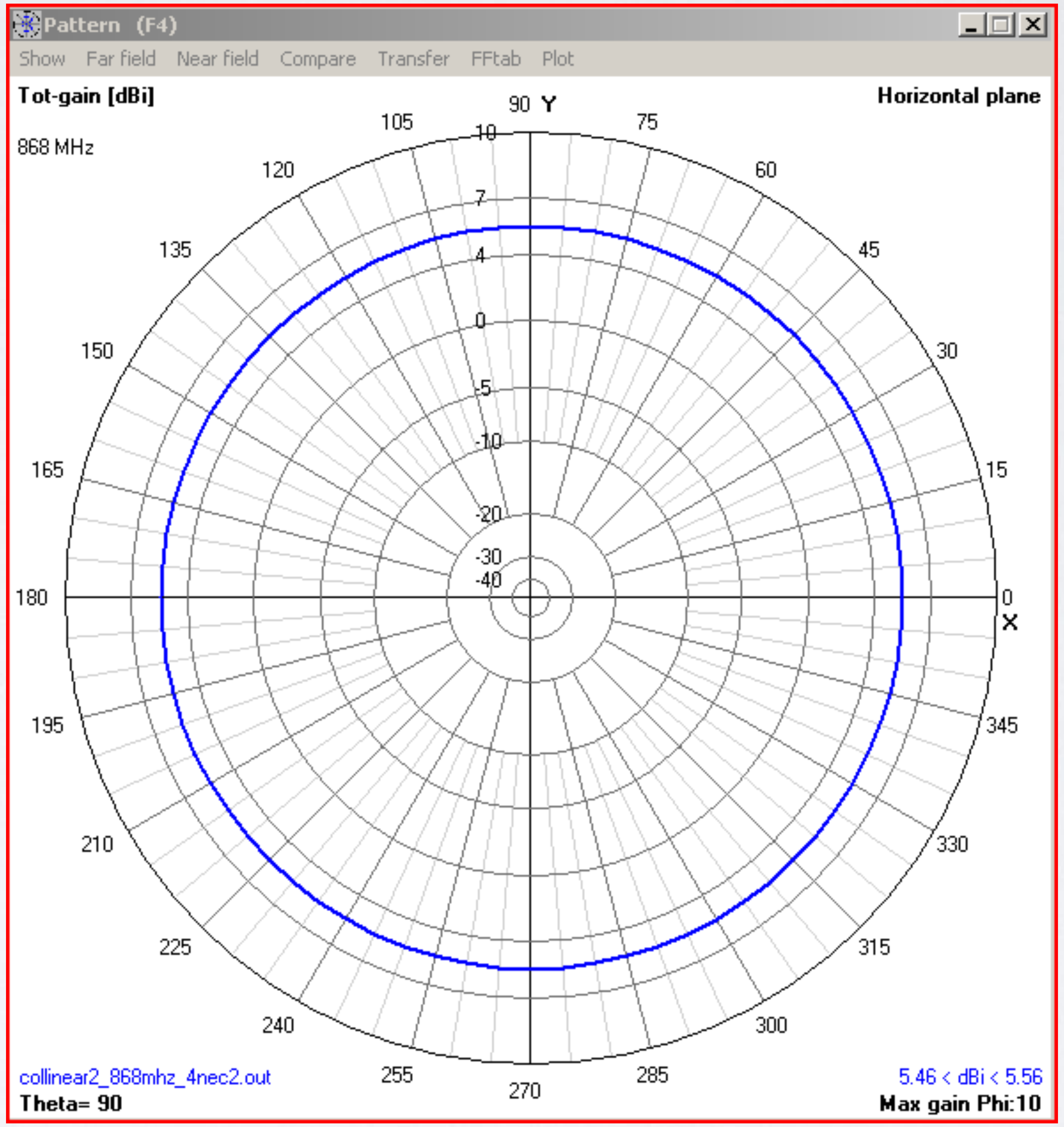
ANTENNA MODELLING 4NEC2

- Using collinear antenna 2, Ground type: real ground (City industrial area) https://www.mobilefish.com/download/lora/collinear2_868mhz_4nec2.nec.txt
  - Free space: VSWR = 1.84, Max gain = 5.56 dBi
  - 50 m above ground: VSWR = 1.84, Max gain = 8.86 dBi (I can not explain this..)
  - 25 m above ground: VSWR = 1.84, Max gain = 6.17 dBi
  - 11 m above ground: VSWR = 1.84, Max gain = 7.7 dBi
  - 1 m above ground: VSWR = 1.84, Max gain = 8.44 dBi

ANTENNA MODELLING NEC-2

- **Free space**

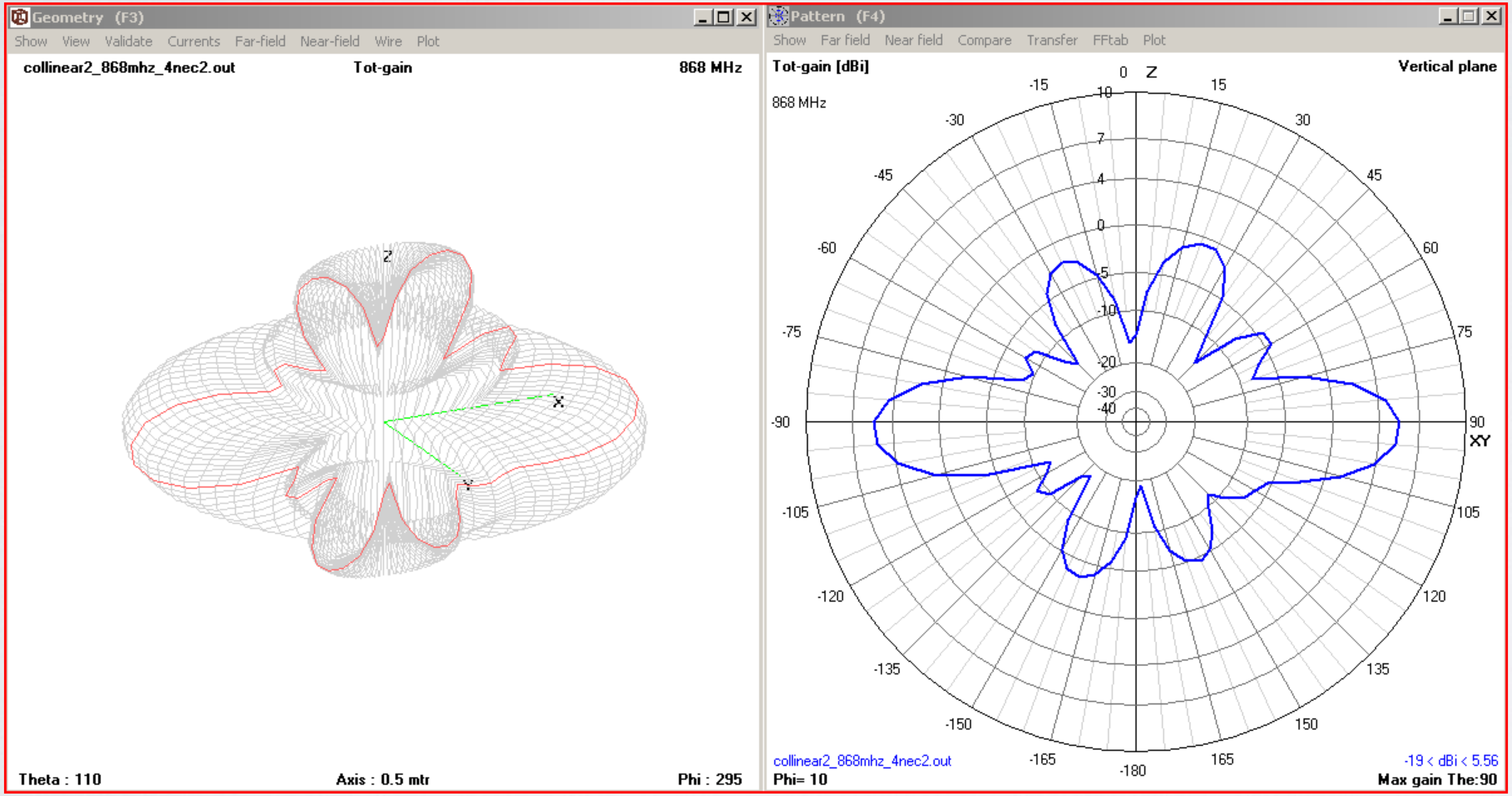




Max gain: 5.56 dBi @ Θ=85°

ANTENNA MODELLING NEC-2

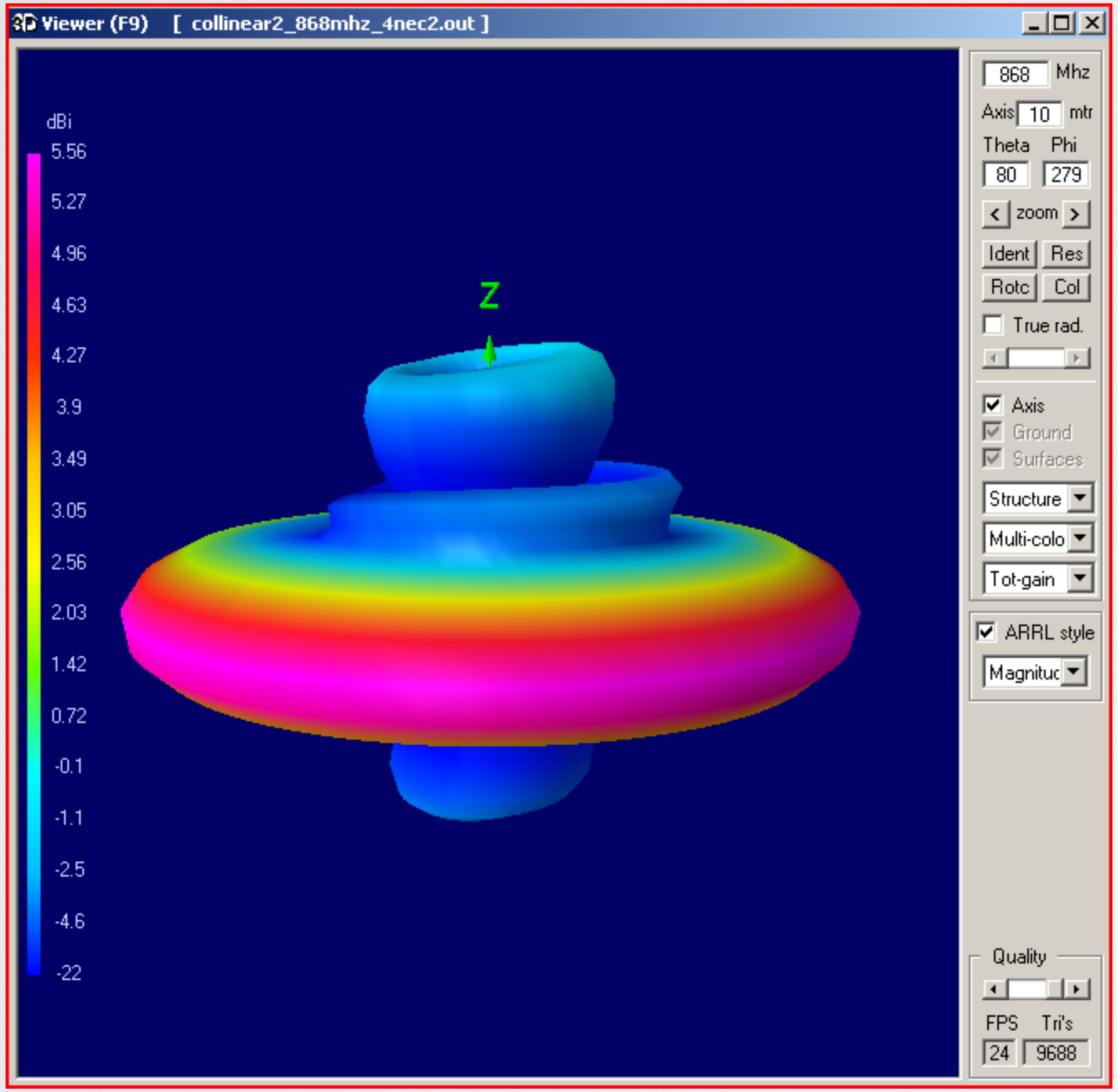
- **Free space**



Max gain: 5.56 dBi @ Θ=85°

ANTENNA MODELLING NEC-2

- **Free space**



COLLINEAR ANTENNA 2 PERFORMANCE TESTS

- Again two performance tests are conducted.

- **Performance test A**:
The collinear antenna 2 is attached to an end node, which is located inside a building, and transmit messages which will be received by nearby gateways in my area.
The average RSSI is calculated and also the total time it took to receive 15 messages.
The test will be repeated using a sleeve dipole antenna.

- **Performance test B**:
The collinear antenna 2 is attached to an end node and transmit messages which will be received by a dedicated gateway 6 meters away. Both devices are indoors.
The average RSSI is calculated and also the total time it took to receive 15 messages.
The test will be repeated using a ½λ dipole antenna.

COLLINEAR ANTENNA 2 PERFORMANCE TEST A

- The collinear antenna 2 performance is compared with a sleeve dipole antenna. More information about sleeve dipole antennas, see tutorial 43.

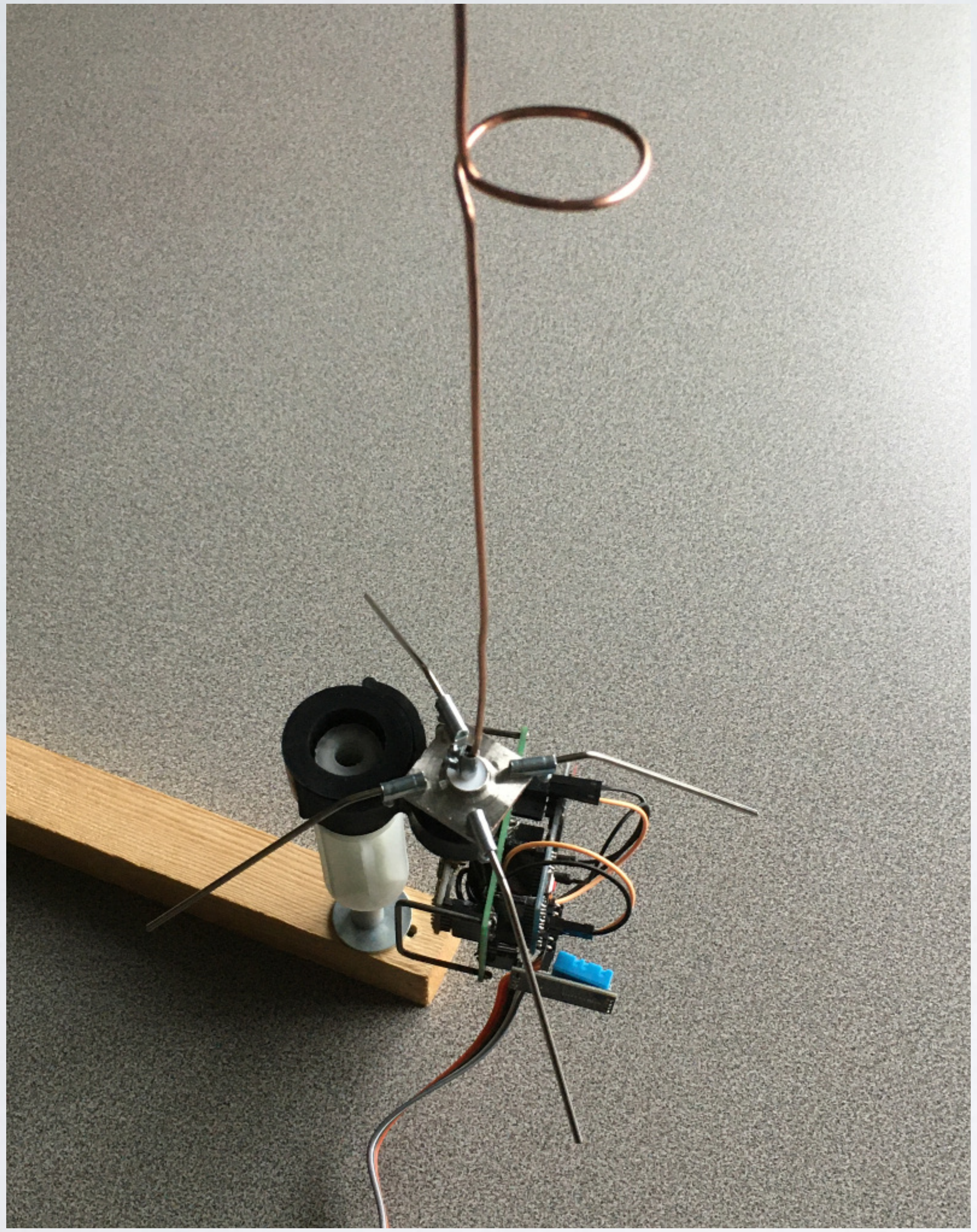
- For this test I am using the end node and antenna C as demonstrated in tutorial 33.

- More information about this end node, see: https://www.mobilefish.com/developer/lorawan/lorawan_quickguide_build_lora_node_rfm95_arduino_pro_mini.html

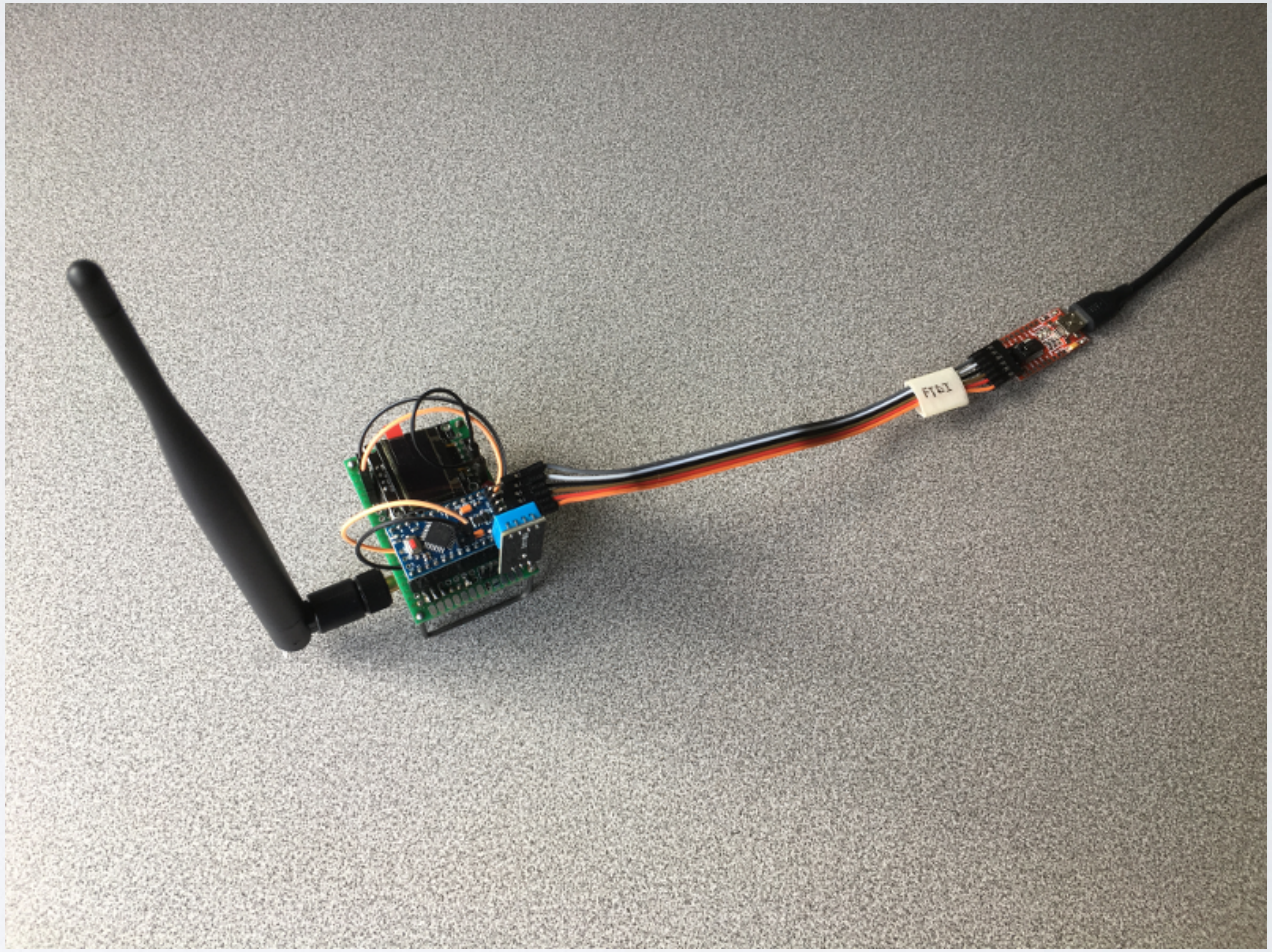
- The end node uses the MCCI LoRaWAN LMIC Library: https://github.com/mcci-catena/arduino-lmic

- The end node uses the following sketch: https://www.mobilefish.com/download/lora/ttn-otaa-pro-mini-sensors.ino.txt

COLLINEAR ANTENNA 2 PERFORMANCE TEST A



Collinear antenna 2 + end node



Sleeve dipole + end node

COLLINEAR ANTENNA 2 PERFORMANCE TEST A

- I have NOT modified the end node transmission power when using collinear antenna 2.

- In my area there are several gateways and I know that these gateways, which are connected to The Things Network, can receive my transmitted data.

- Collinear antenna 2 is attached to the end node at location A and transmits data. I have done the same with the sleeve dipole antenna. In both cases two messages per minute were transmitted.

- The logged data can be found at:
  https://www.mobilefish.com/download/lora/collinear2_test_results.txt

COLLINEAR ANTENNA 2 PERFORMANCE TEST A

- End node tx power = 14 dBm
  Data from: collinear2_test_results.txt

Gateway	Distance from end device to gateway[km]	Ant. Altitude [m]	Collinear Average RSSI [dBm]	Sleeve dipole Average RSSI [dBm]	Elevation angle α [°]
eui-000080029c10dc24	14.7	45	-121 *	-119 *	1.32
eui-000080029c10db9b	4.36	30	-115.5 *	-	0.25
eui-7276ff000b031ebb	0.73	38	**-91.5**	**-91.5**	2.12
eui-60c5a8fffe760e60	4.15	30	-111.5 *	-	0.26
eui-1dee0d9b5b2dc3a2	11.3	?	-115 *	-	?
eui-0ba0000000000001	5.02	20	**-118.3**	-119 *	0.10
eui-aa555a0000088013	1.57	42	-114 *	-	1.13

* Only one or few measurements. I will ignore these results.

COLLINEAR ANTENNA 2 PERFORMANCE TEST A

- There is no significant difference in the average RSSI values between the collinear antenna 2 and the sleeve dipole antenna.

- However more gateways were able to receive the transmitted data from collinear antenna 2 compared to the sleeve dipole antenna.

- The time it took for the gateways to receive the 15 messages from the end node:
  Using the sleeve dipole antenna: 8.5 minutes
  Using collinear antenna 2: 8.5 minutes

- The Arduino sketch is configured to transmit 2 message per minute. In a perfect situation it should take 7.5 to 8 minutes to receive these 15 messages.

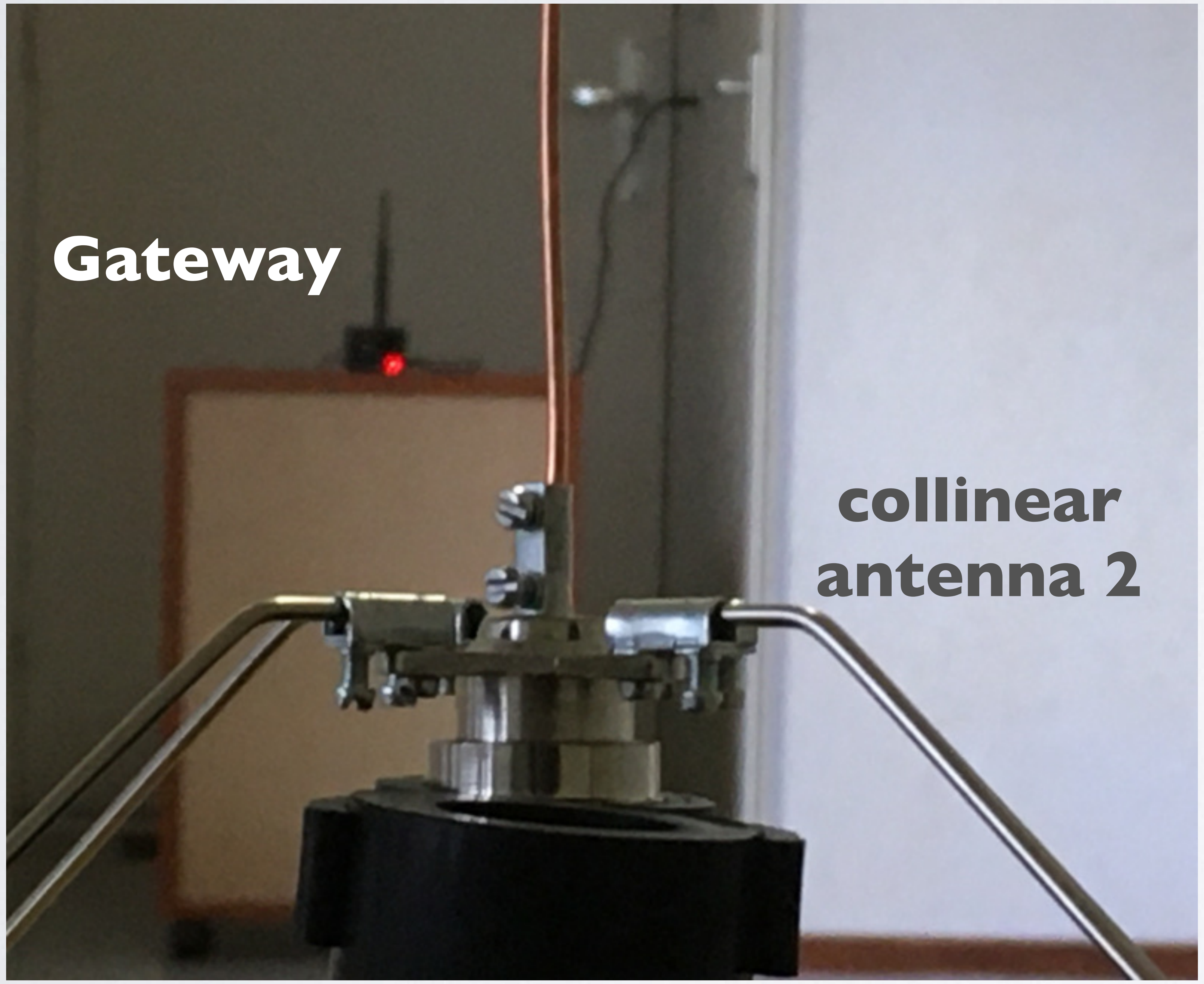
COLLINEAR ANTENNA 2 PERFORMANCE TEST B

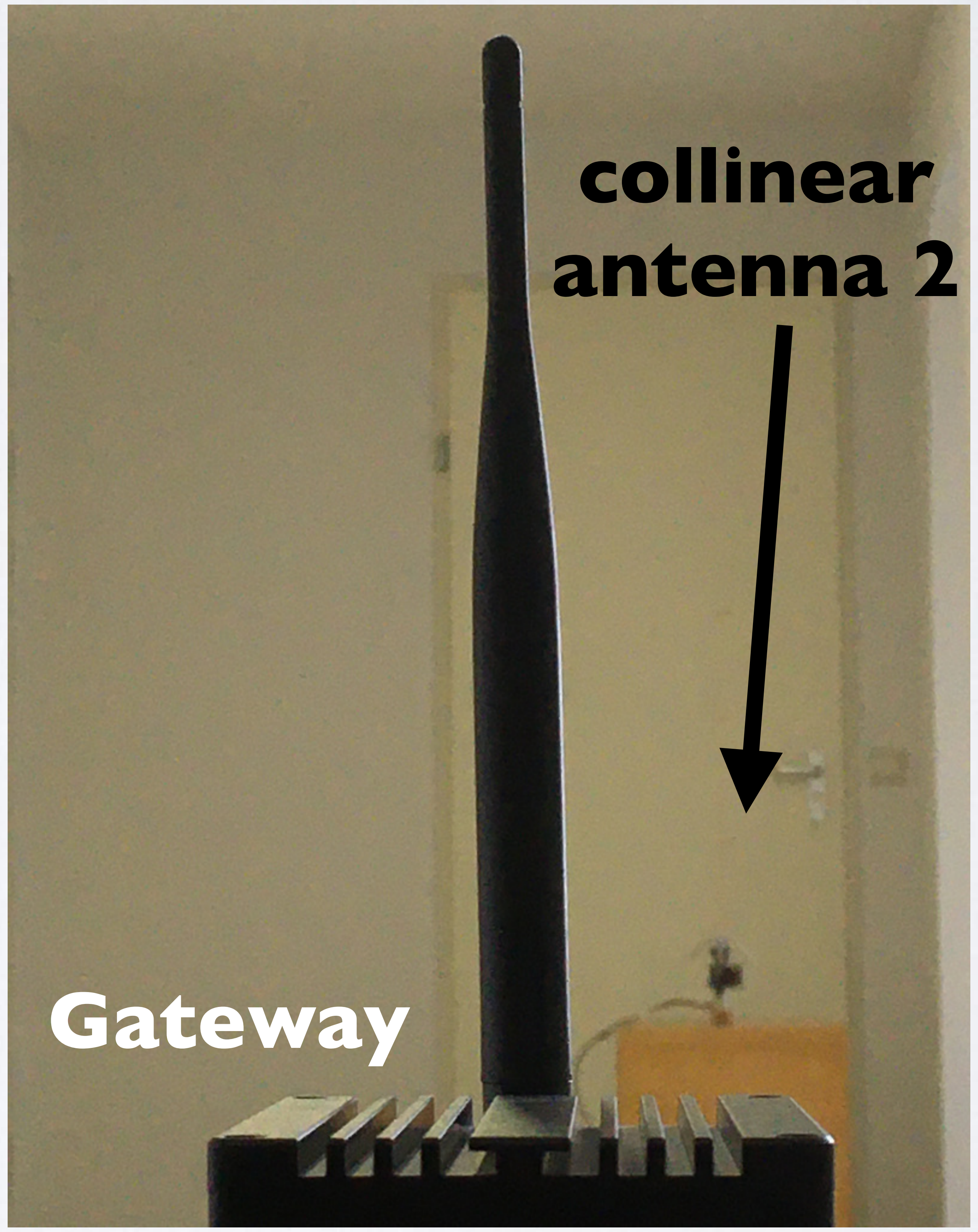
- Make sure you keep everything in your setup the same when switching from the collinear antenna 2 to the ½λ dipole antenna.

- A slight change can impact your measurements.

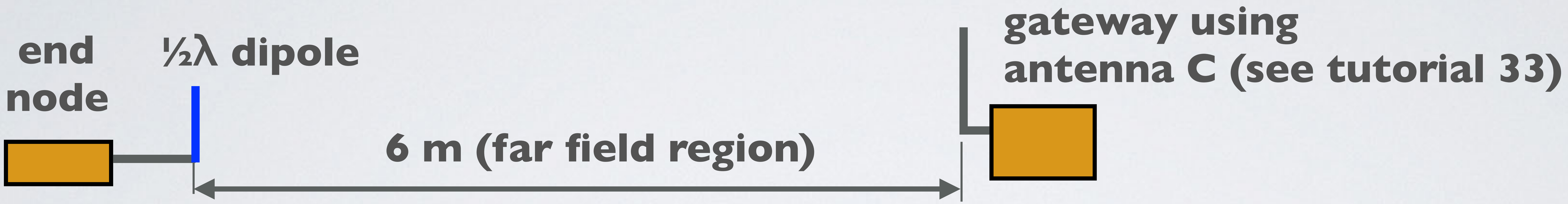
- - Do not change the height of the end node and the height of the gateway.
  - Do not change the distance between end node and the gateway.
  - Use the same end node and gateway.
  - Use the same connectors.
  - During the measurements I did not stay in the same room.
  - The distance between transmitter and receiver should be > 4λ (Far field region)
    More information about near and far field, see tutorial 34.

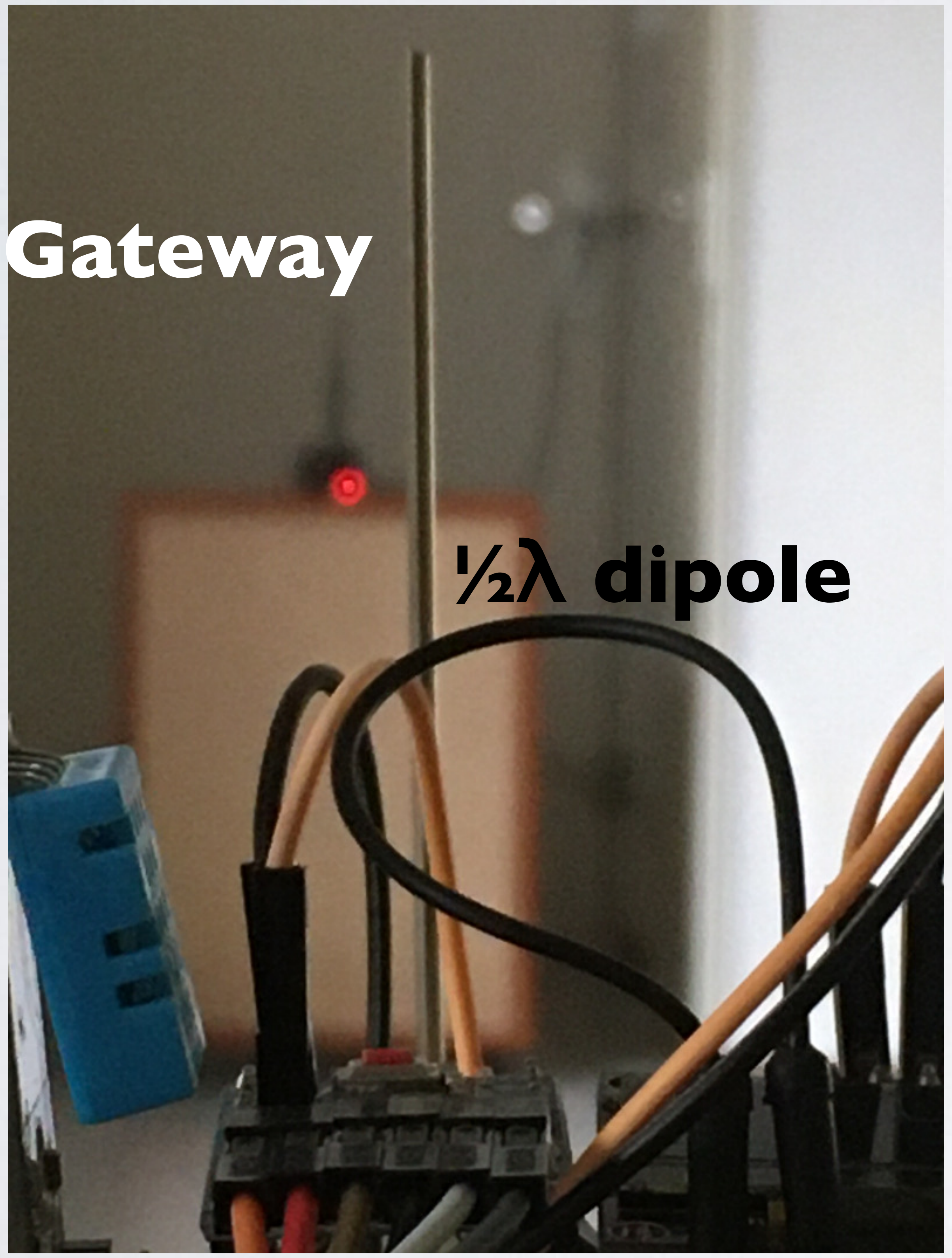
COLLINEAR ANTENNA 2 PERFORMANCE TEST B

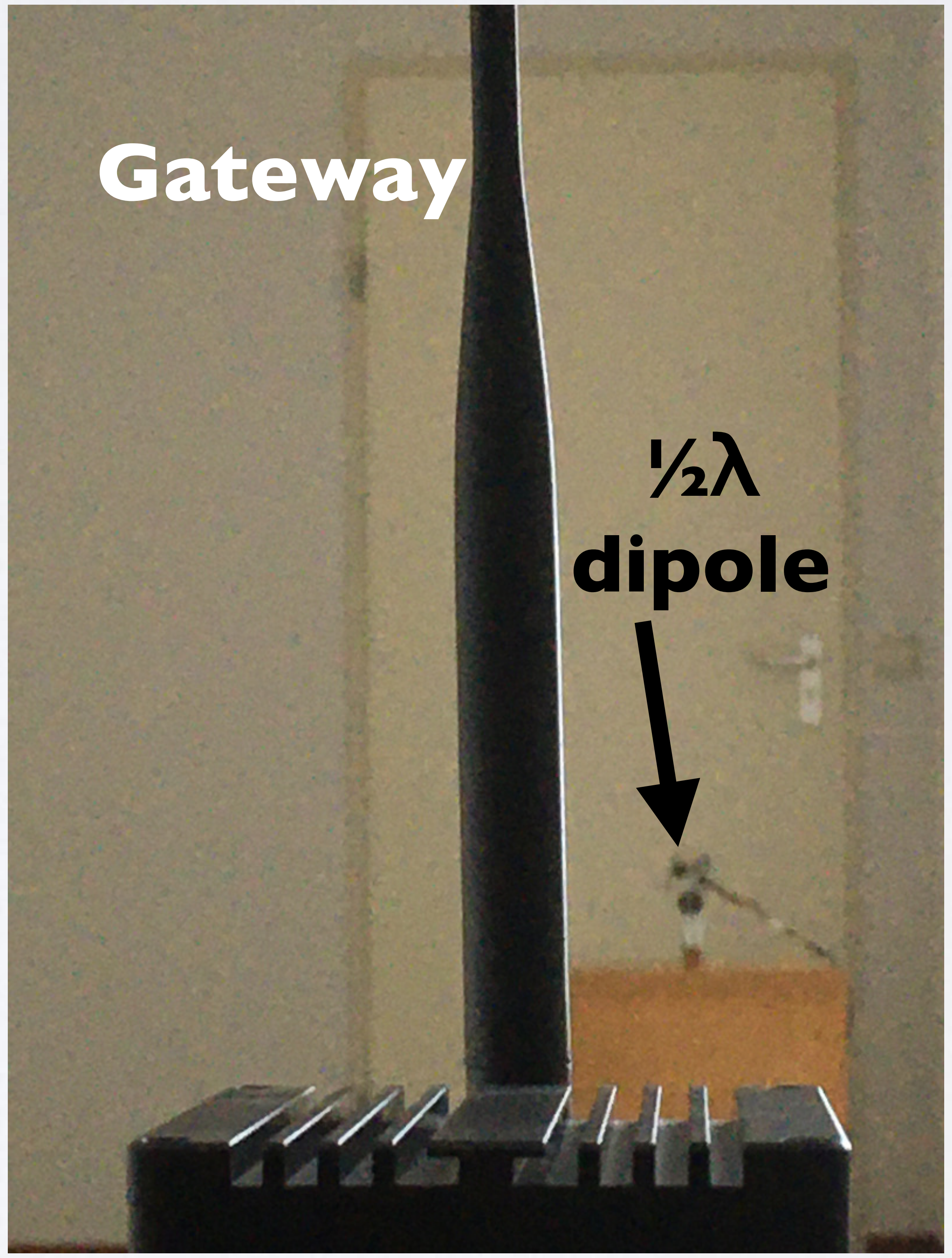




COLLINEAR ANTENNA 2 PERFORMANCE TEST B

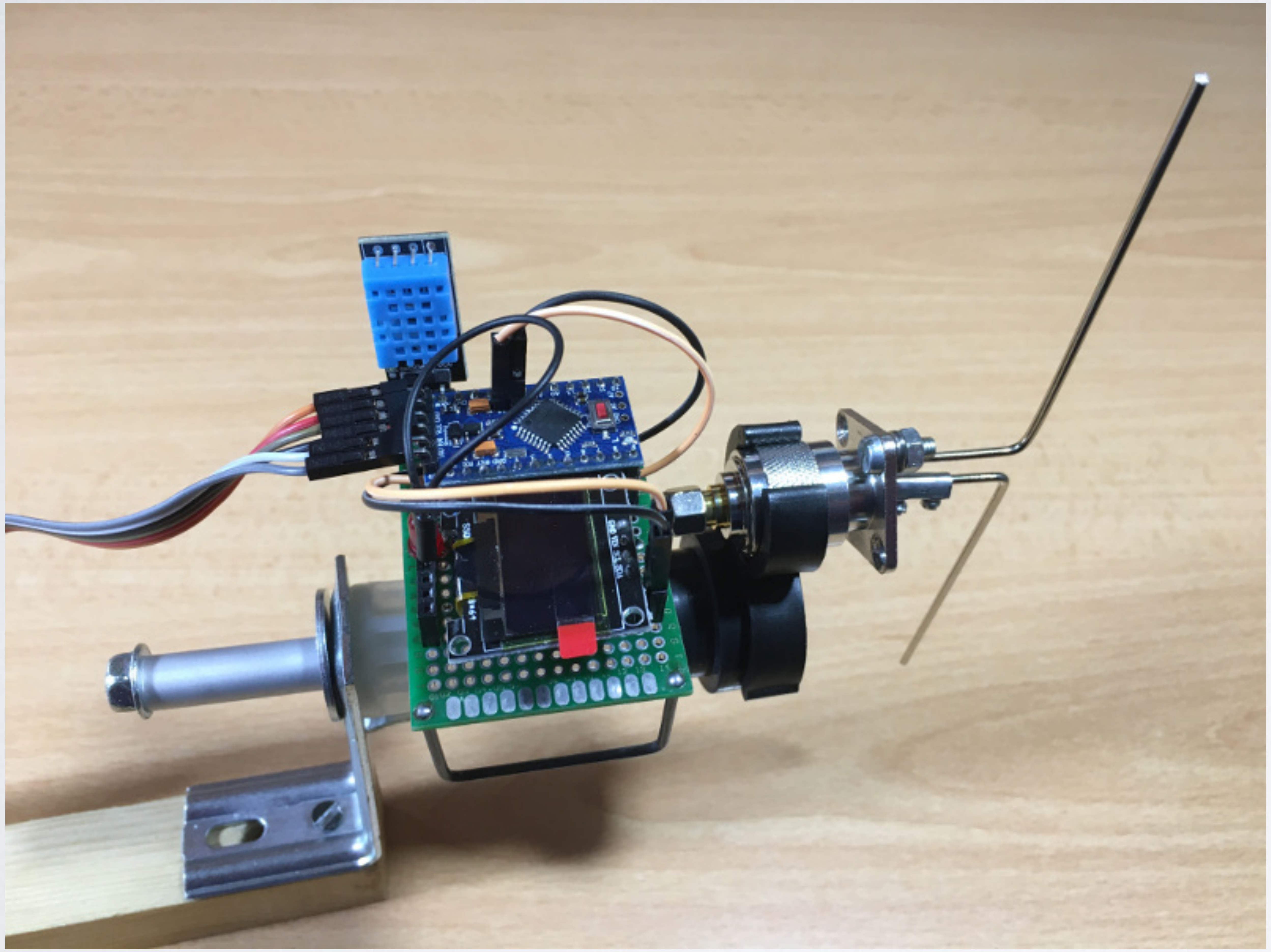






COLLINEAR ANTENNA 2 PERFORMANCE TEST B

- This ½λ dipole antenna is used in this setup, see tutorial 41.



VSWR ≈ 1.1
Z ≈ 54Ω
S11 ≈ -27 dB

COLLINEAR ANTENNA 2 PERFORMANCE TEST B

- The logged data can be found at:
  https://www.mobilefish.com/download/lora/collinear2_antenna_gain.txt

- The average RSSI when using the ½λ dipole antenna: -33.8 dBm
  The average RSSI when using collinear antenna 2: -37.5 dBm

COLLINEAR ANTENNA 2 PERFORMANCE TEST B

- The time it took for the gateway to receive the 15 messages from the end node:
  Using the ½λ dipole antenna: 8.5 minutes
  Using collinear antenna 2: 9 minutes

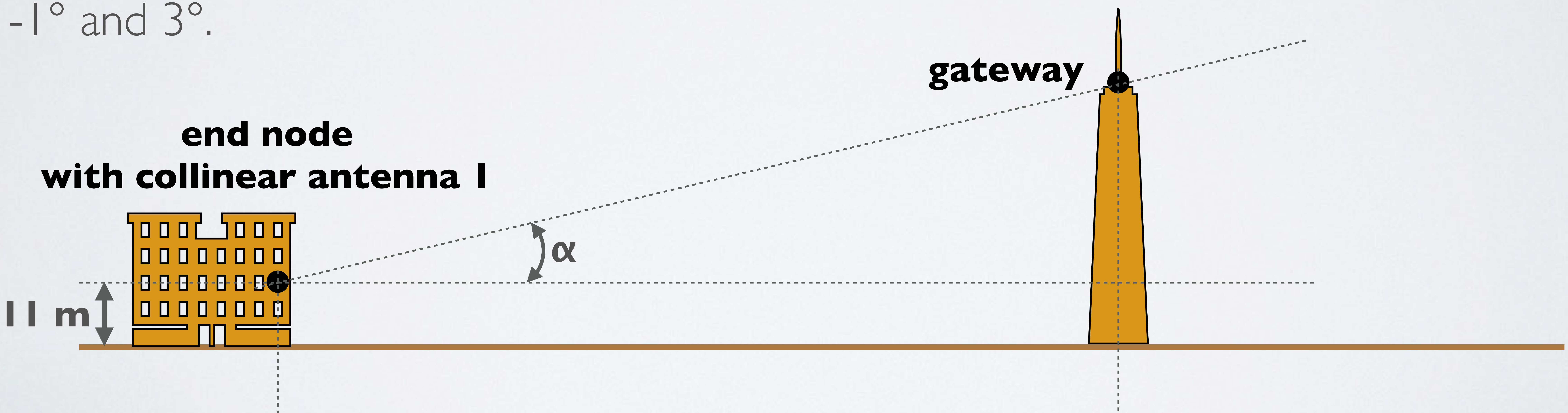
- The Arduino sketch is configured to transmit 2 message per minute. In a perfect situation it should take 7.5 to 8 minutes to transmit these 15 messages.

COLLINEAR ANTENNA 2 CONCLUSION

- Based on the results of performance test A and B, I conclude that the collinear antenna 2 performance is much better compared to the ½λ dipole antenna.

- More gateways in my area were able to receive the transmitted sensor data.

- This is also collaborated looking at the 4NEC2 radiation pattern in the vertical plane and the fact that all my nearby gateways operates at an elevation angle (α) between -1° and 3°.



COLLINEAR ANTENNA 1 VS COLLINEAR ANTENNA 2

- Collinear antenna 2 has a better antenna performance compared to collinear antenna 1.

- More gateways were able to receive the transmitted sensor data using collinear antenna 2 compared to collinear antenna 1.

- Collinear antenna 2 has a higher gain at elevation angles between -1° and 3° compared to collinear antenna 1, according to the 4NEC2 radiation patterns in the vertical plane.

REMARKS

- The 4NEC2 program simulates how the antenna behaves but MY collinear antennas are not accurately modelled. Which means that the generated radiation patterns and other antenna parameters are just a rough indication of how the real collinear antennas behaves.

- If you want accurate radiation patterns and other antenna parameters, these antenna measurements should be performed in an anechoic chamber.

- Normally a collinear antenna is attached to a gateway and not to an end device.
  Let's assume you bought a collinear antenna which has a maximum gain of 6 dBi.
  This is the same as 3.85 dBd
  Calculation: dBi = dBd + 2.15; 6 = dBd + 2.15; dBd = 6 - 2.15 = 3.85
  In the gateway global_conf.json file (see tutorial 30) you must specify the
  antenna_gain = 3.85

REMARKS

- If a collinear antenna is put inside a plastic / glass fiber tube, always measure the antenna parameters with an antenna analyser when the antenna is inside the tube.

- It is possible to put the collinear antenna inside a PVC tube, but use a thin tube wall.

- Gray PVC tubes may contain carbon. Carbon absorbs or reflect RF signals.
  To check if the PVC tube contains carbon, you can apply the "microwave" method.
  The microwave method is explained at:
  https://www.thethingsnetwork.org/forum/t/diy-external-antenna-for-gateway/3011/17

  WARNING: IF YOU APPLY THE MICROWAVE METHOD, IT MAY DESTROY YOUR MICROWAVE. DO THIS AT YOUR OWN RISK!