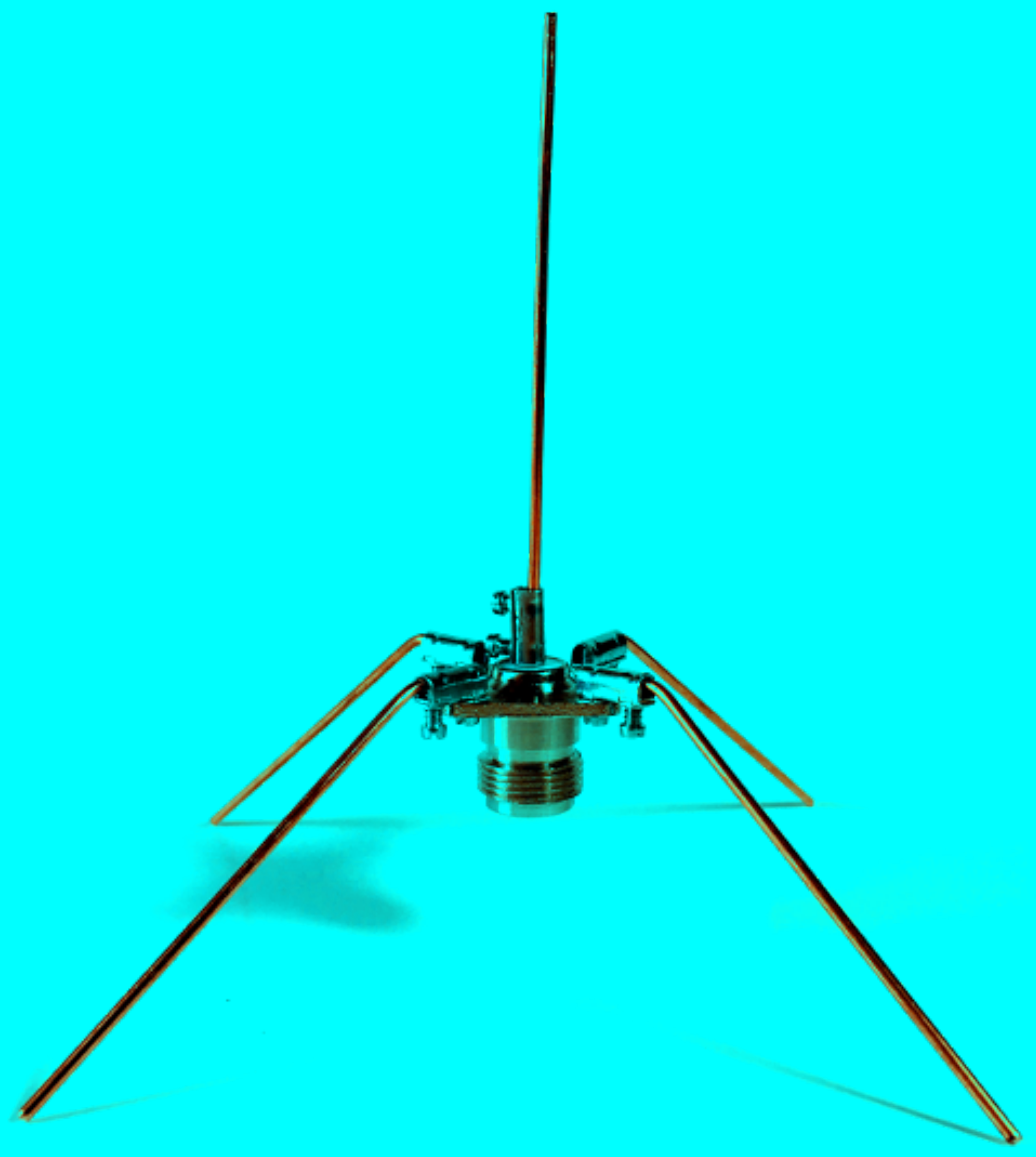
mobilefish.com

# LORA / LORAWAN TUTORIAL 44

## Quarter Wave Ground Plane Antenna



v1.1.0

# INTRO

- In this tutorial I will explain how to build a ¼ wave ground plane antenna.

# 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.**

# BUILD A ¼ WAVE GROUND PLANE ANTENNA

- The ¼ wave ground plane antenna (aka spider antenna) has radials.

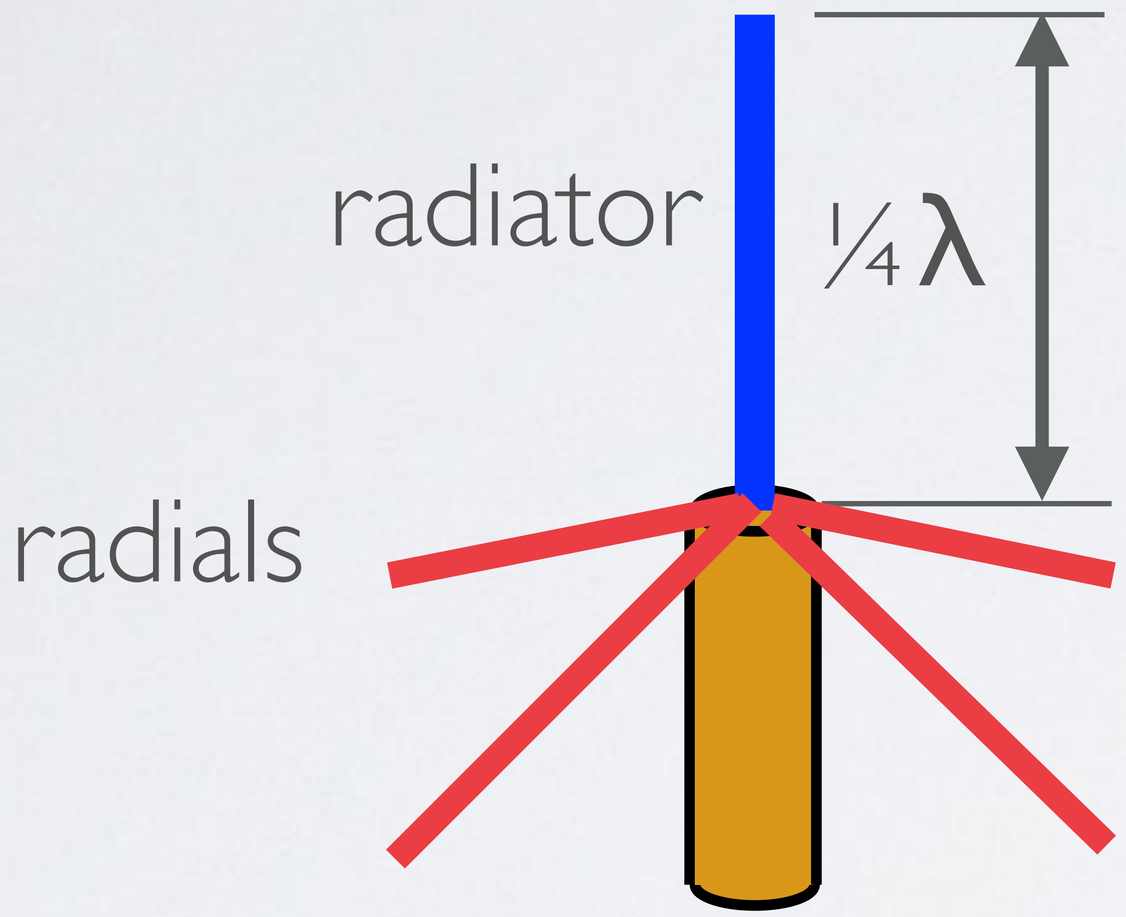
- Often four ¼ wave radials are used to sufficiently simulate a complete circular conductive ground plane which works as a reflector as already explained in tutorial 42.

- The current in the reflected image has the same direction as the current in the real antenna.

- If the radials are straight, meaning not bend, the impedance at the feed point will be around 37Ω. If the radials are bend down at an angle of 40° the impedance at the feed point will be around 50Ω. The ¼ wave ground plane antenna is an unbalanced antenna thus a 50Ω coax cable, which is an unbalanced feed line, can be directly attached to it.

# BUILD A ¼ WAVE GROUND PLANE ANTENNA

- The ¼ wave ground plane antenna has only one radiating element which is fed in the lower end which is near the conductive surface.

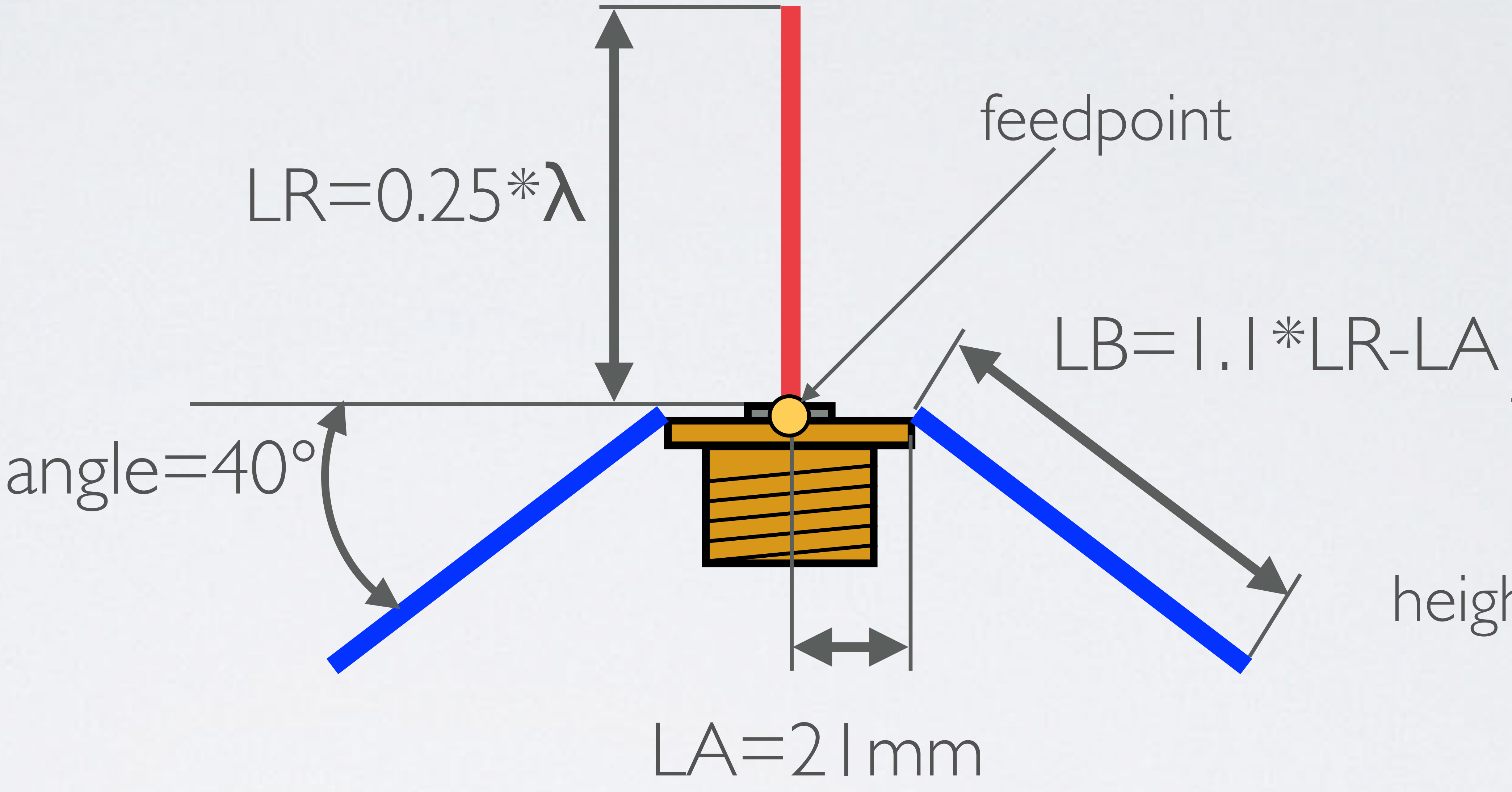


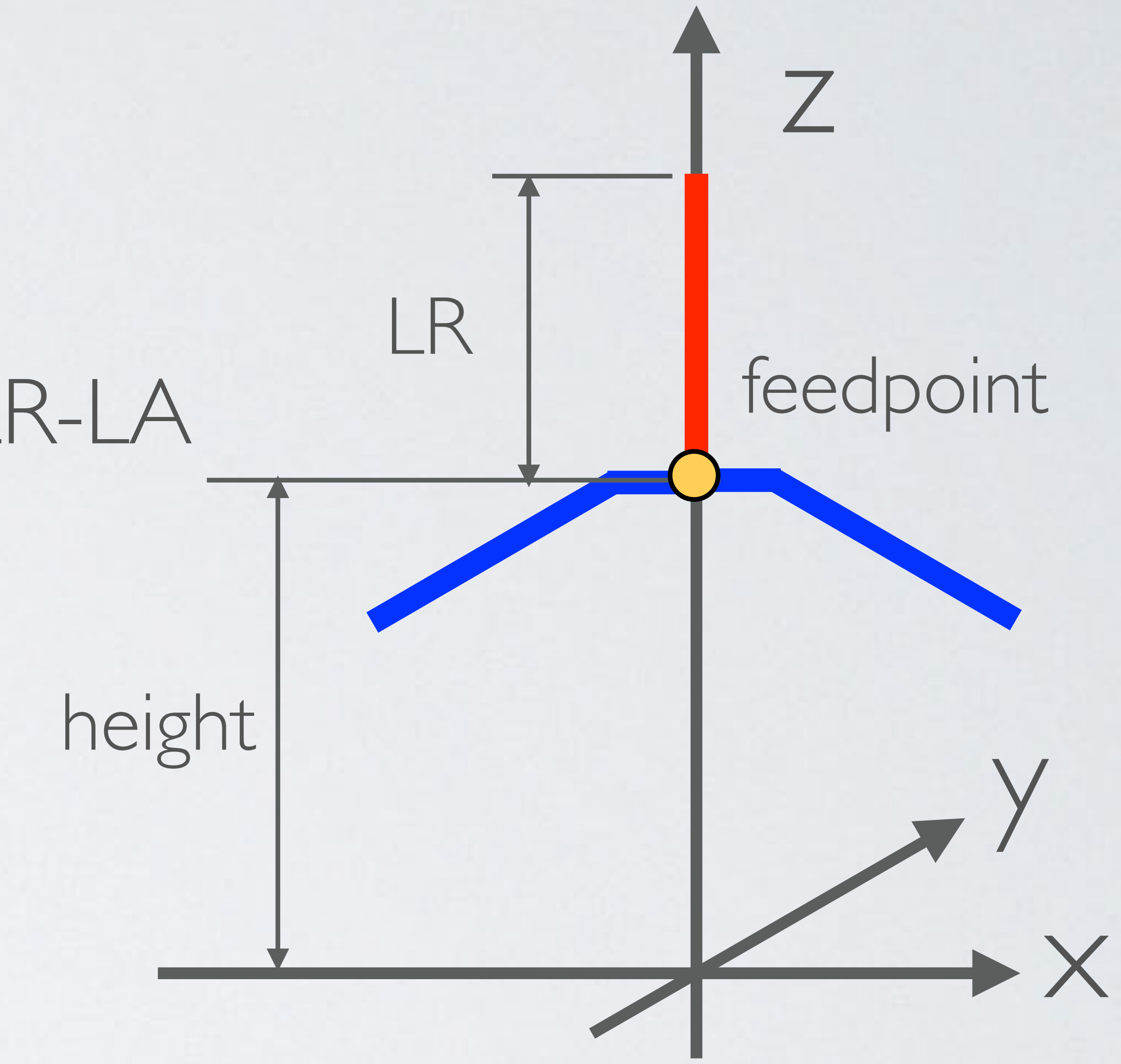

- The radiating element length $L_{Radiating}$ = ¼ x λ and the radials are slightly longer.
- The radiating element is also called the driven element, radiator or resonator.

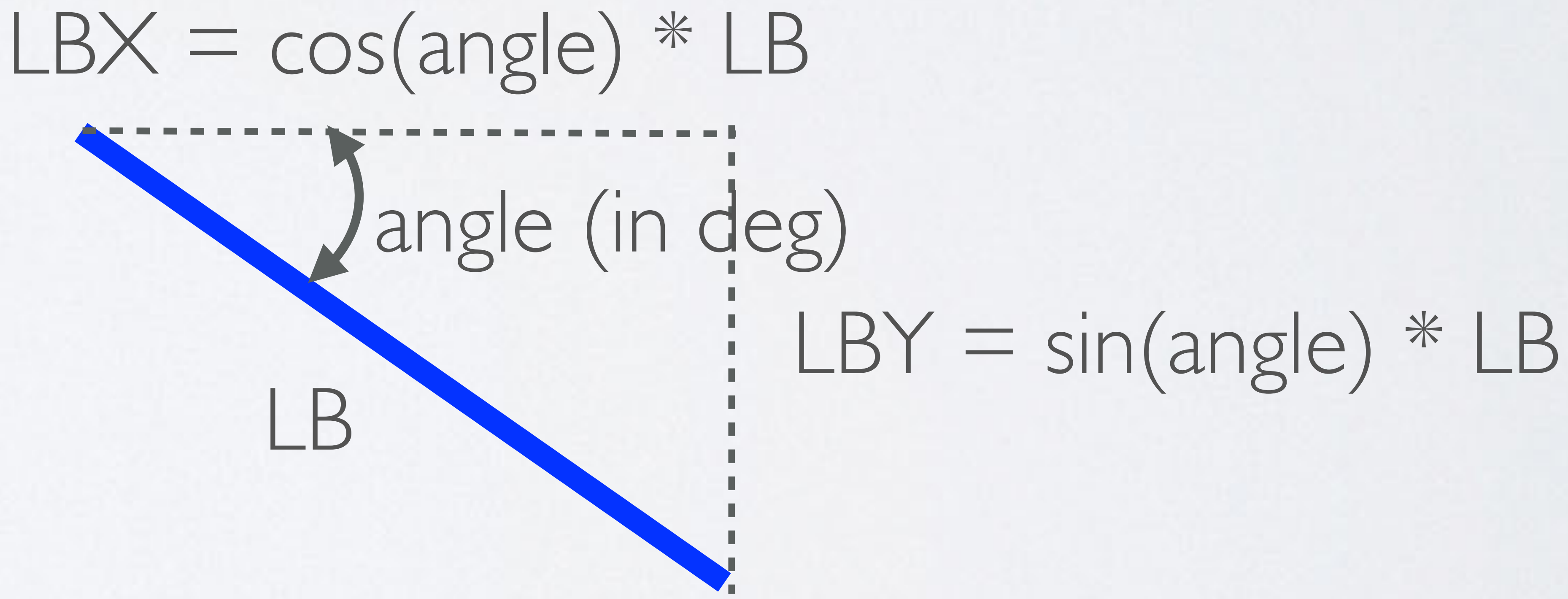
# ANTENNA MODELLING 4NEC2

- Antenna parameters:
  f = 868 MHz
  wire material = copper
  wire diameter = 1.65 mm
  wire radius = 0.825 mm = 0.000825 m
  height = 11 m
  ground type: real ground (City industrial area)

  Note:
  λ = 0.34538 m
  ¼λ = 0.086345 m

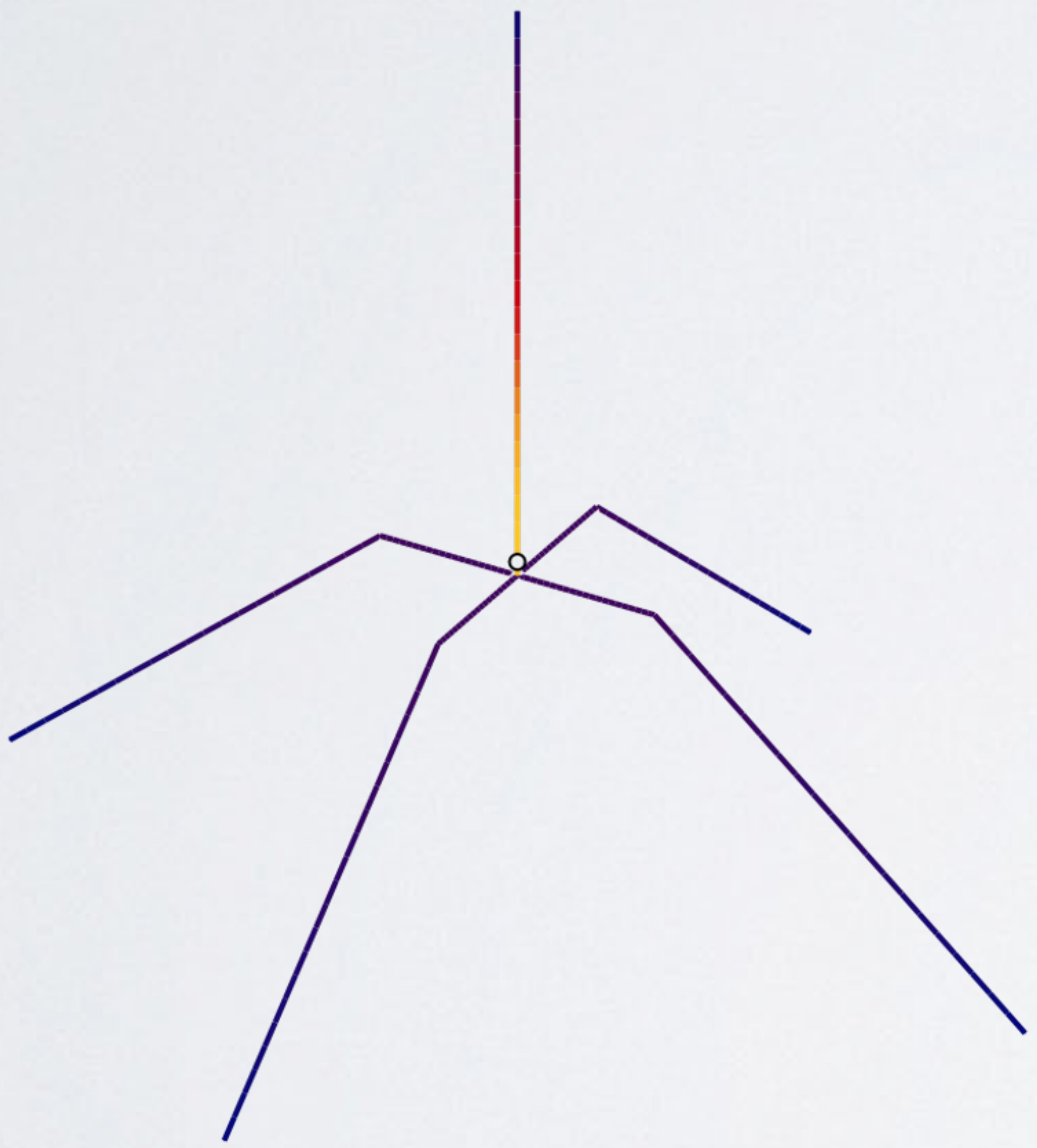


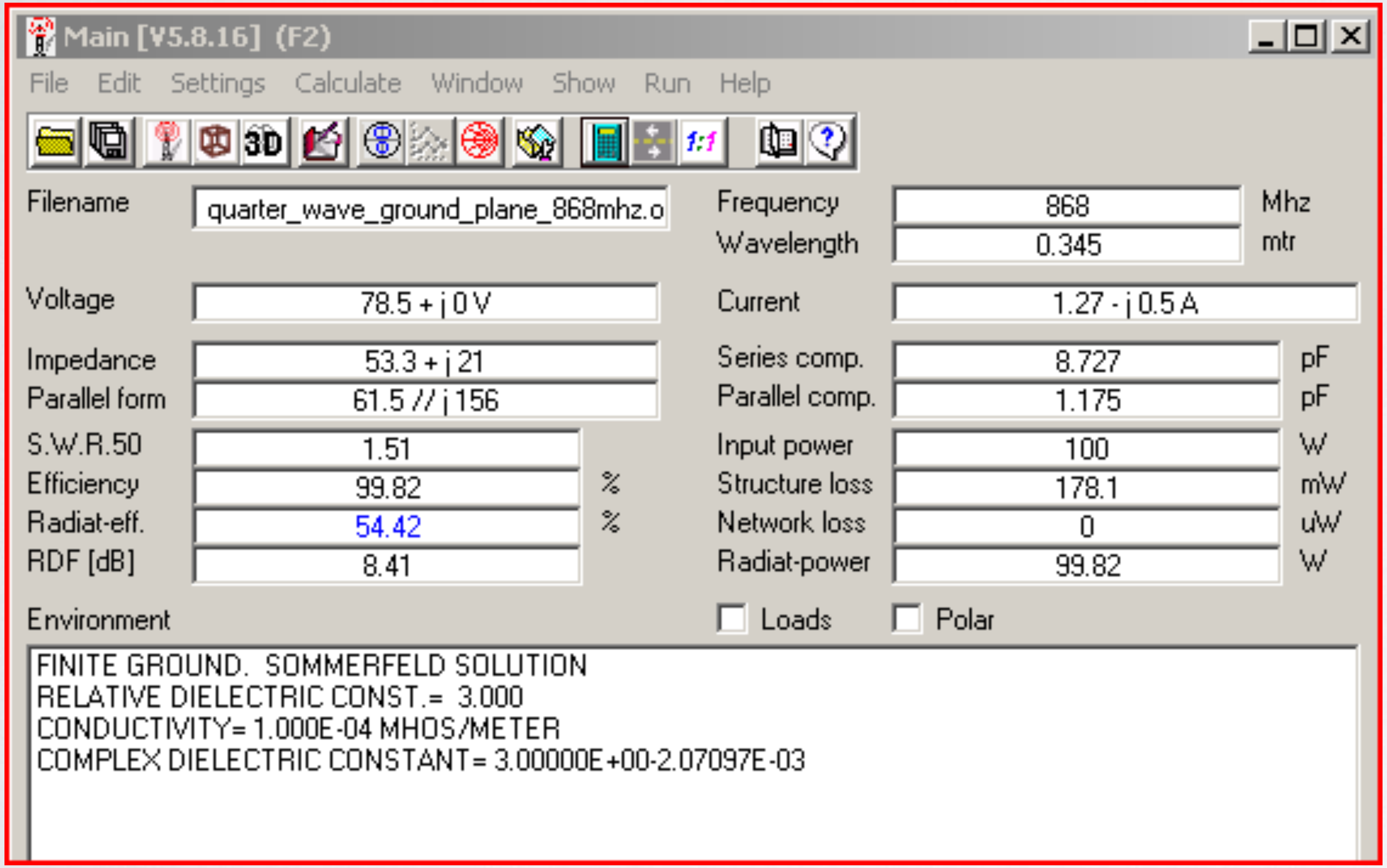
# ANTENNA MODELLING 4NEC2

- 4NEC2 card deck: https://www.mobilefish.com/download/lora/quarter_wave_ground_plane_868mhz.nec.txt



```
SY height=11
SY diameter=0.00165
SY radius=diameter/2
SY LR=0.086345
SY LA=0.021
SY LB=1.1*LR-LA
SY angle=40
SY LBX=cos(angle)*LB
SY LBY=sin(angle)*LB
```

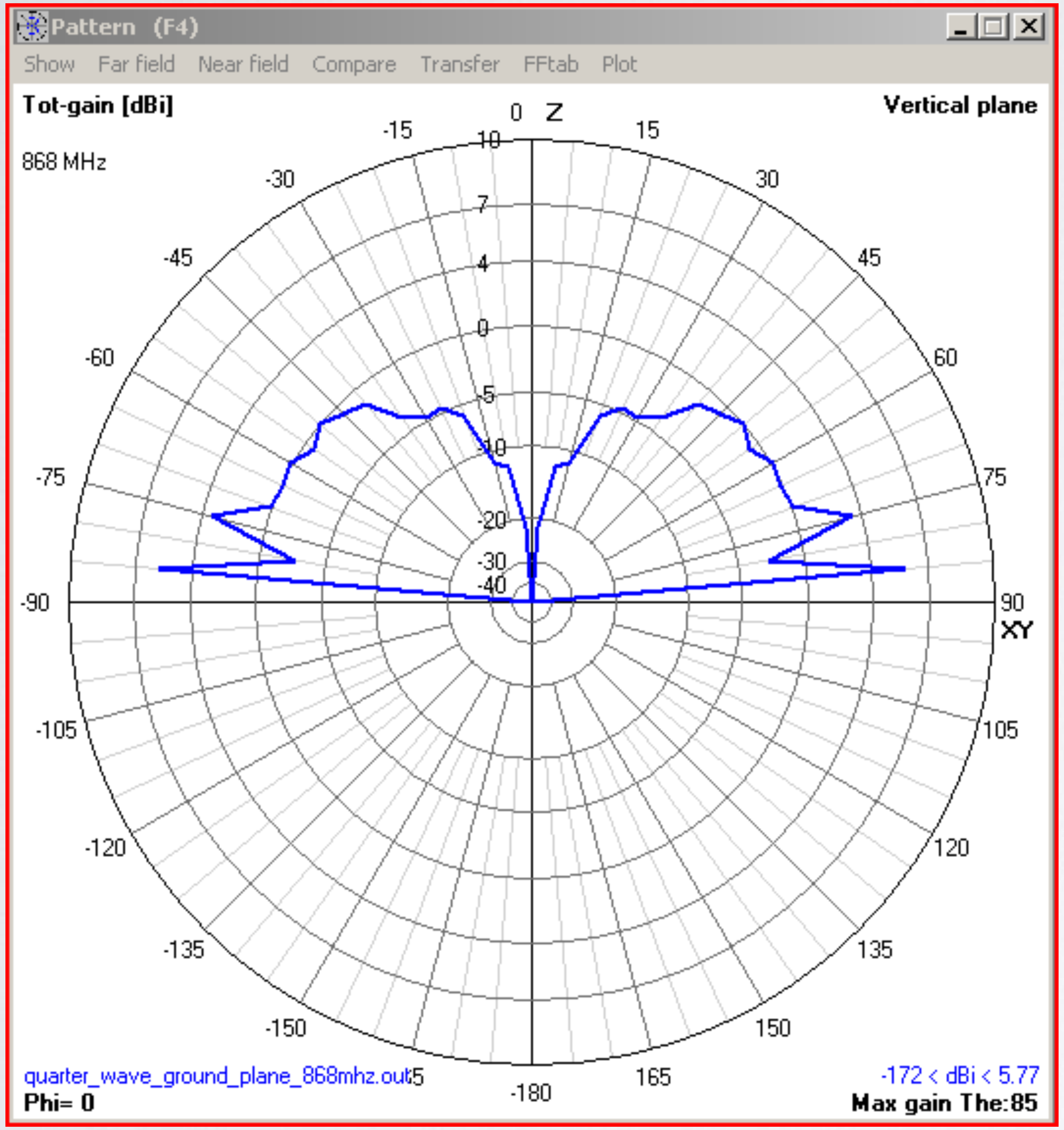
# ANTENNA MODELLING 4NEC2

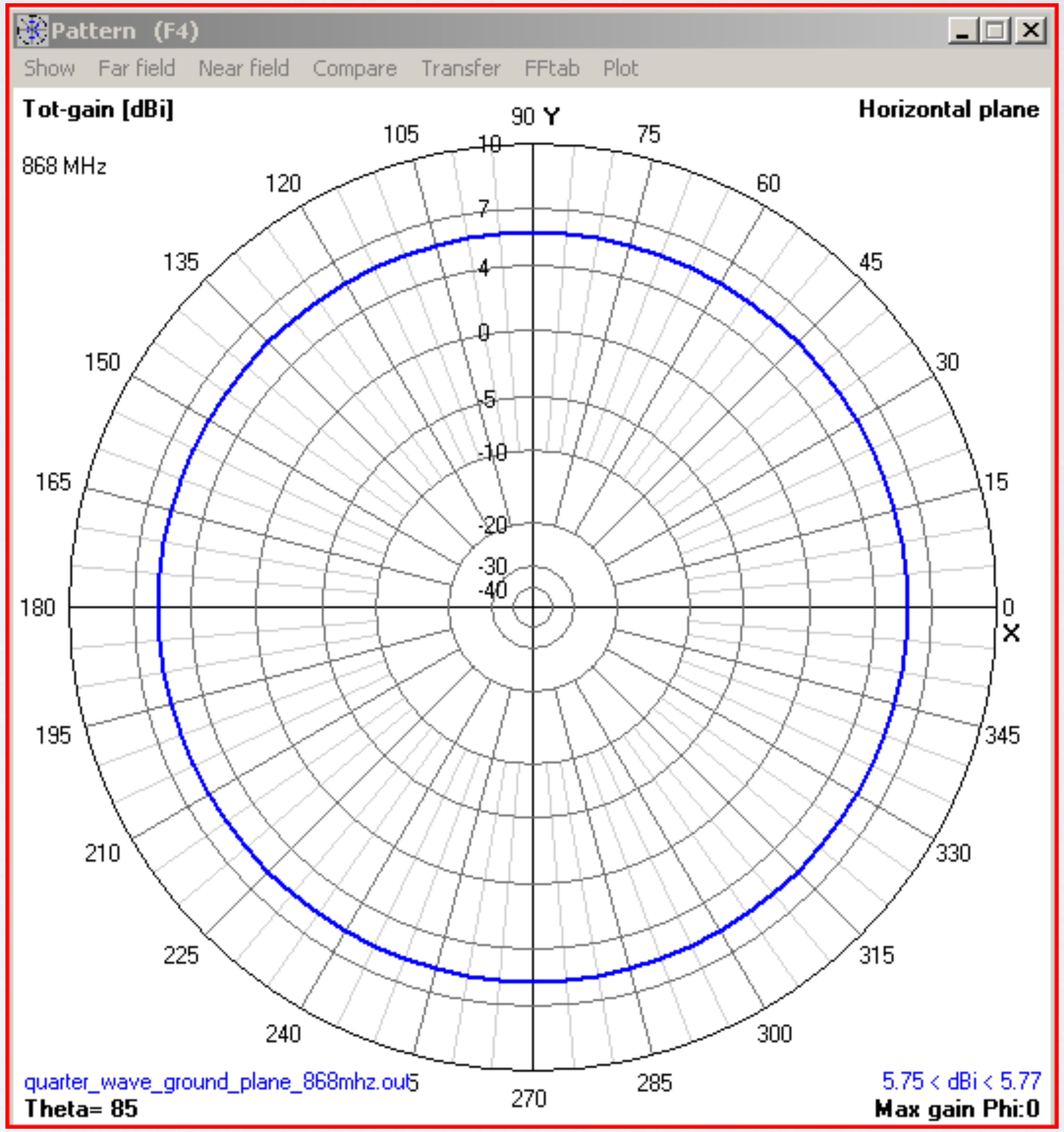



Radiating element length
LR =0.25*λ = 86.345 mm

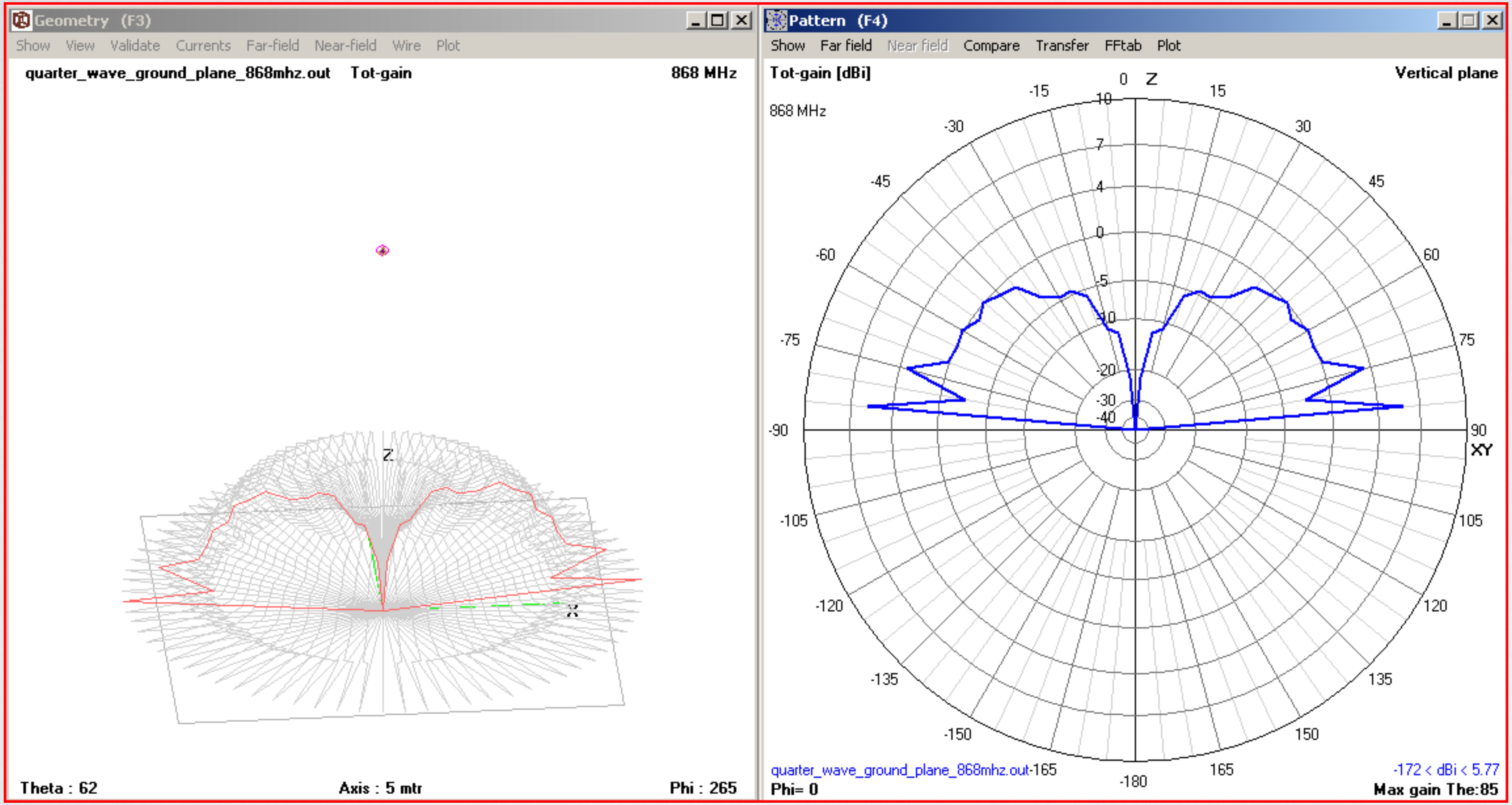
VSWR = 1.51
Max gain = 5.77 dBi

# ANTENNA MODELLING 4NEC2

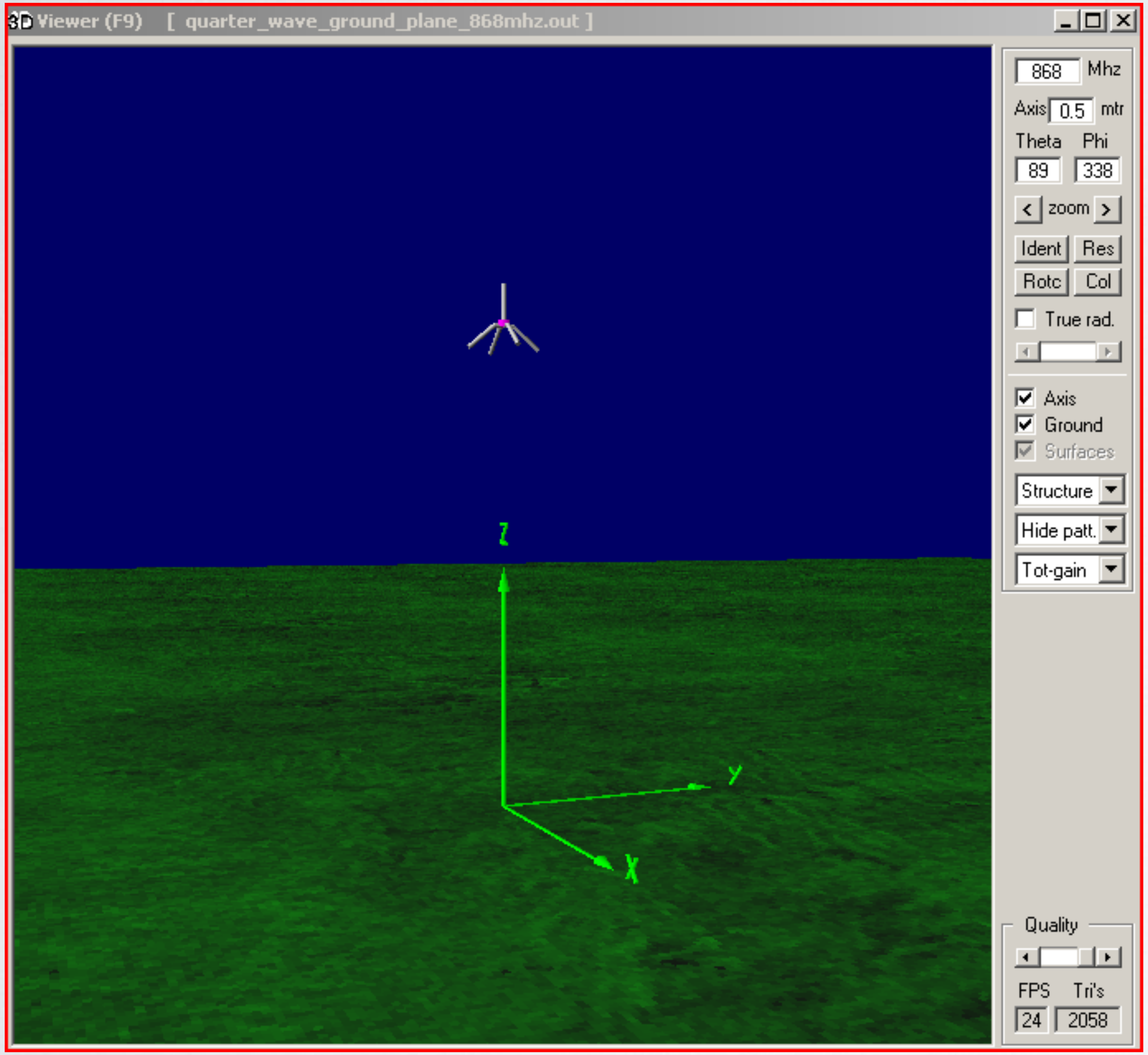


# ANTENNA MODELLING 4NEC2

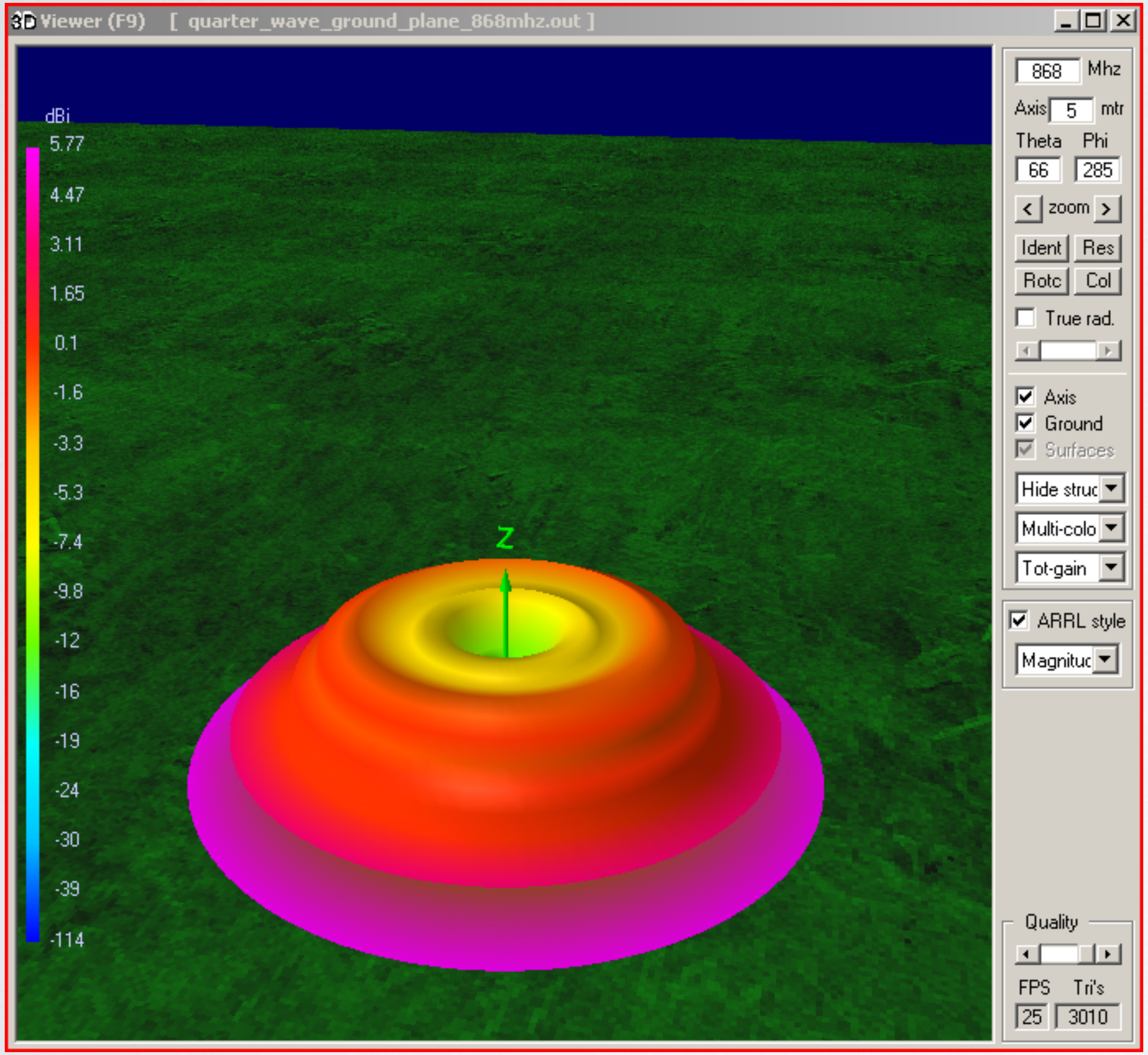


# ANTENNA MODELLING 4NEC2




The ¼ wave ground plane antenna in 3D

# ANTENNA MODELLING 4NEC2

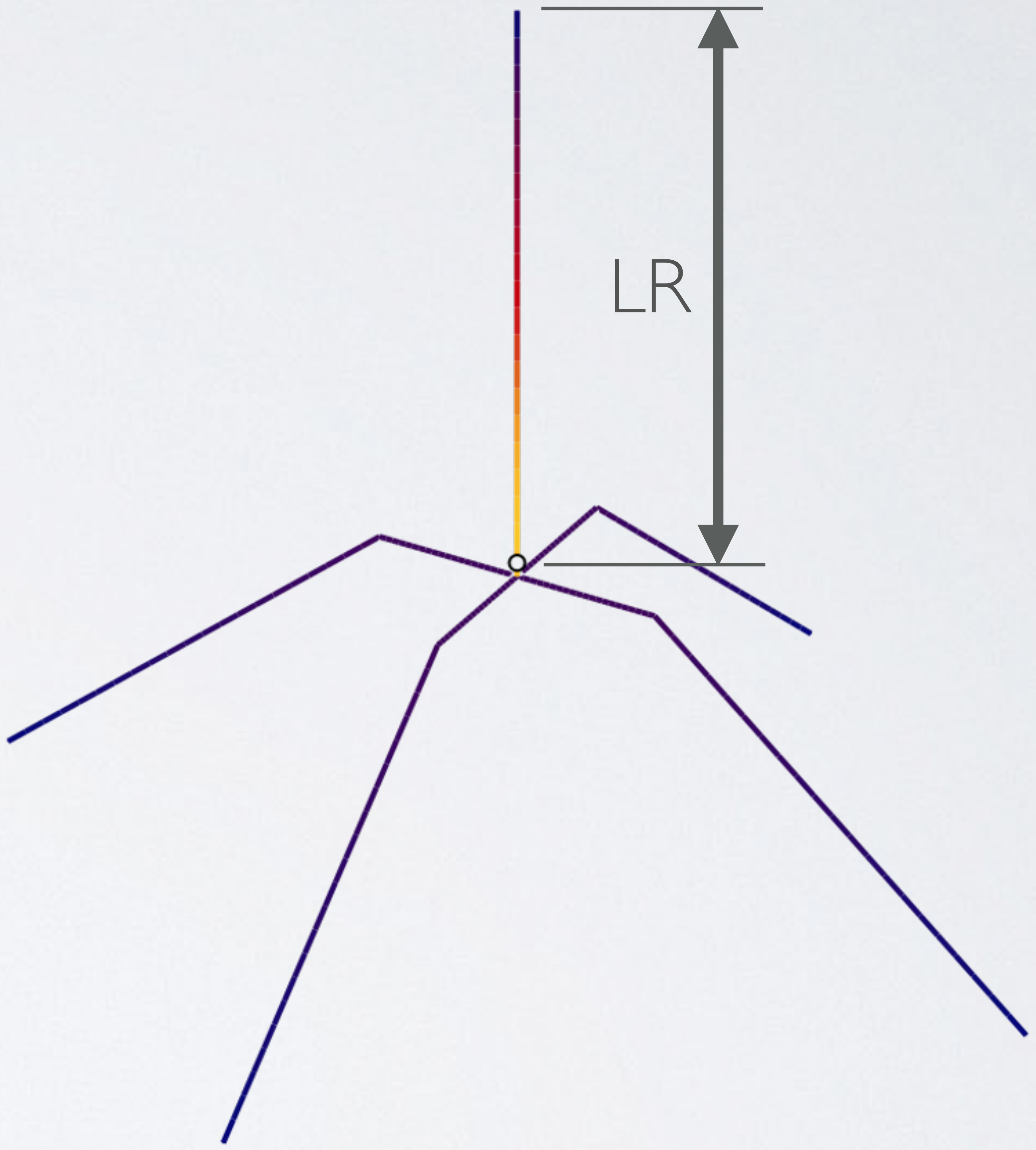



- Please be aware that the generated radiation patterns are merely a ROUGH indication how the real quarter wave ground plane antenna behaves.
- The real quarter wave ground plane antenna is not 100% accurately modelled.
- If you want accurate radiation patterns of real antennas than the antenna radiation patterns measurements should be performed in an anechoic chamber.

# ANTENNA MODELLING 4NEC2

- As mentioned earlier:
  LR = 0.25*λ = 86.345 mm
  VSWR = 1.51
  Max gain = 5.77 dBi

- If the antenna model is optimised by changing the radiating element length:
  LR = ¼ x λ x VF (copper)
  LR = 86.345 x 0.95 = 82 mm
  VSWR = 1.18
  Max gain = 5.82 dBi



# ANTENNA MODELLING 4NEC2

- Using the optimised ¼ wave ground plane antenna: LR = 82 mm
  Ground type: real ground (City industrial area)
  https://www.mobilefish.com/download/lora/quarter_wave_ground_plane_868mhz.nec.txt

  - Free space: VSWR = 1.18, Max gain = 1.48 dBi
  - 50 m above ground: VSWR = 1.18, Max gain = 3.15 dBi
  - 25 m above ground: VSWR = 1.18, Max gain = 5.28 dBi
  - 11 m above ground: VSWR = 1.18, Max gain = 5.82 dBi
  - 1 m above ground: VSWR = 1.19, Max gain = 5.99 dBi

The higher the antenna, the lower the max gain.

# ANTENNA MODELLING 4NEC2

- Using the optimised ½λ dipole antenna: length = 160 mm (tutorial 41)
  Ground type: real ground (City industrial area)
  https://www.mobilefish.com/download/lora/dipole_vertical_868mhz_4nec2.nec.txt
  - Free space: VSWR = 1.43, Max gain = 2.08 dBi
  - 50 m above ground: VSWR = 1.43, Max gain = 4.42 dBi
  - 25 m above ground: VSWR = 1.43, Max gain = 5.51 dBi
  - 11 m above ground: VSWR = 1.43, Max gain = 6.23 dBi
  - 1 m above ground: VSWR = 1.43, Max gain = 6.49 dBi

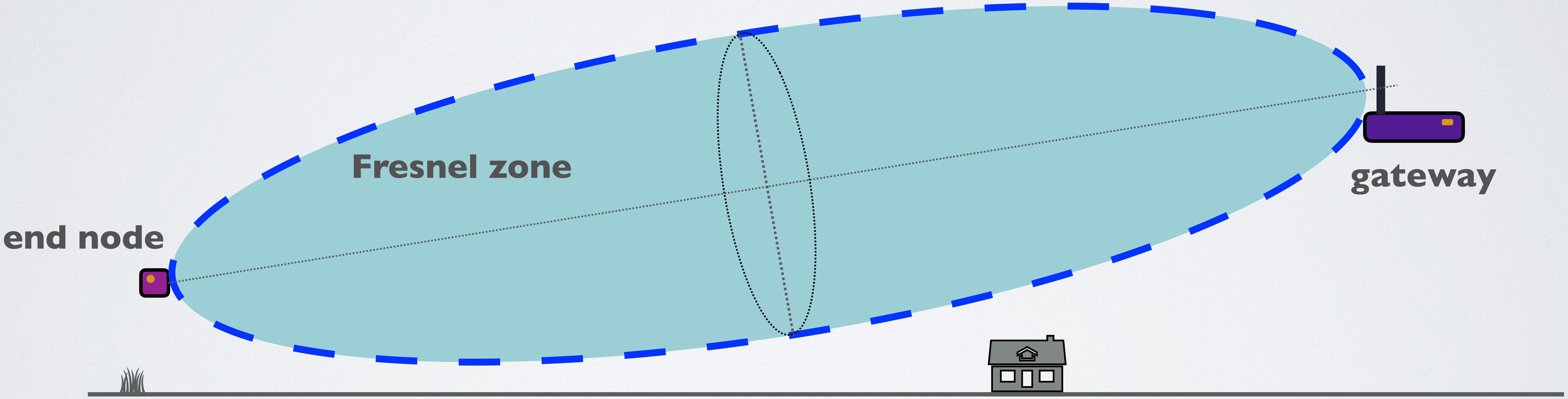
The higher the antenna, the lower the max gain.

# ANTENNA MODELLING 4NEC2

- Based on the 4NEC2 antenna model results, the ½ wave dipole antenna has a slightly higher maximum gain compared to the ¼ wave ground plane antenna.

# FRESNEL ZONE

- You might think by placing the antenna near the ground you will get the best antenna performance (= higher gain). But placing the antenna near the ground is not a good idea because of the Fresnel Zone. If you do not know what the Fresnel Zone is, watch tutorial 7.




**End node sends signal to gateway without any interference**
**No obstacles in the Fresnel zone**

# ¼ WAVE GROUND PLANE ANTENNA PROS AND CONS

- Pros:
  - Provides good performance.
  - Easy to build with consistent results.
  - Can be used at all frequency bands including LF, MF, HF, VHF and beyond.
  - Omnidirectional radiation.
  - Vertically polarised signals.
  - Low cost.
  - Low angle of radiation which means the signal is not directed towards the sky.
  - The radiation pattern is fairly uniform both vertically and horizontally.

# ¼ WAVE GROUND PLANE ANTENNA PROS AND CONS

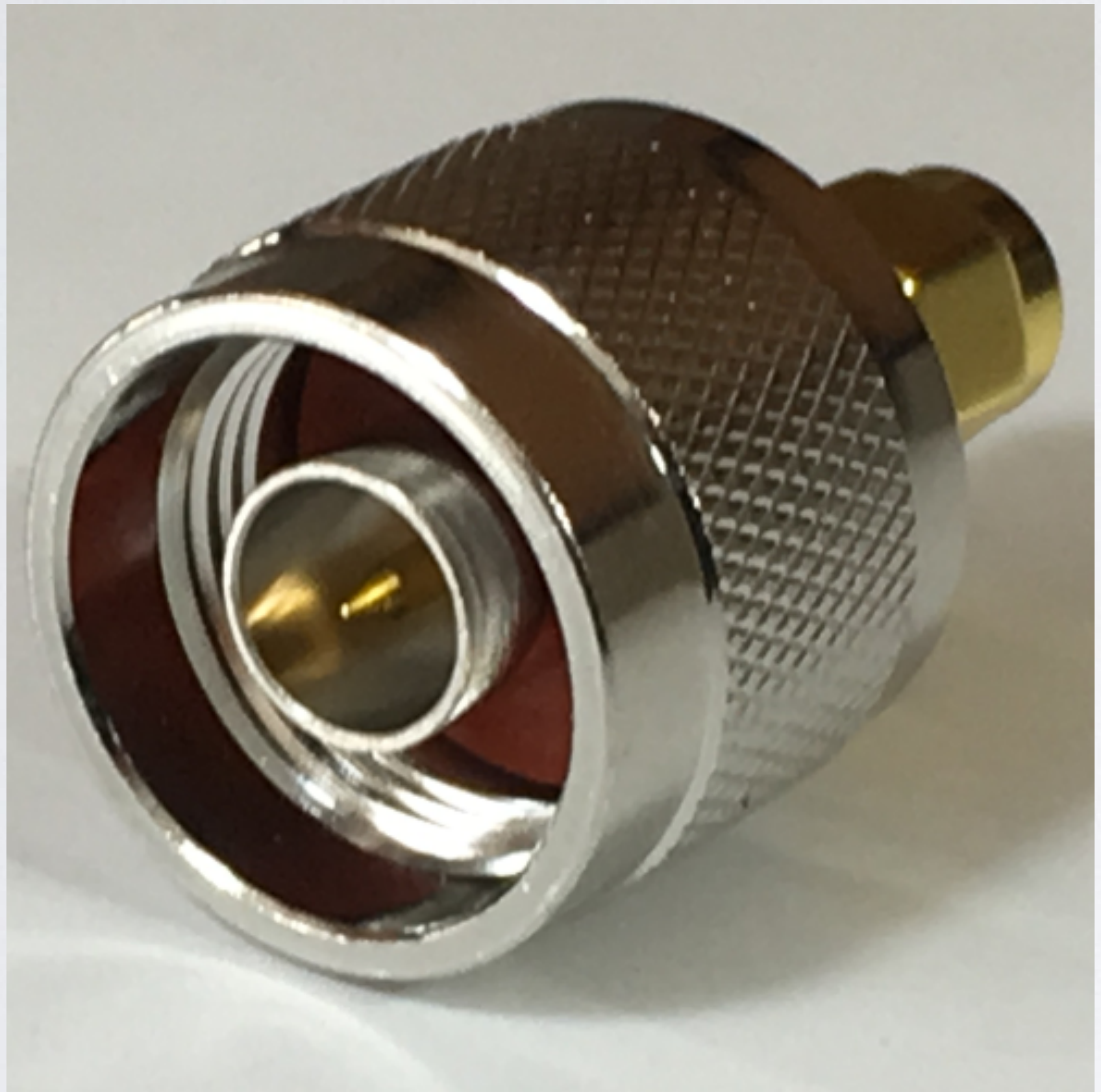
- Cons:
  - It requires a ground plane (radials)
  - A ½ wave dipole antenna has a slightly higher maximum gain compared to a ¼ wave ground plane antenna.

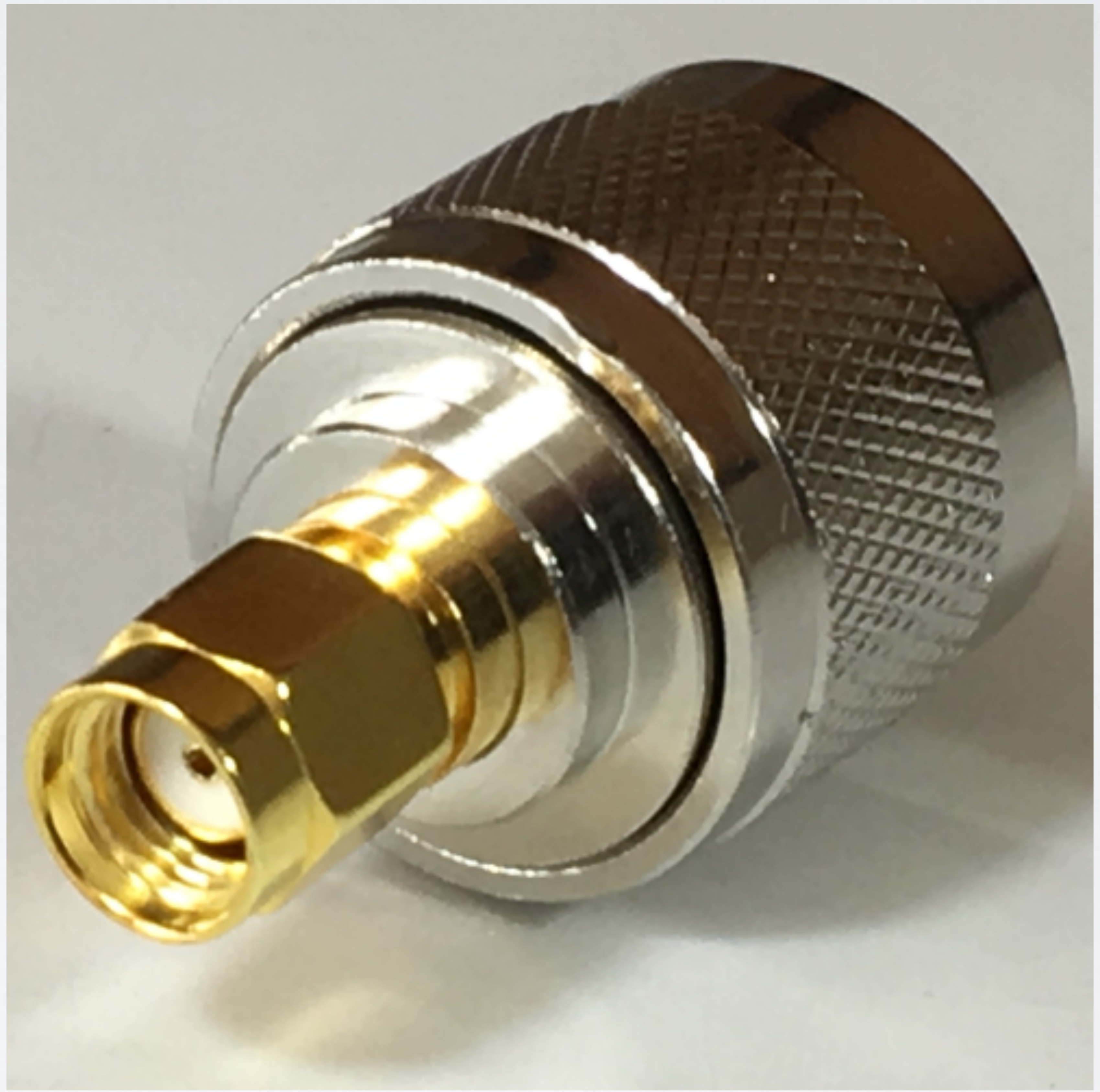
# BUILD A ¼ WAVE GROUND PLANE ANTENNA

- 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 A ¼ WAVE GROUND PLANE ANTENNA

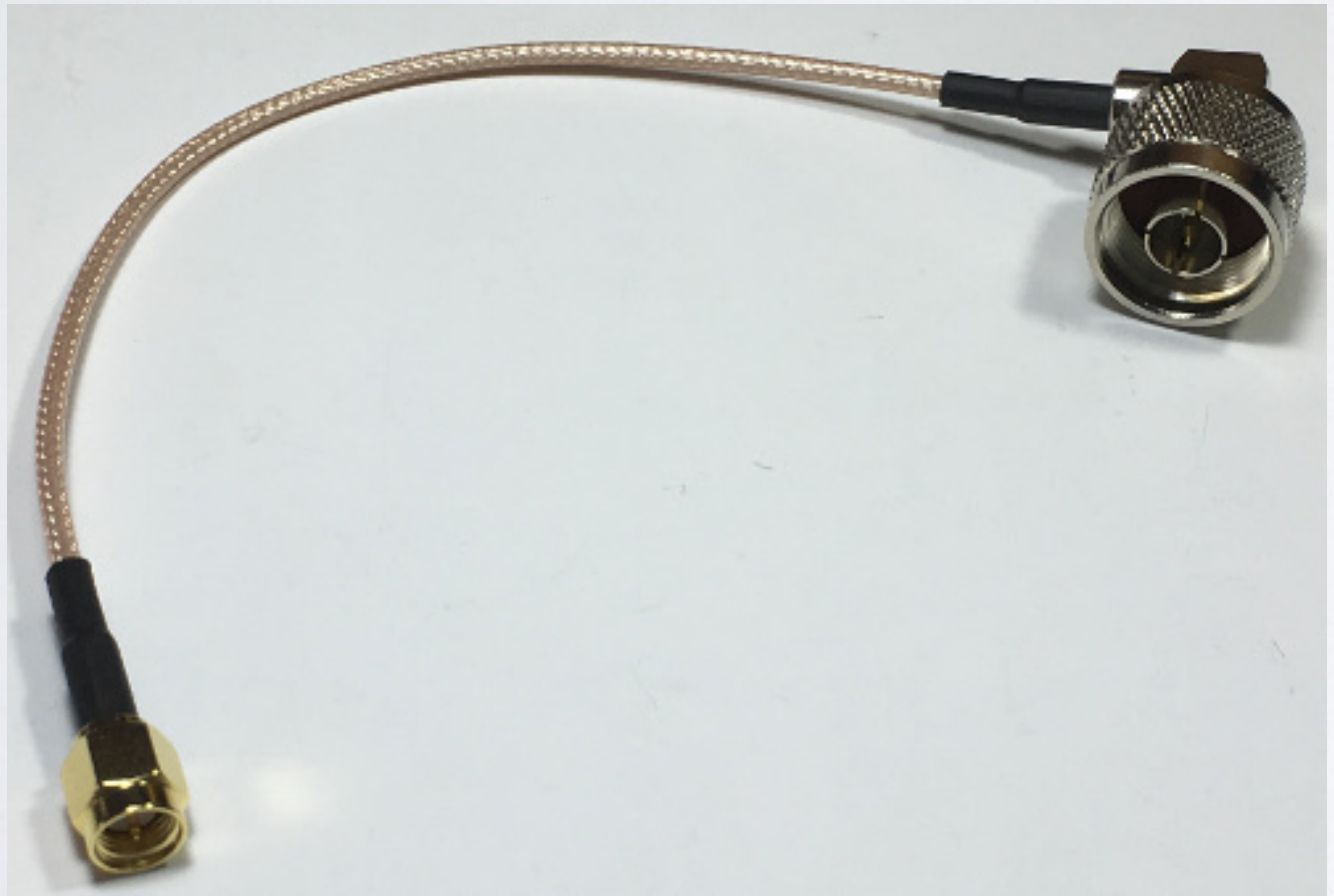
- [OPTIONAL] Type N male to RP-SMA male plug adapter coaxial cable connector. Cost: € 1.44

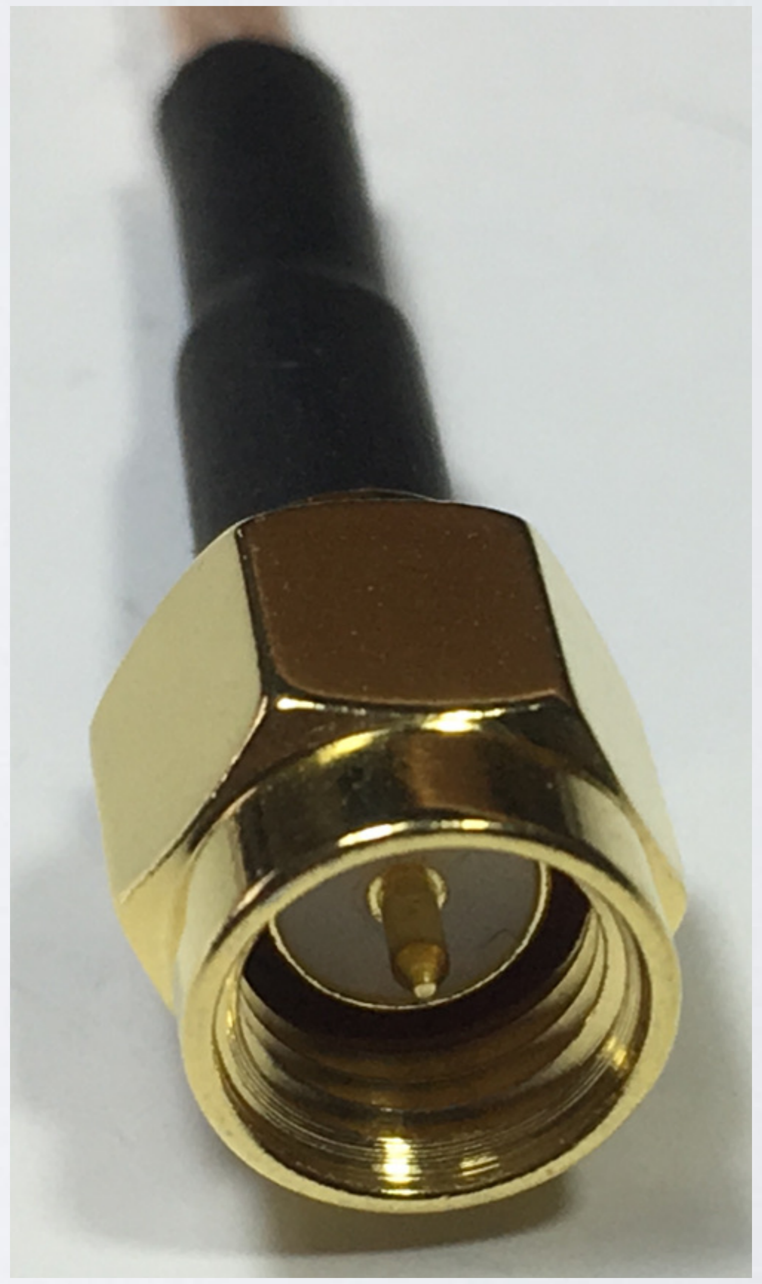




# BUILD A ¼ WAVE GROUND PLANE ANTENNA

- RF coaxial cable RG316, length 20 cm with type N male plug right angle to SMA male connector.
  Impedance: 50Ω
  Coax: RG316
  Cost: € 3.39



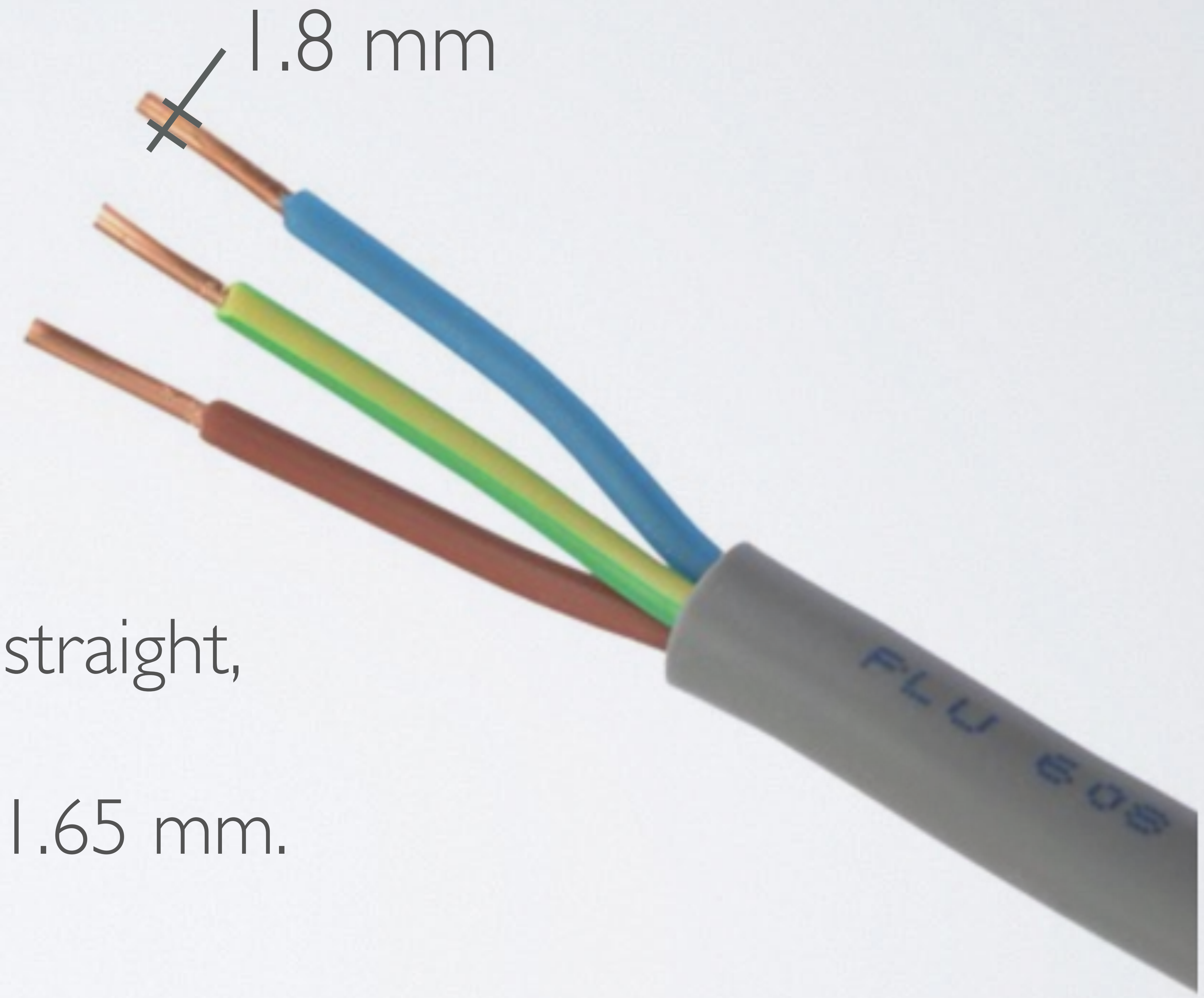


# BUILD A ¼ WAVE GROUND PLANE ANTENNA

- 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

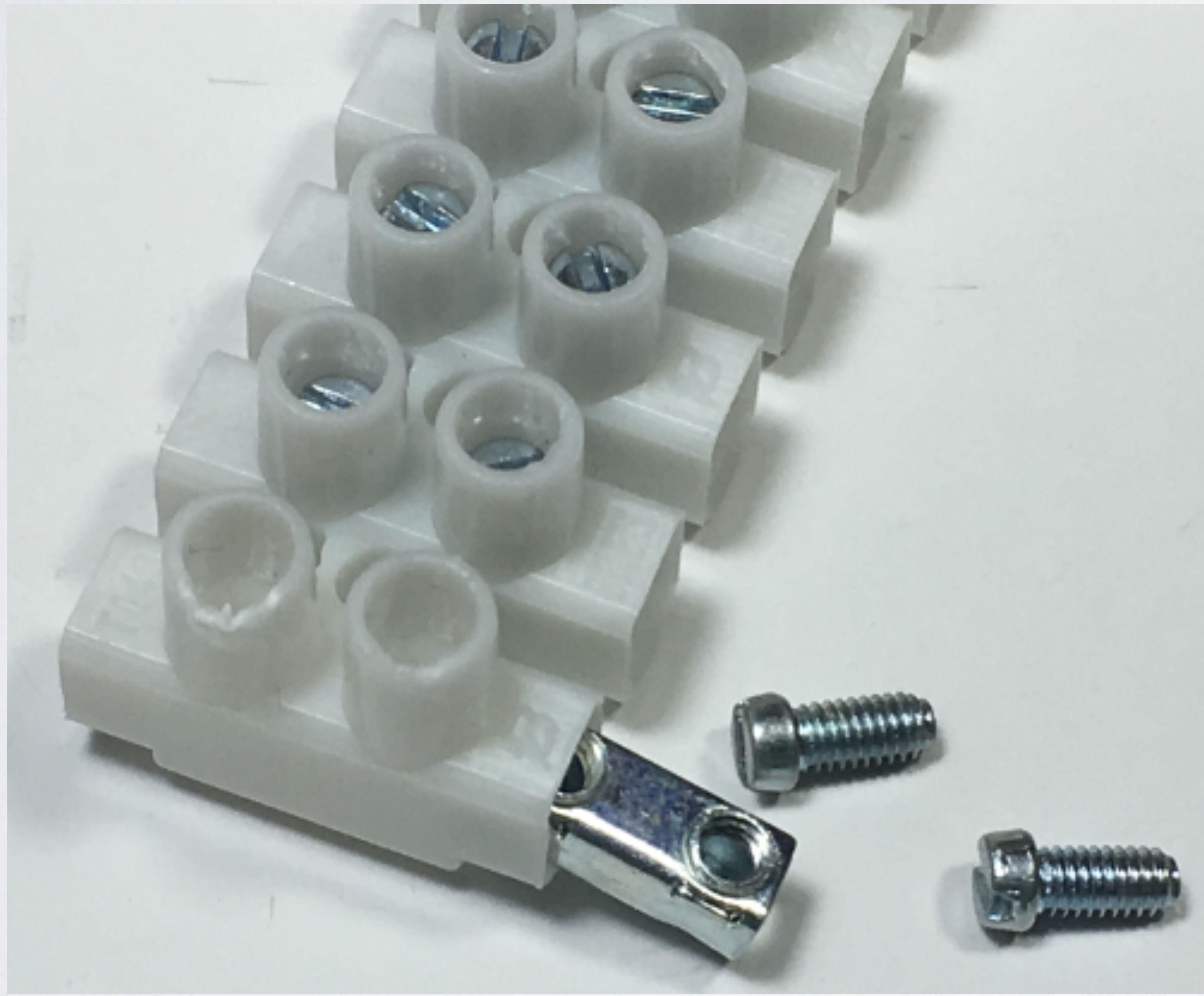
- The electrical insulator can be easily removed using a Stanley knife.

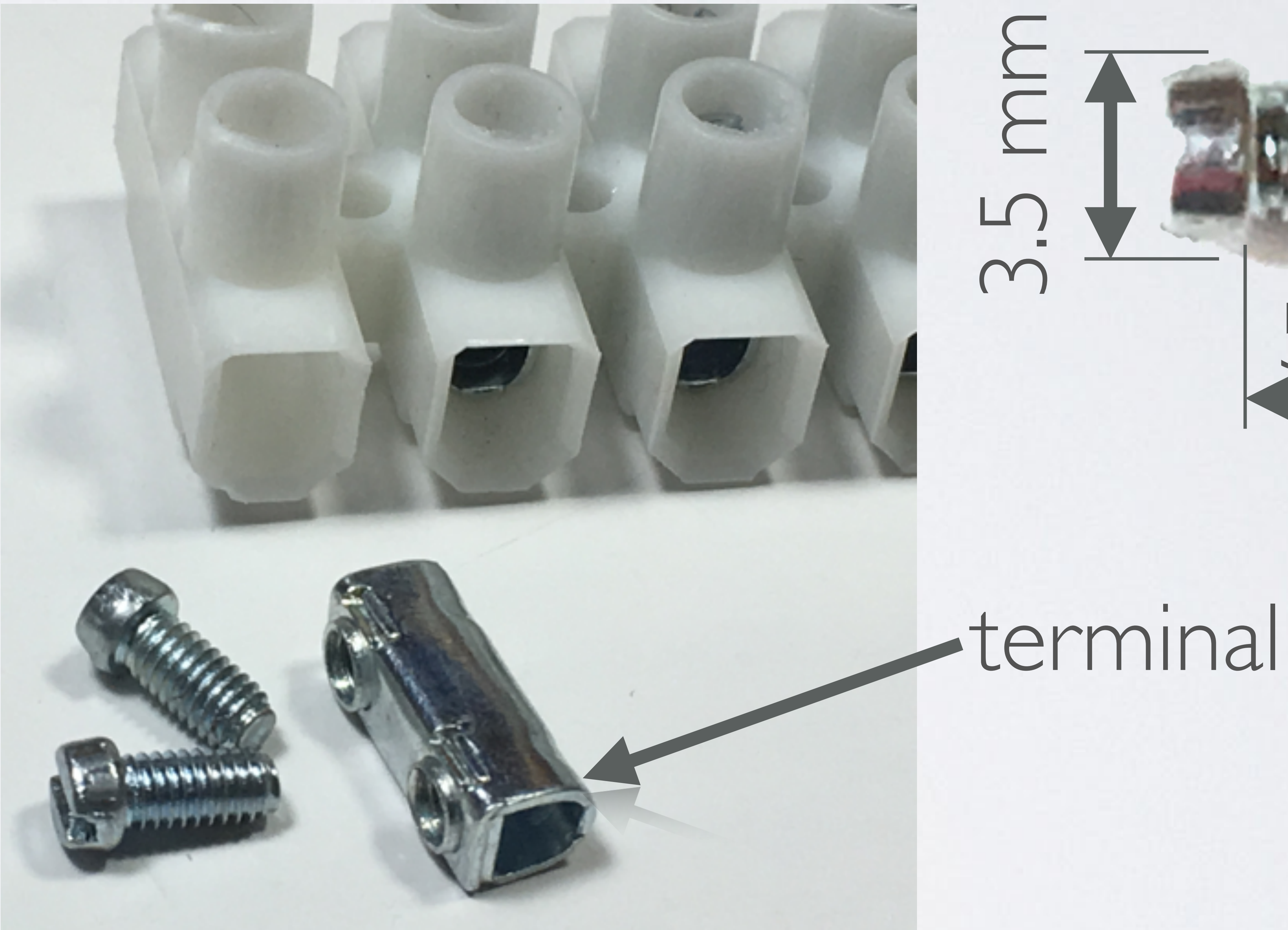
- The copper wire can be stretched out.
  The stretched out wire will be stiffer, more straight, and the wire diameter will decrease.
  In my case the wire diameter decreases to 1.65 mm.

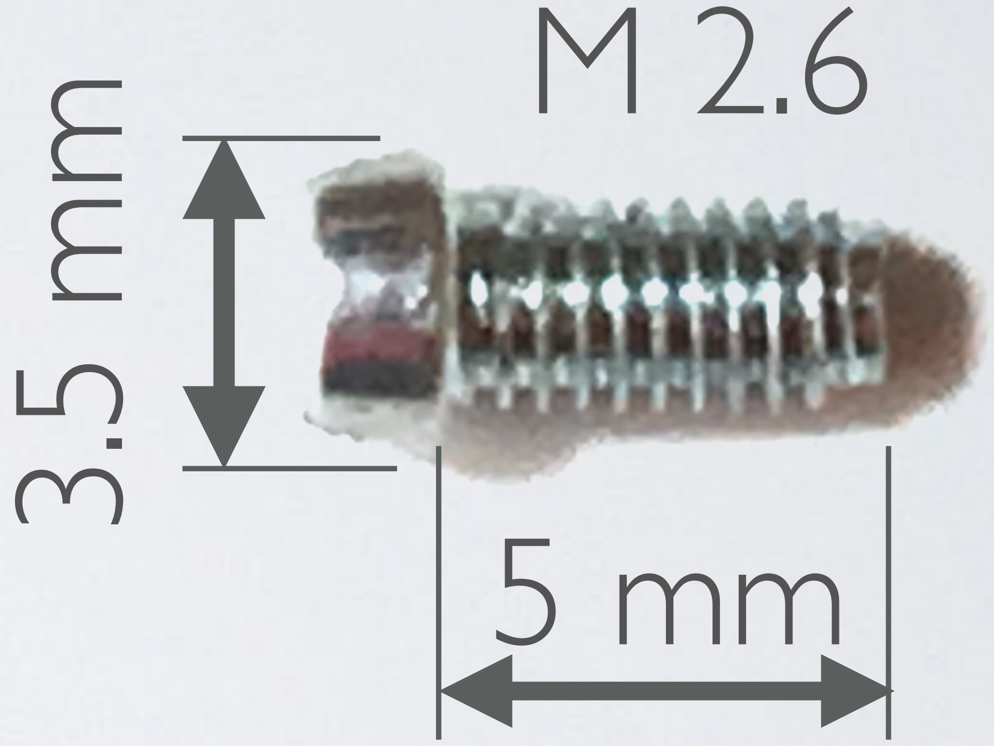


# BUILD A ¼ WAVE GROUND PLANE ANTENNA

- Terminal strip block 1.5-4.0 mm²
  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)

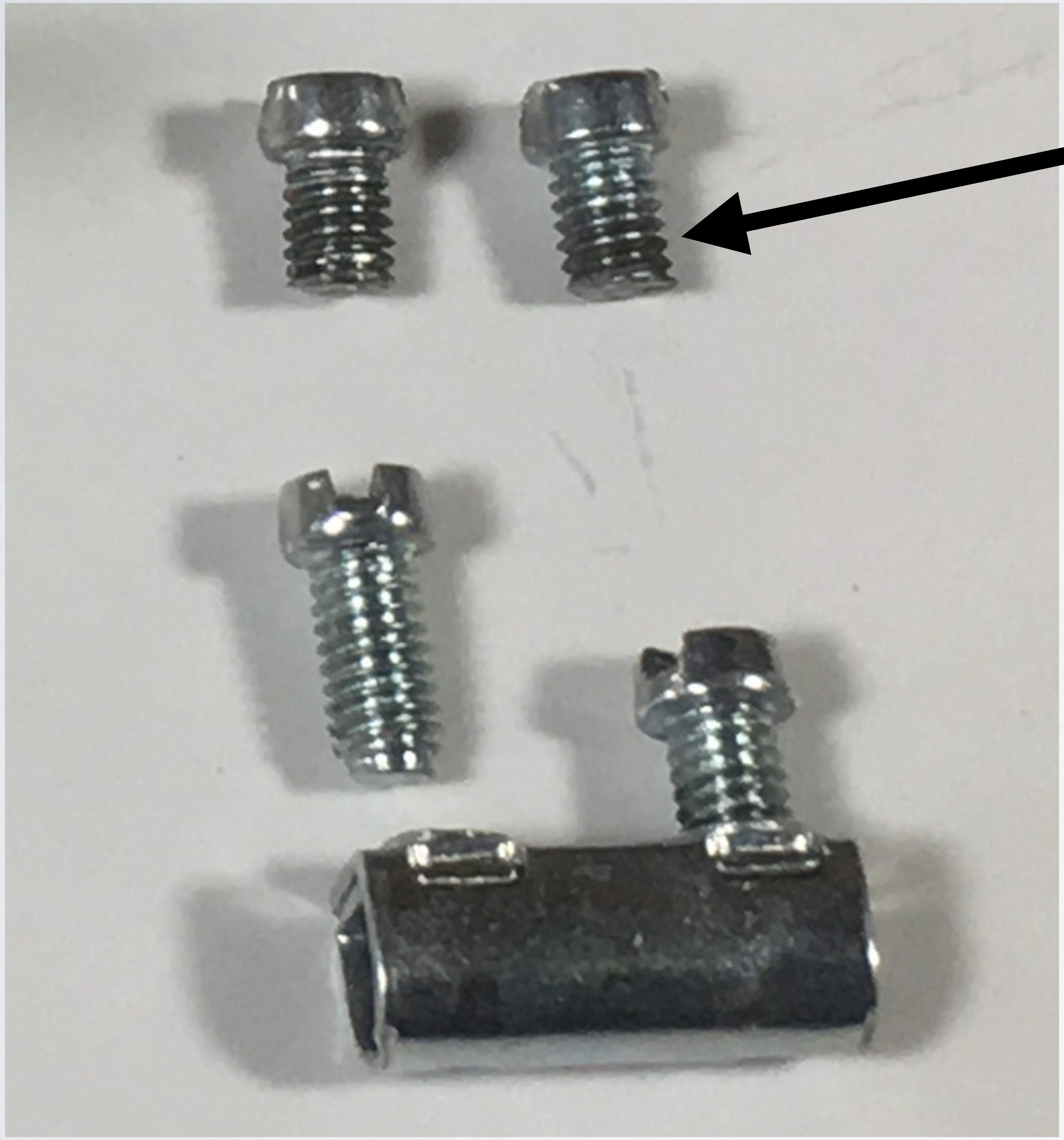




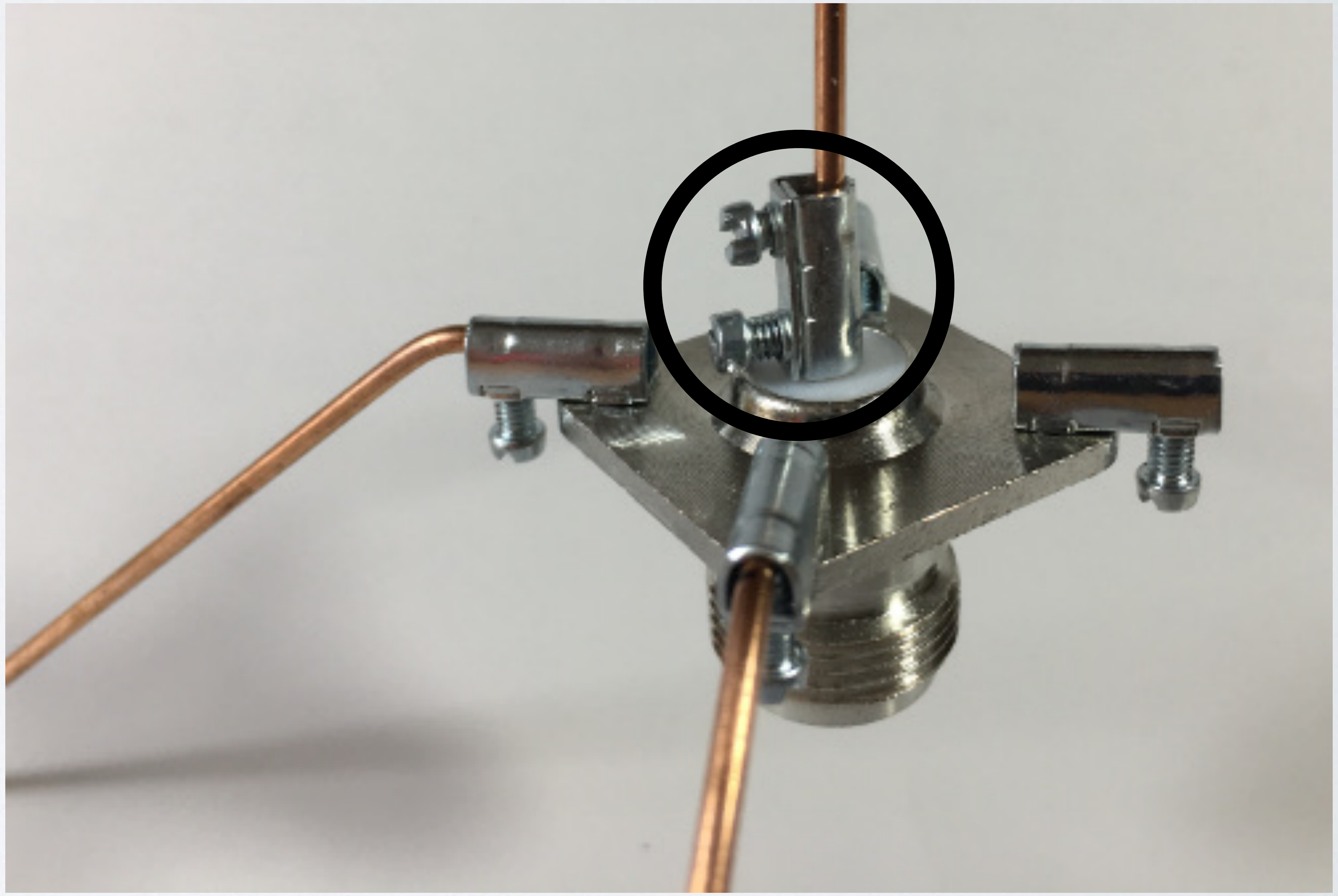




**The terminals and screws are tiny. Will not withstand harsh weather conditions.**

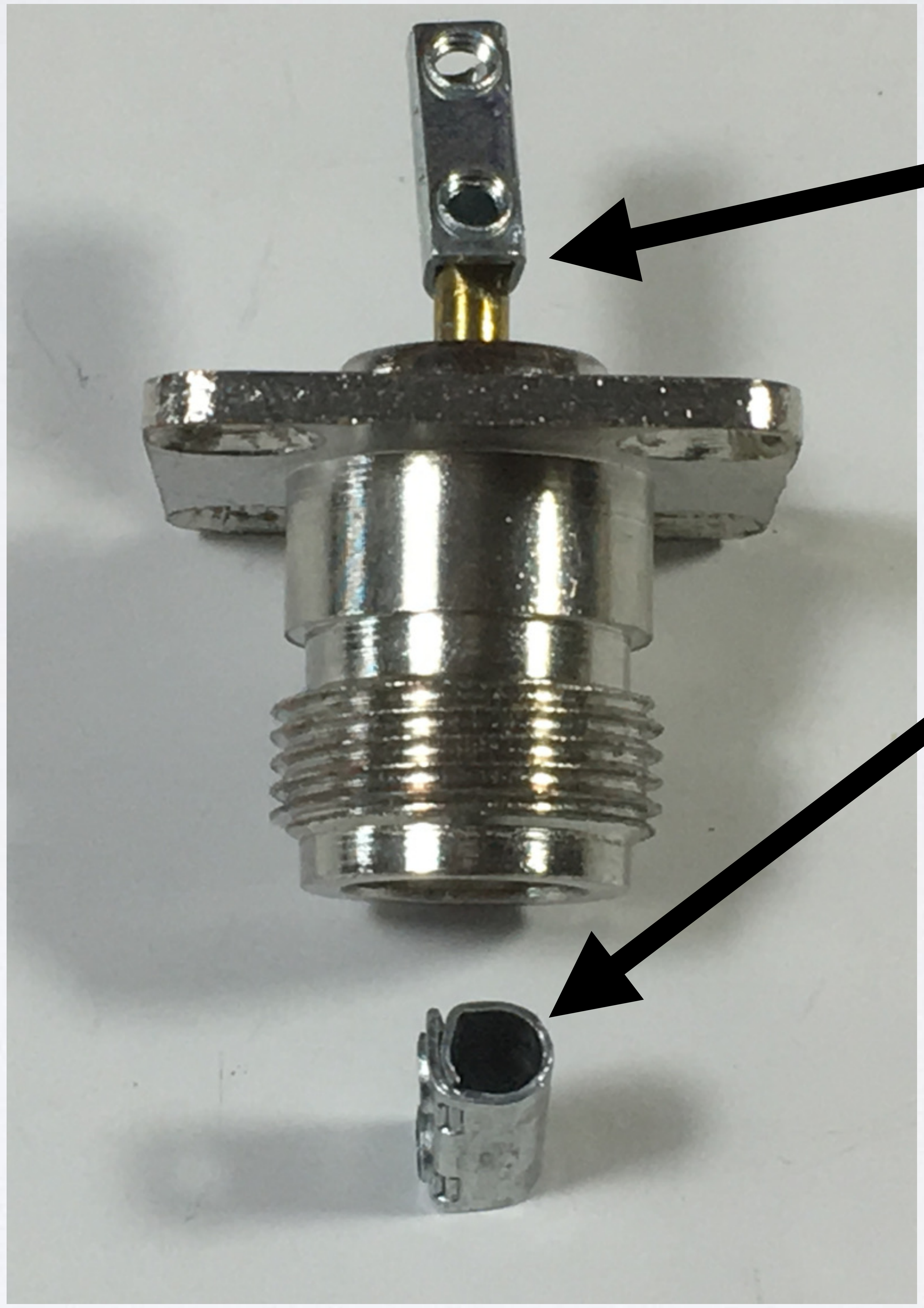
# BUILD A ¼ WAVE GROUND PLANE ANTENNA



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



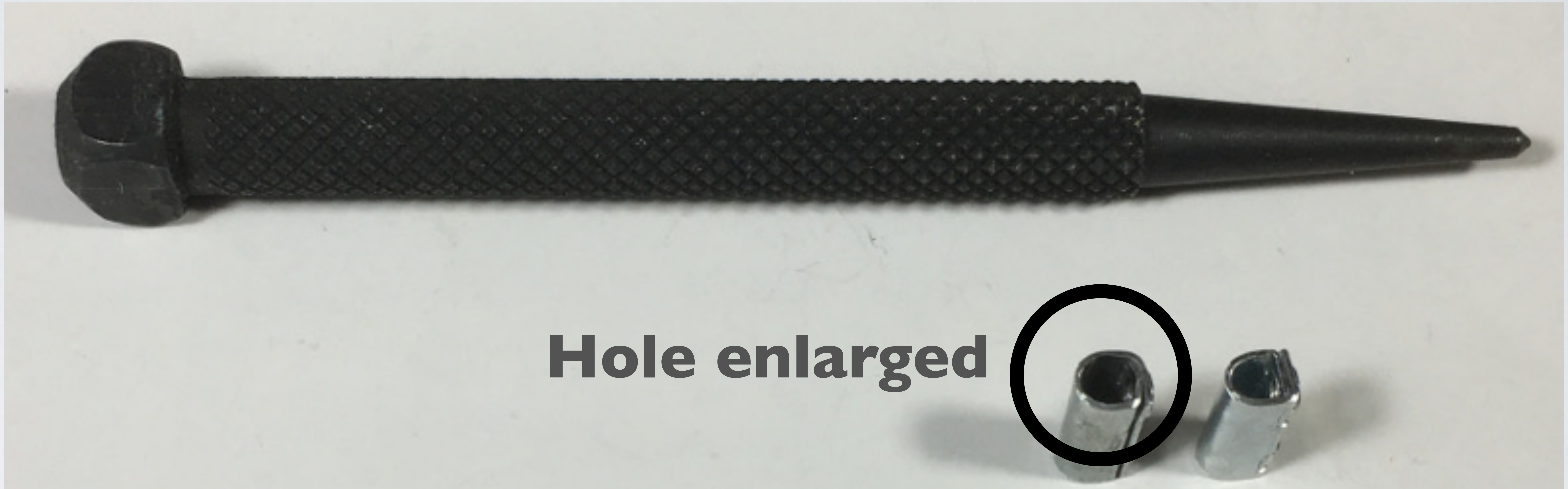
# BUILD A ¼ WAVE GROUND PLANE ANTENNA



Terminal does not fit.

Enlarge the hole of a terminal.

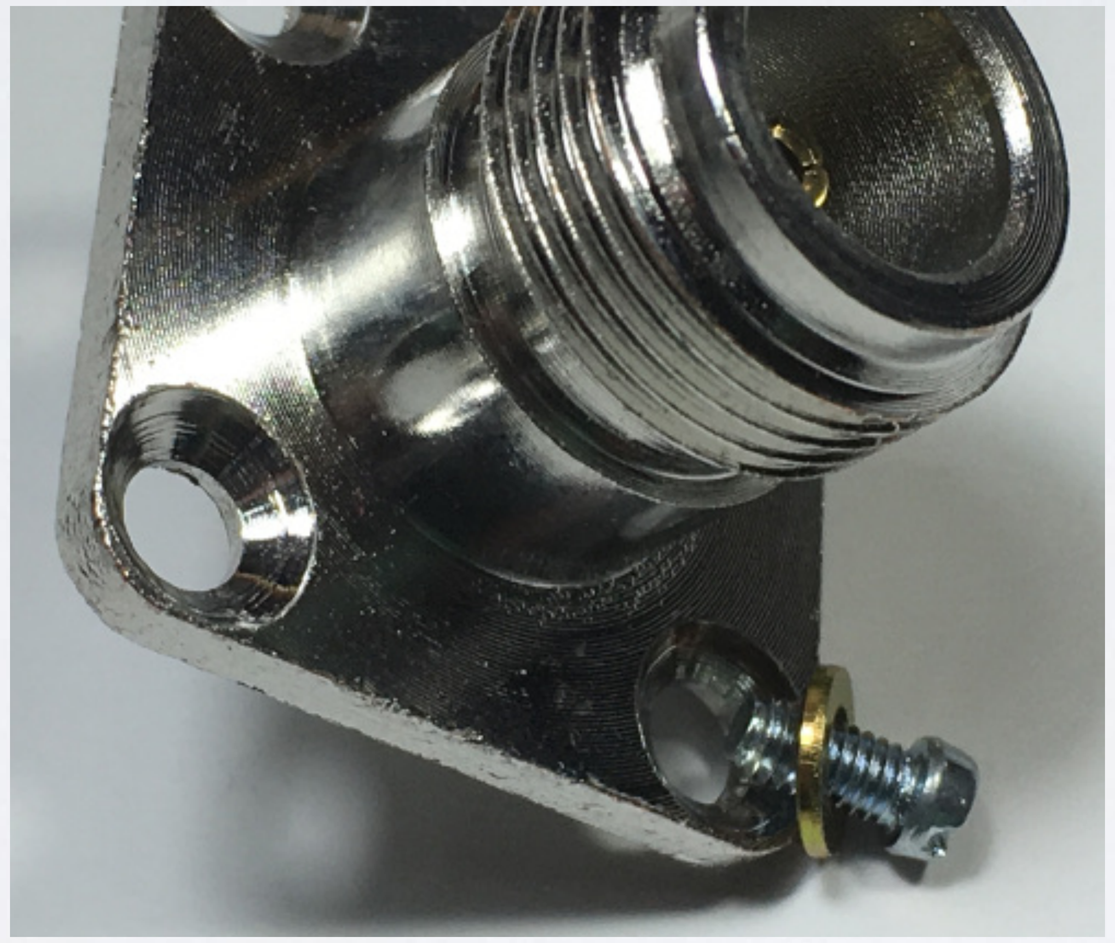
# BUILD A ¼ WAVE GROUND PLANE ANTENNA

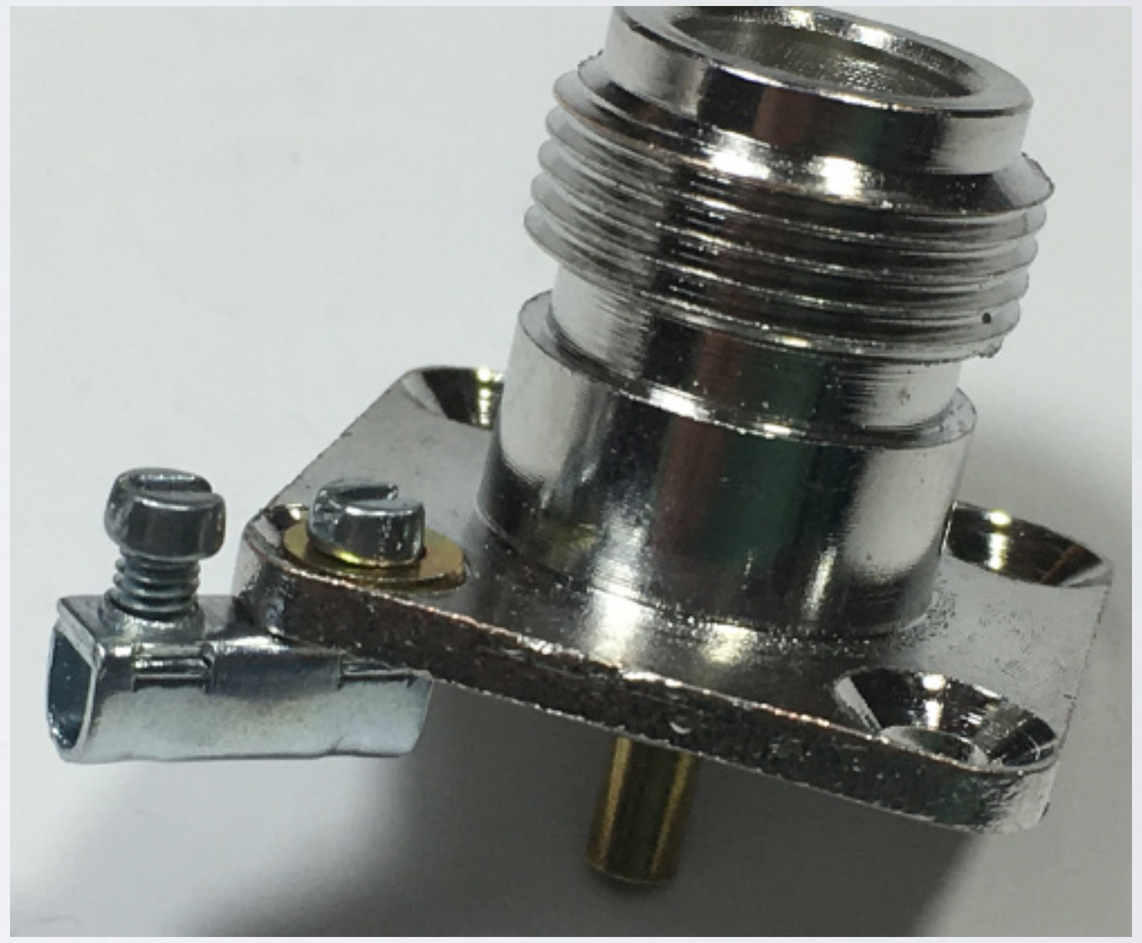



Use a punch to enlarge the hole of a terminal.

# BUILD A ¼ WAVE GROUND PLANE ANTENNA

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



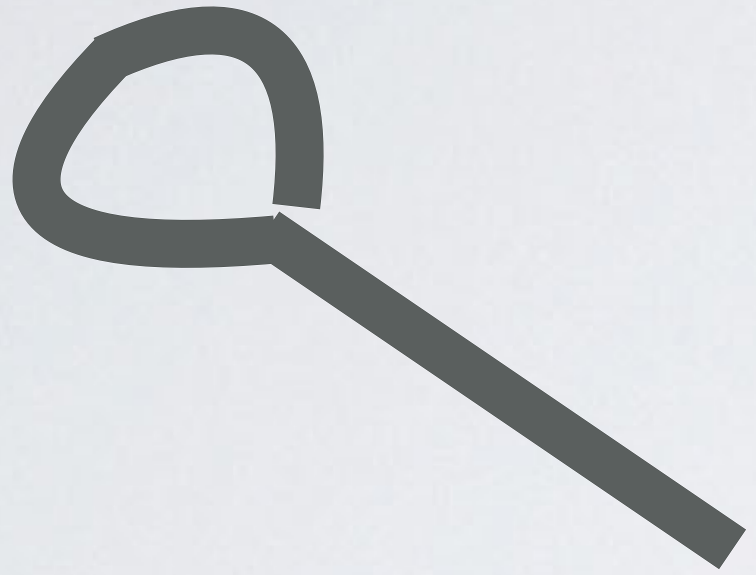
- The terminal screw head diameter (3.5 mm) is the same size as the type N connector hole diameter (3.5 mm) and that is why metal washers are needed.

# ALTERNATIVE COMPONENTS ¼ WAVE GND PLANE ANT

- Alternative components / methods can be used to build the ¼ wave ground plane antenna. Here are just a few suggestions:
  - Use aluminium or copper tube instead of wires because copper wires bend easily.
  - If the type N female chassis has a silver coating, the radials can be soldered onto the chassis. In this case no terminals are needed.
  - Instead of terminals, attach crimp terminal rings to the radials.

# ALTERNATIVE COMPONENTS ¼ WAVE GND PLANE ANT

- Make a wire loop at the end of each radial. In this case no terminals are needed.



- Instead of the type N female chassis use a SMA female chassis panel mount 4-hole flange.

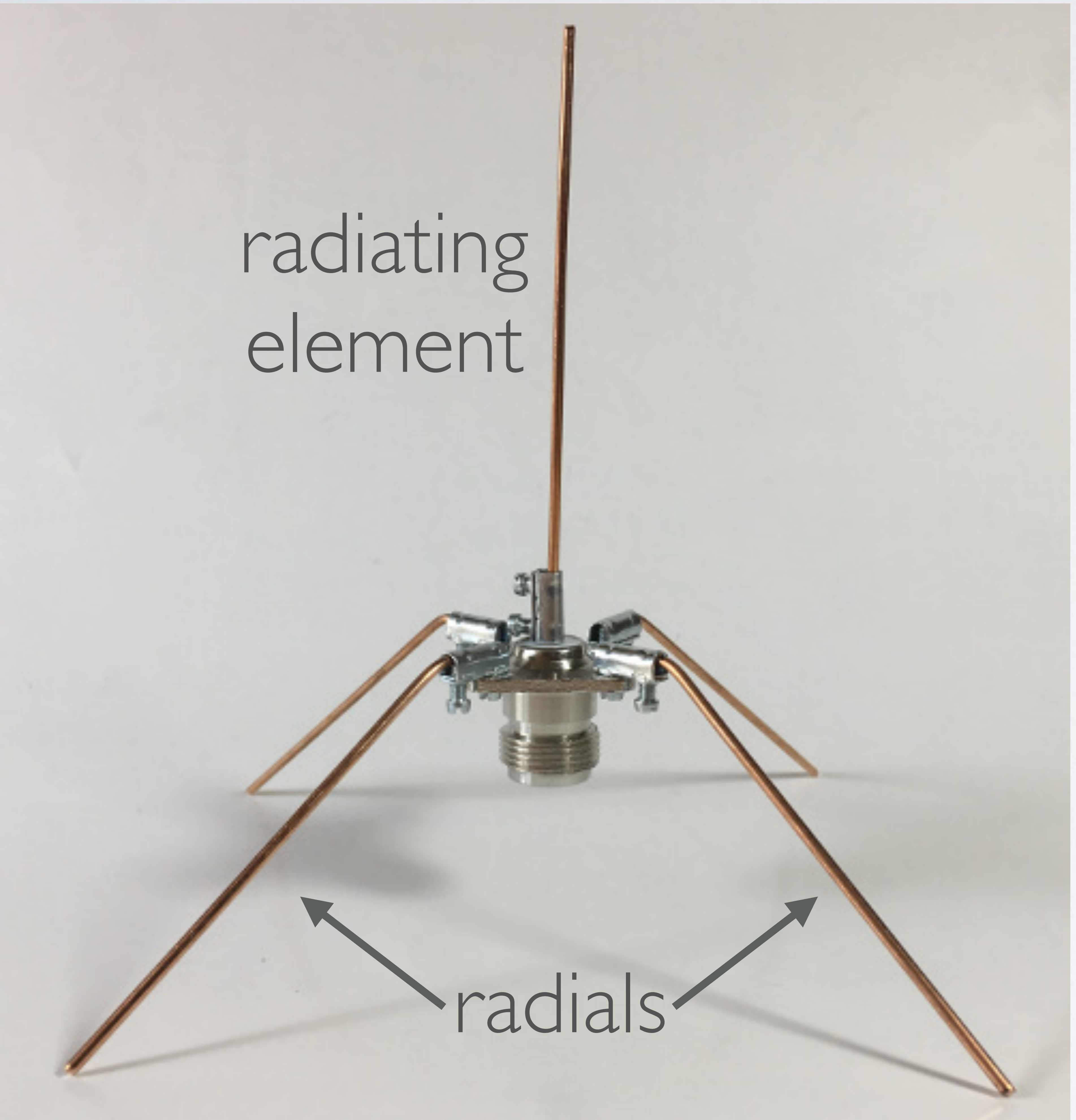
# ALTERNATIVE COMPONENTS ¼ WAVE GND PLANE ANT

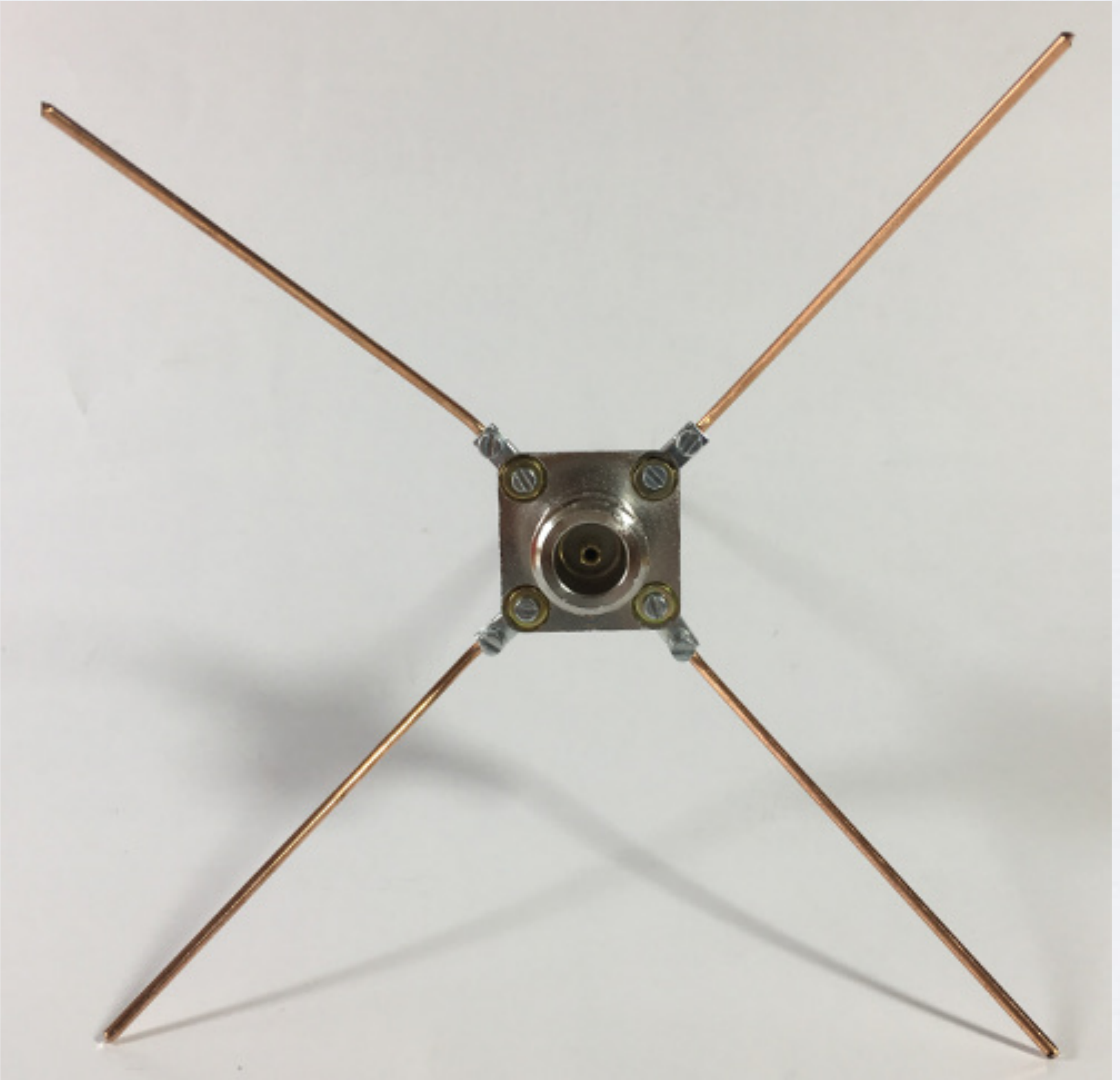
- Instead of the type N female chassis use a SMA female PCB mount straight RF connector.

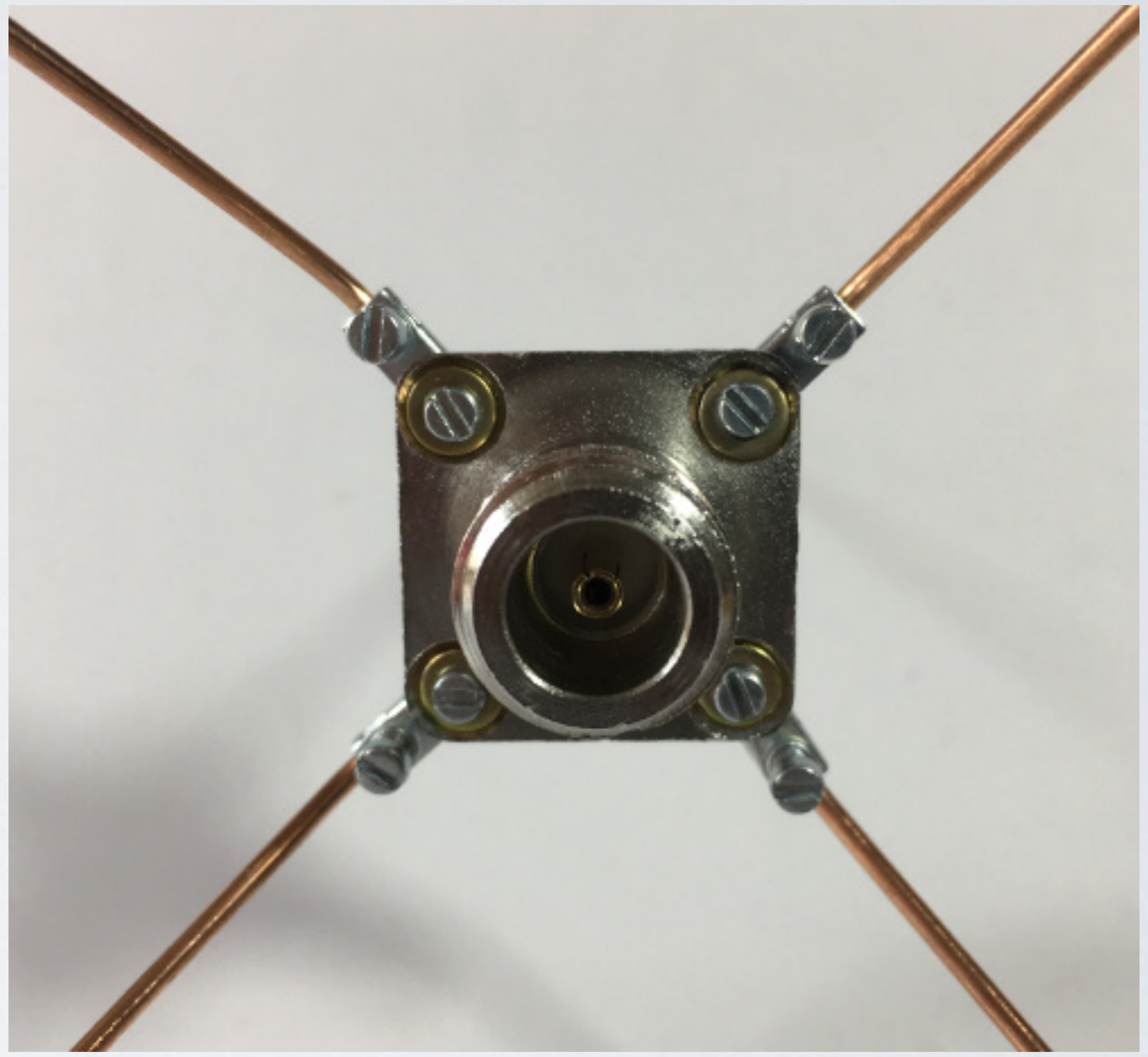
# ALTERNATIVE COMPONENTS ¼ WAVE GND PLANE ANT

- If you have a type N female RF connector with no flange, use a metal ring washer. Drill 4 holes in the metal ring and attach the radials.

# BUILD A ¼ WAVE GROUND PLANE ANTENNA

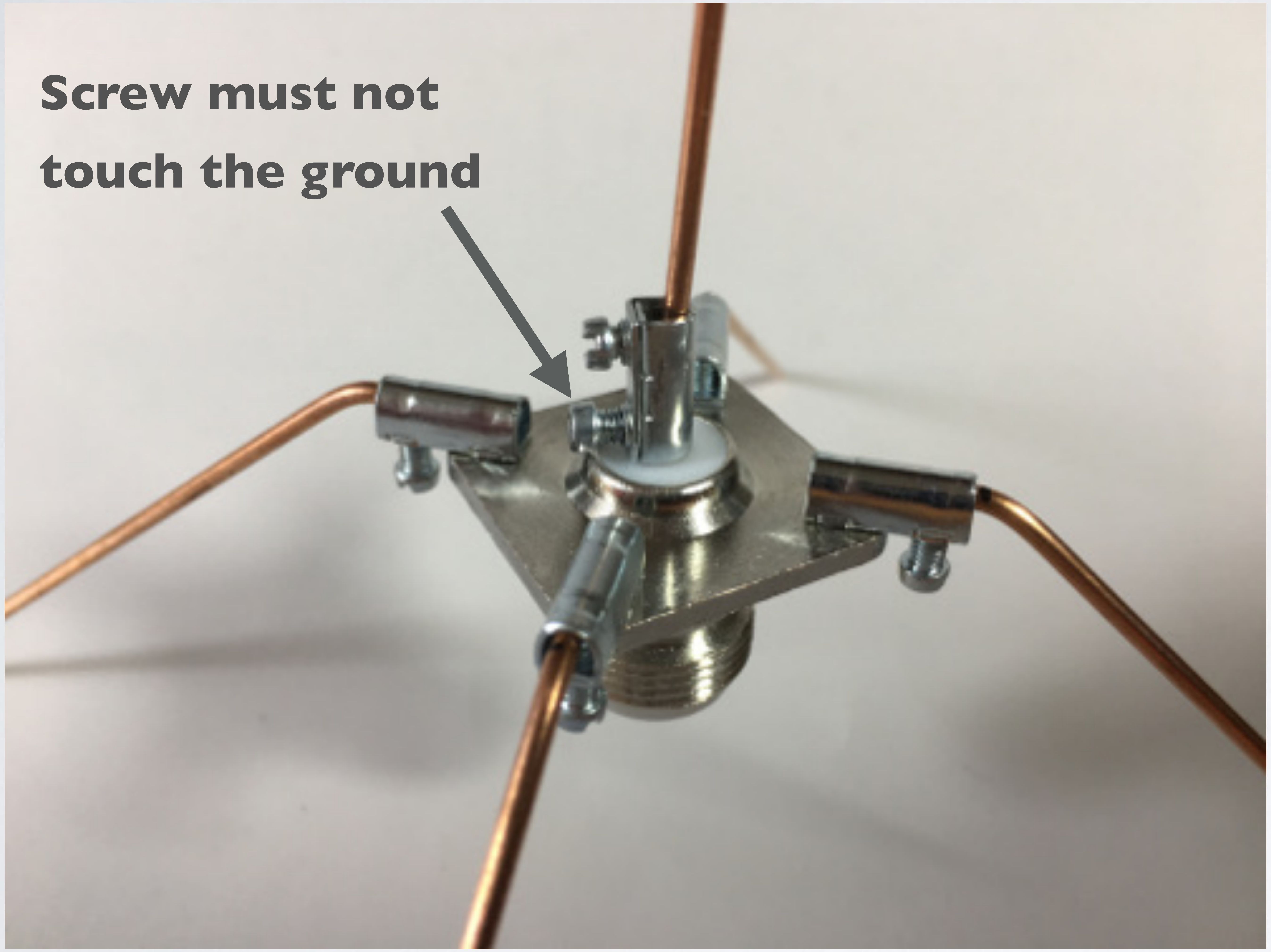


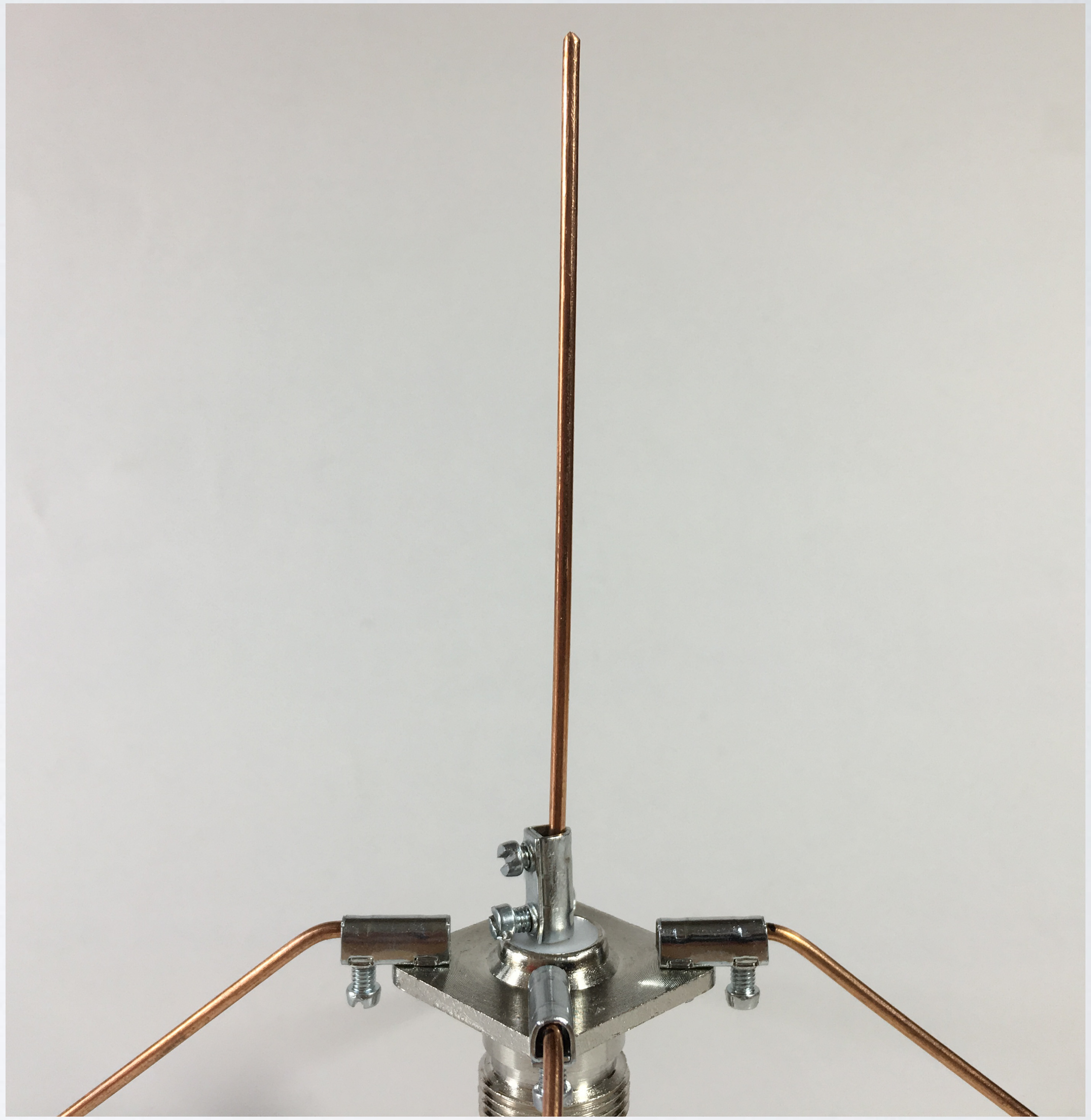





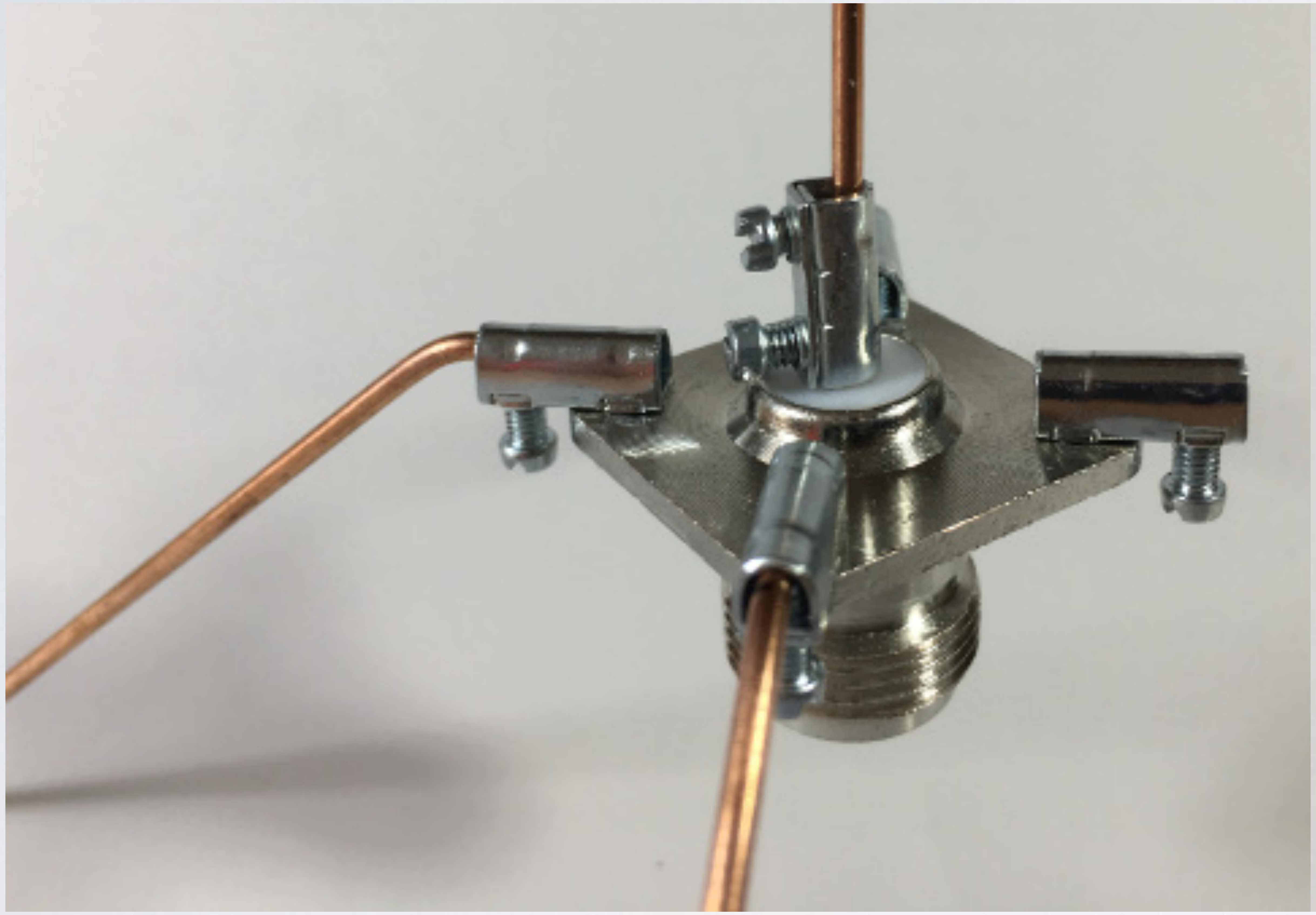
Attention: Using terminals with screws does not improve the antenna performance.

# BUILD A ¼ WAVE GROUND PLANE ANTENNA



# BUILD A ¼ WAVE GROUND PLANE ANTENNA



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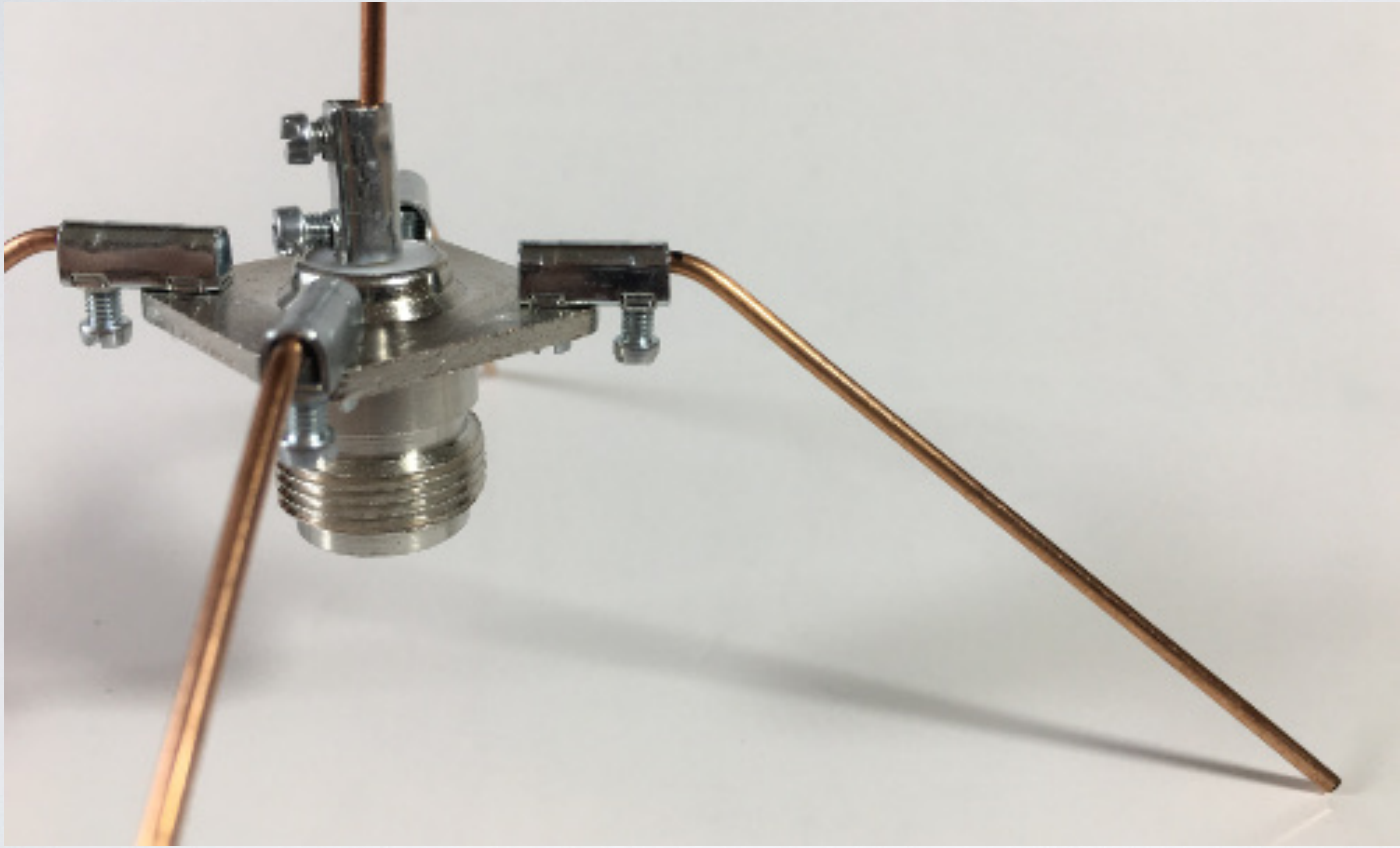

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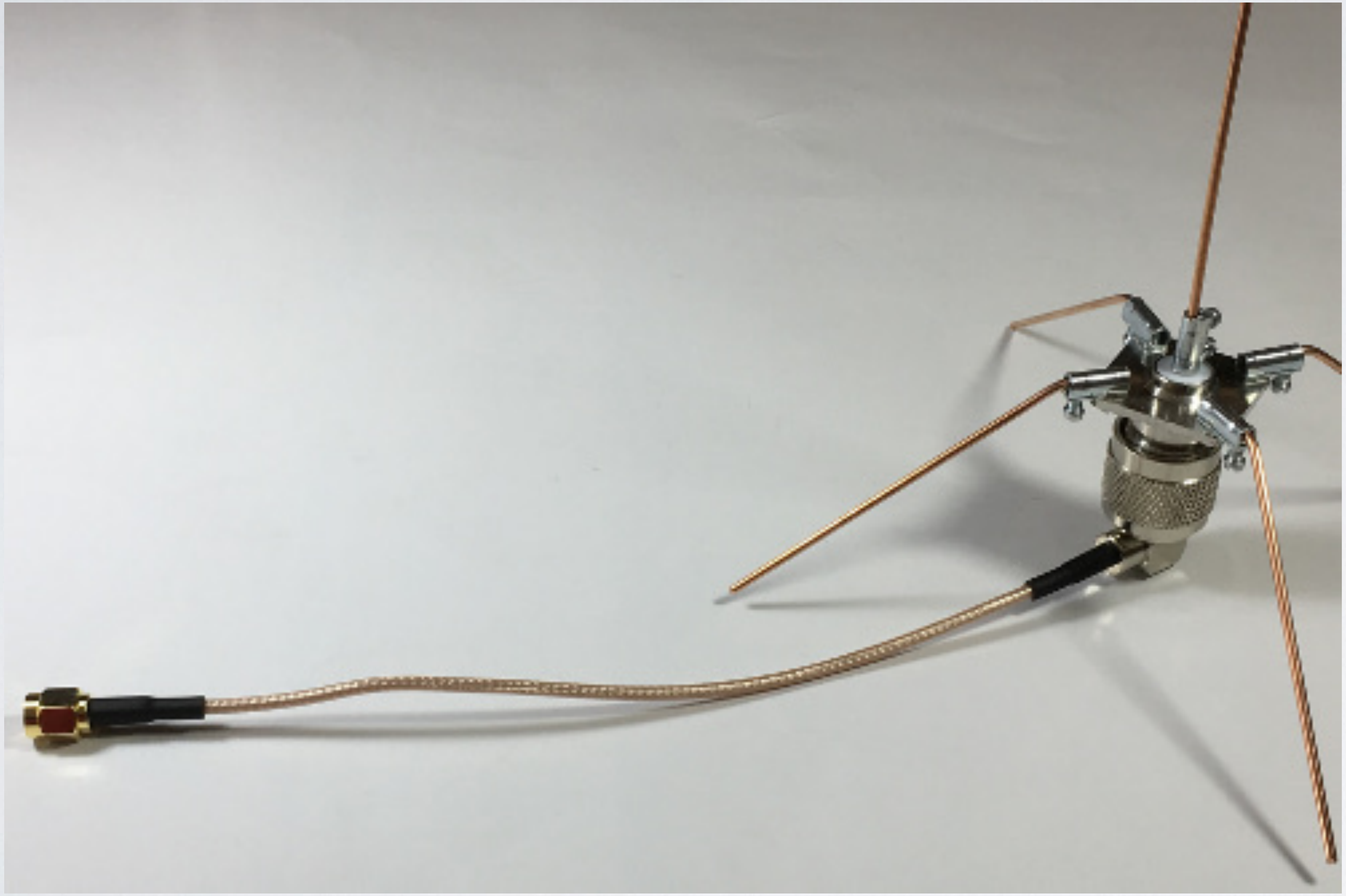
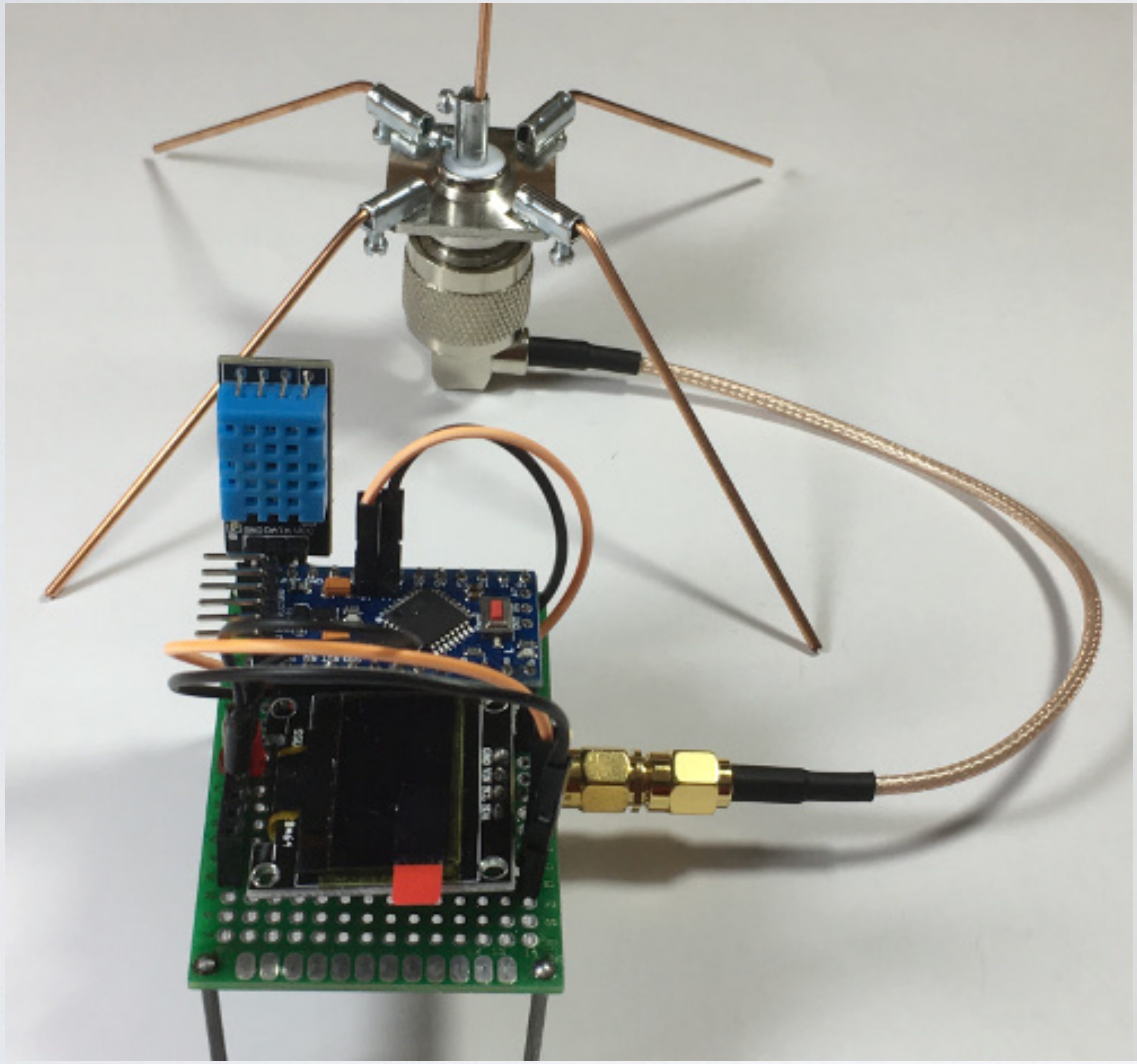
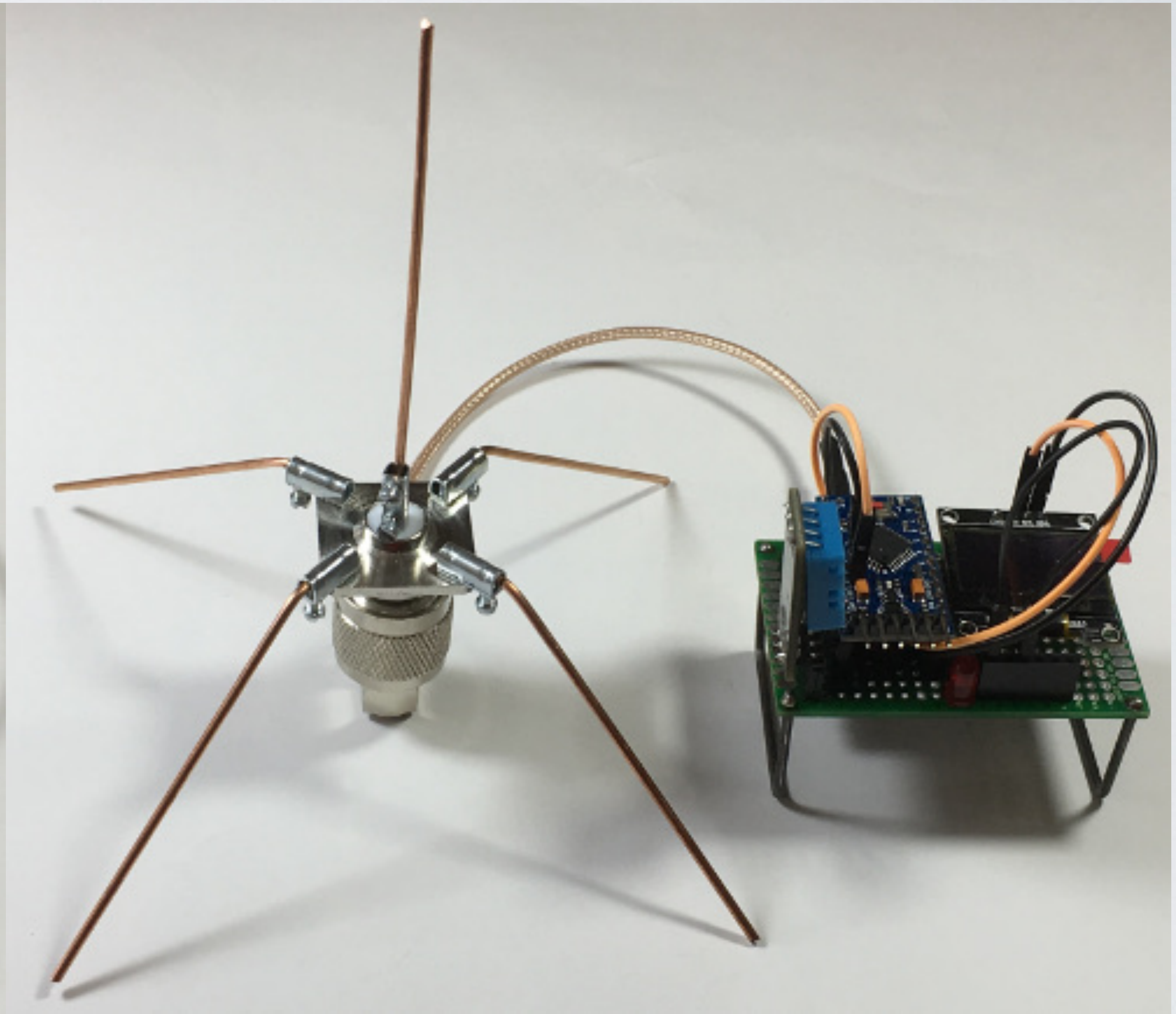


# BUILD A ¼ WAVE GROUND PLANE ANTENNA





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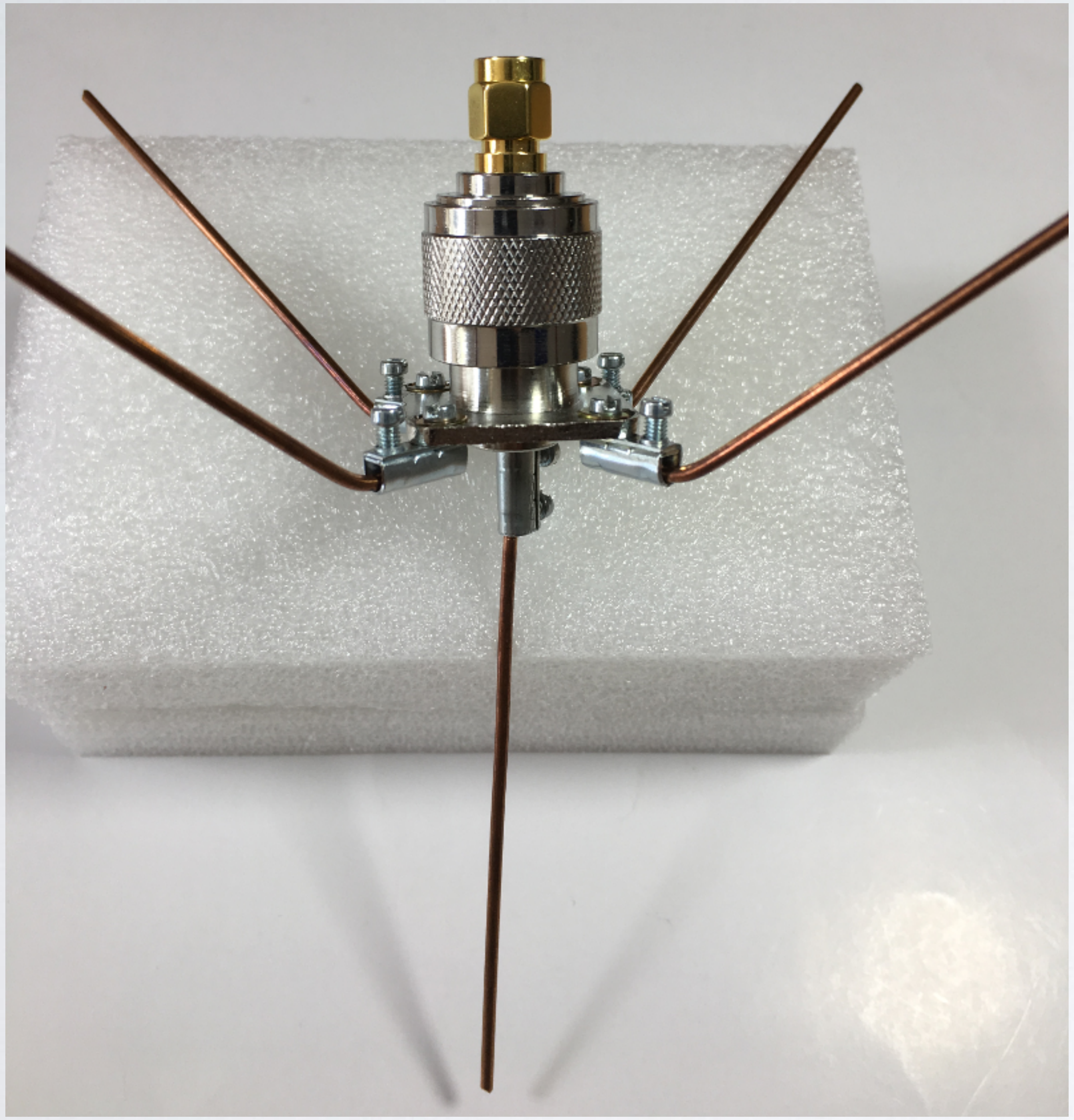

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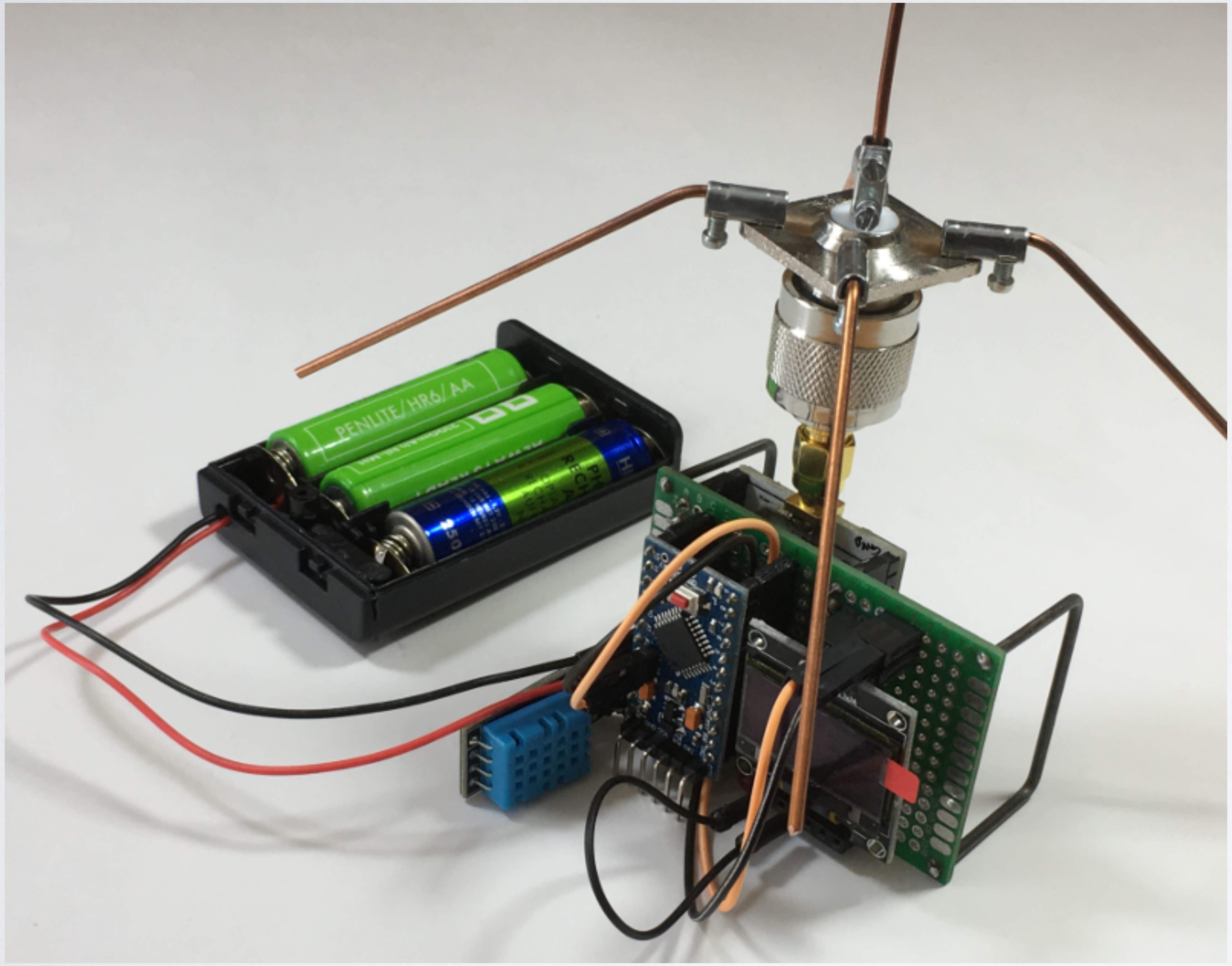
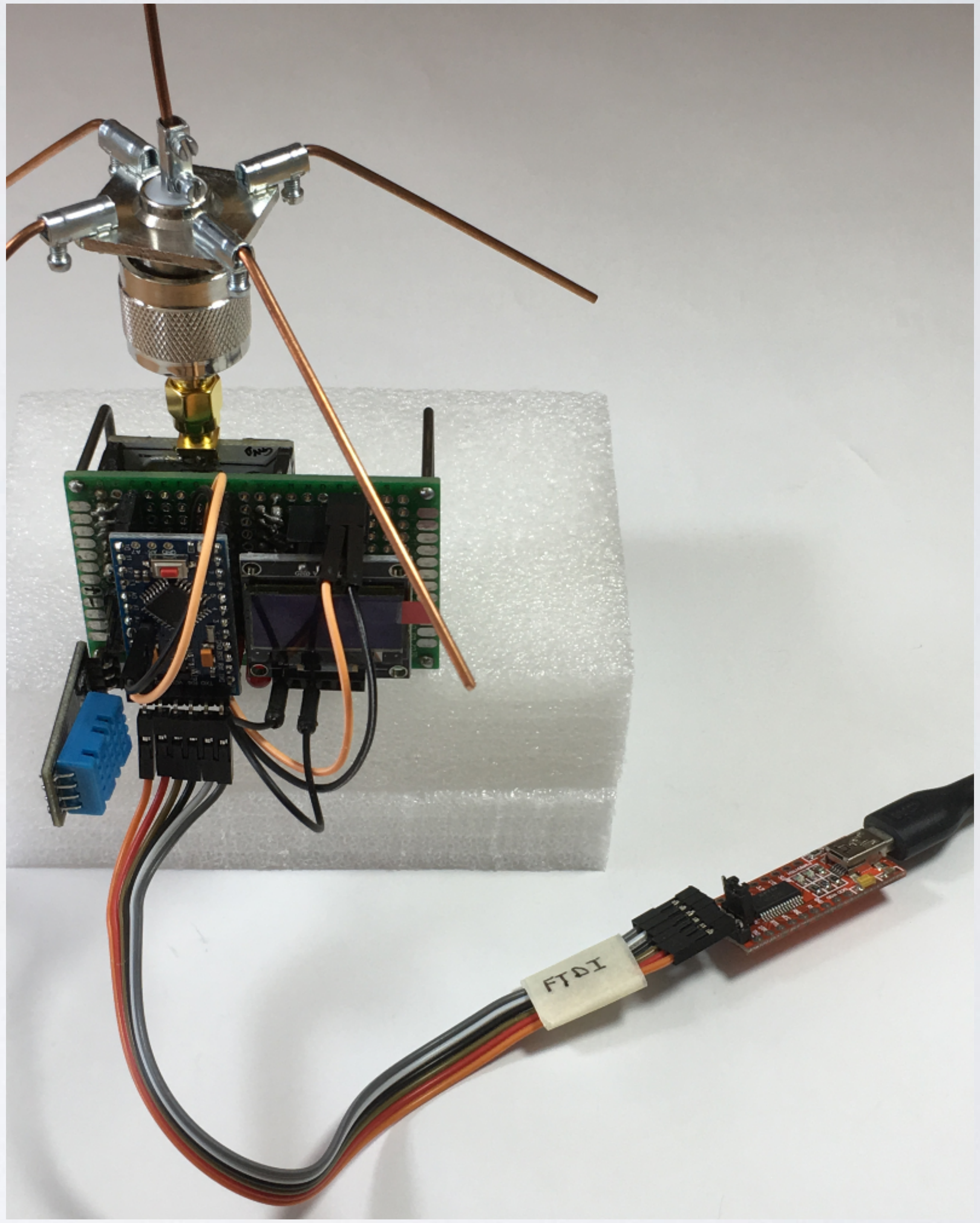


# BUILD A ¼ WAVE GROUND PLANE ANTENNA

- If frequency f = **868 MHz** and light speed c = 299792458 m/s:
  wavelength $\lambda = c / f$
  $\lambda = 299792458 / 868000000 = 0.34538$ m = 345.38 mm

- If the radiating element is made of copper, the velocity factor VF = 0.95
  The radiating element length $L_{Radiating} = ¼ \times \lambda \times VF = ¼ \times 345.38 \times 0.95 = 82.03$ mm

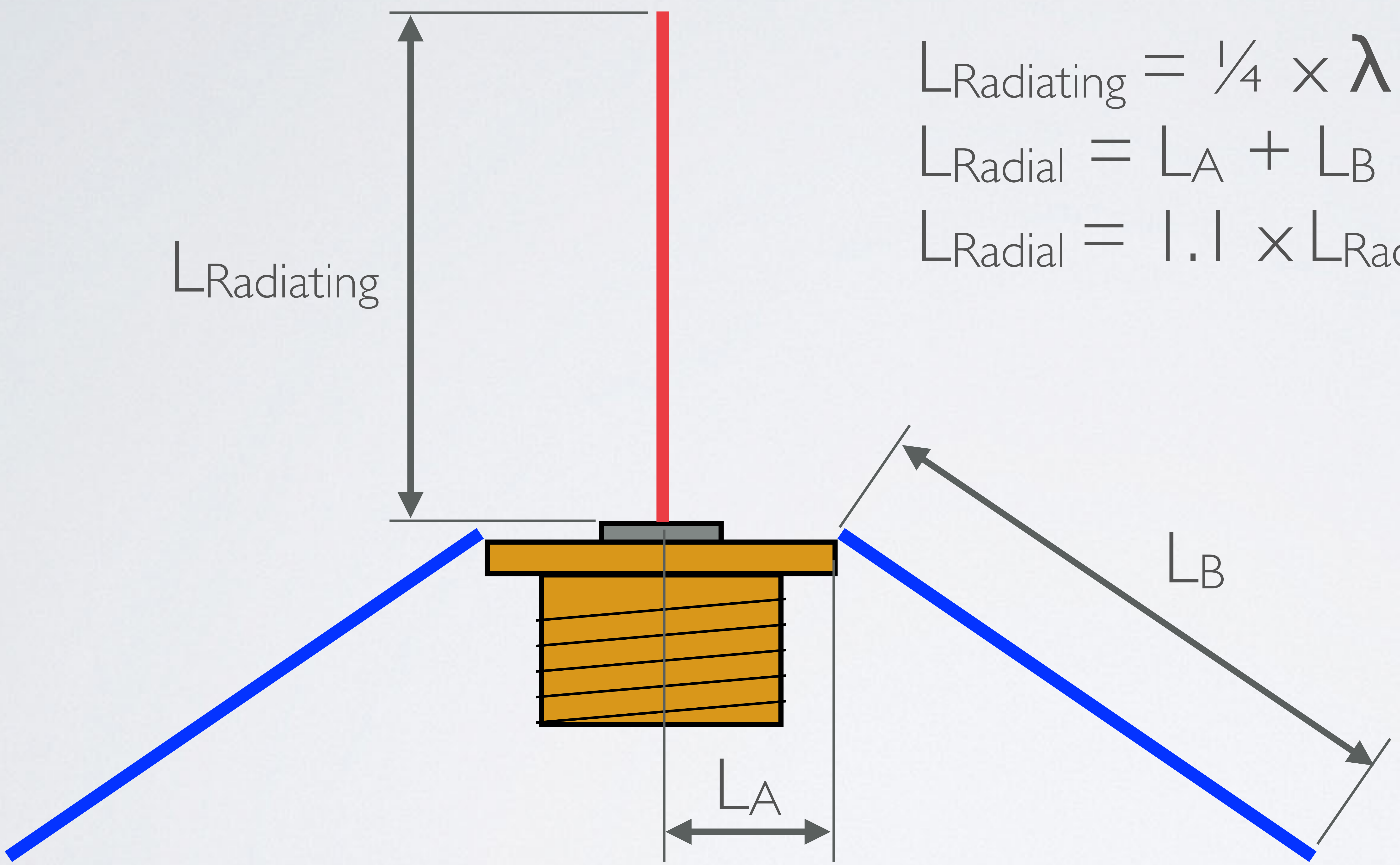
- Usually the radial length is 5% - 12% longer than the radiating length.
  The radial length is measured from the base of the antenna.
  Make the radial length 10% longer than the radiating length:
  The radial length $L_{Radial} = 82.03 \times 1.1 = 90.23$ mm

# BUILD A ¼ WAVE GROUND PLANE ANTENNA

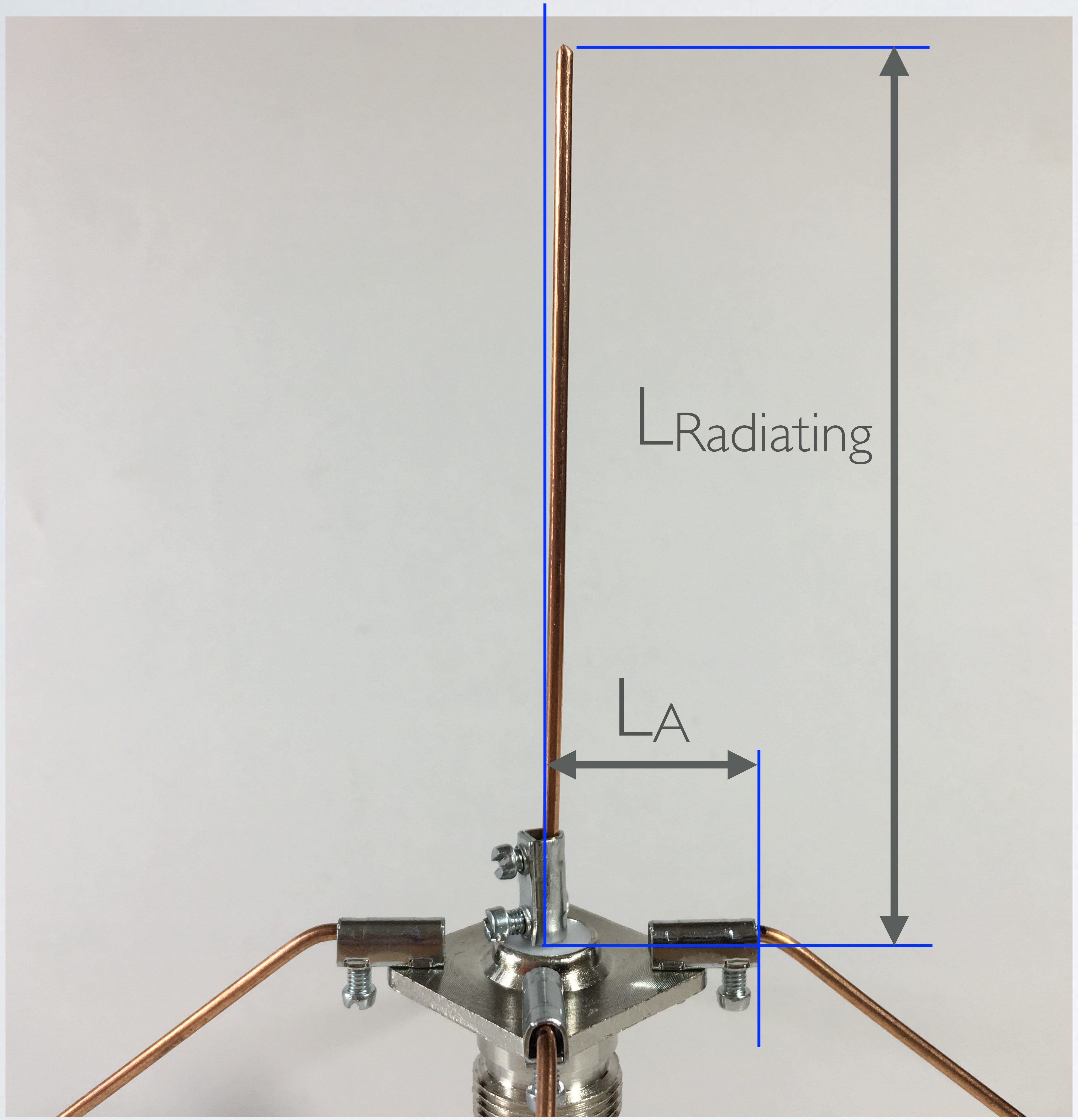
$$L_{Radiating} = \frac{1}{4} \times \lambda \times VF$$

$$L_{Radial} = L_A + L_B$$

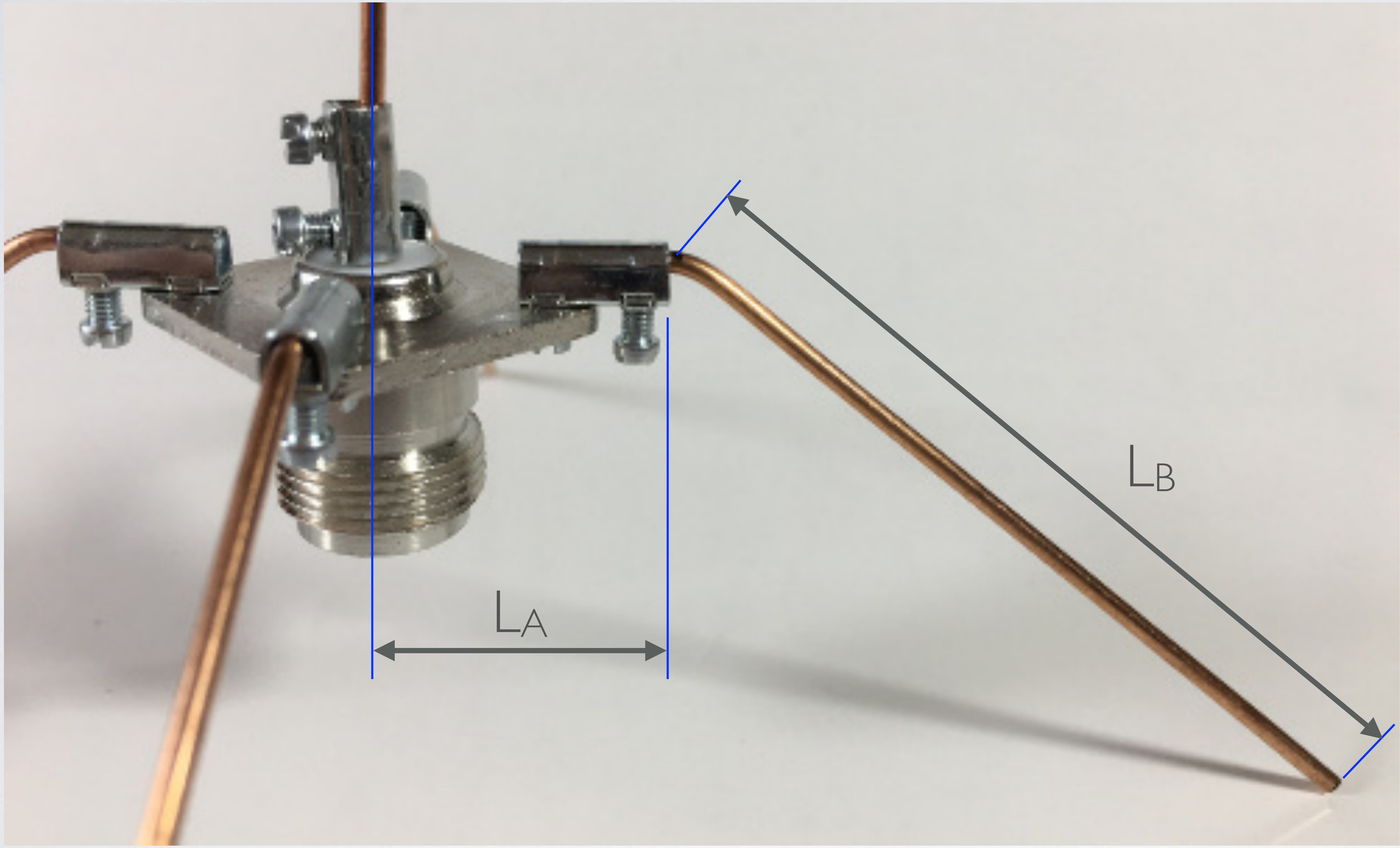
$$L_{Radial} = 1.1 \times L_{Radiating}$$



# BUILD A ¼ WAVE GROUND PLANE ANTENNA



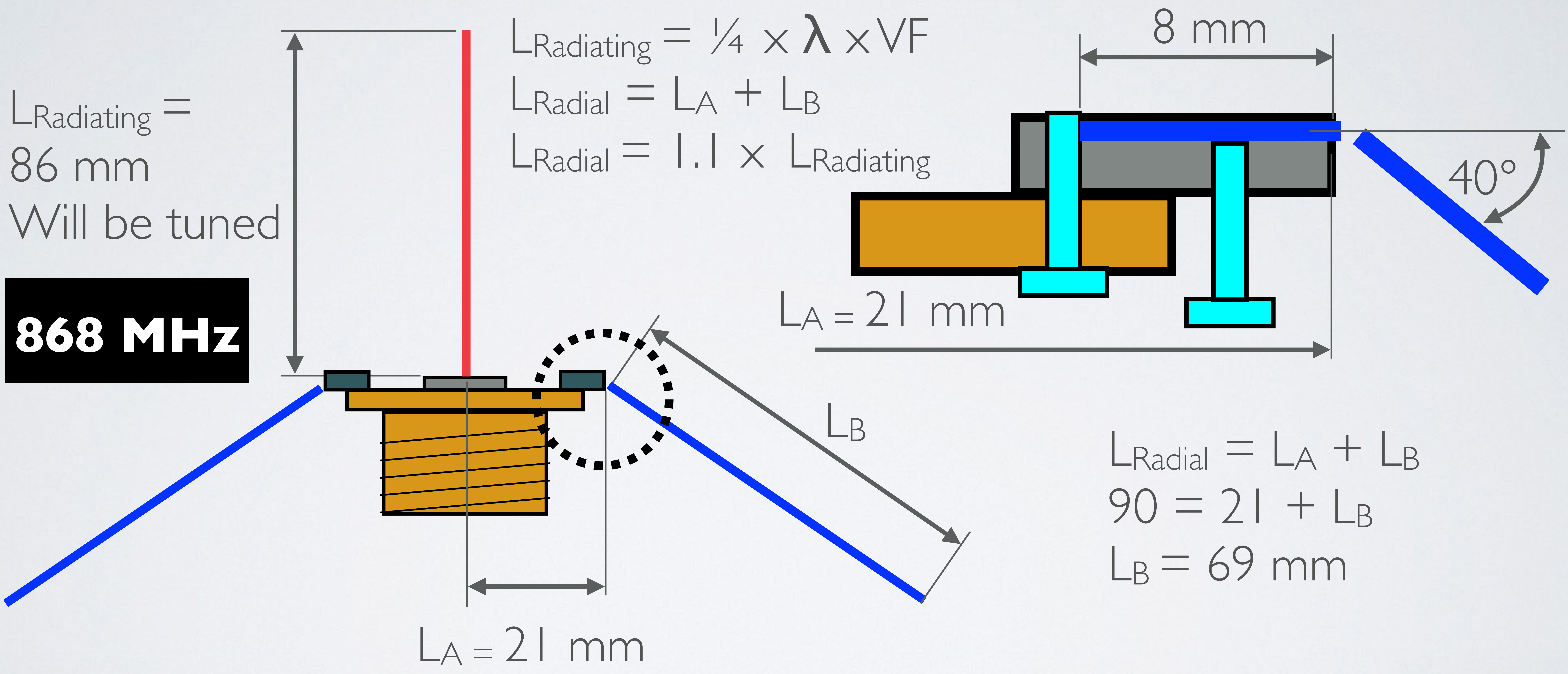
# BUILD A ¼ WAVE GROUND PLANE ANTENNA



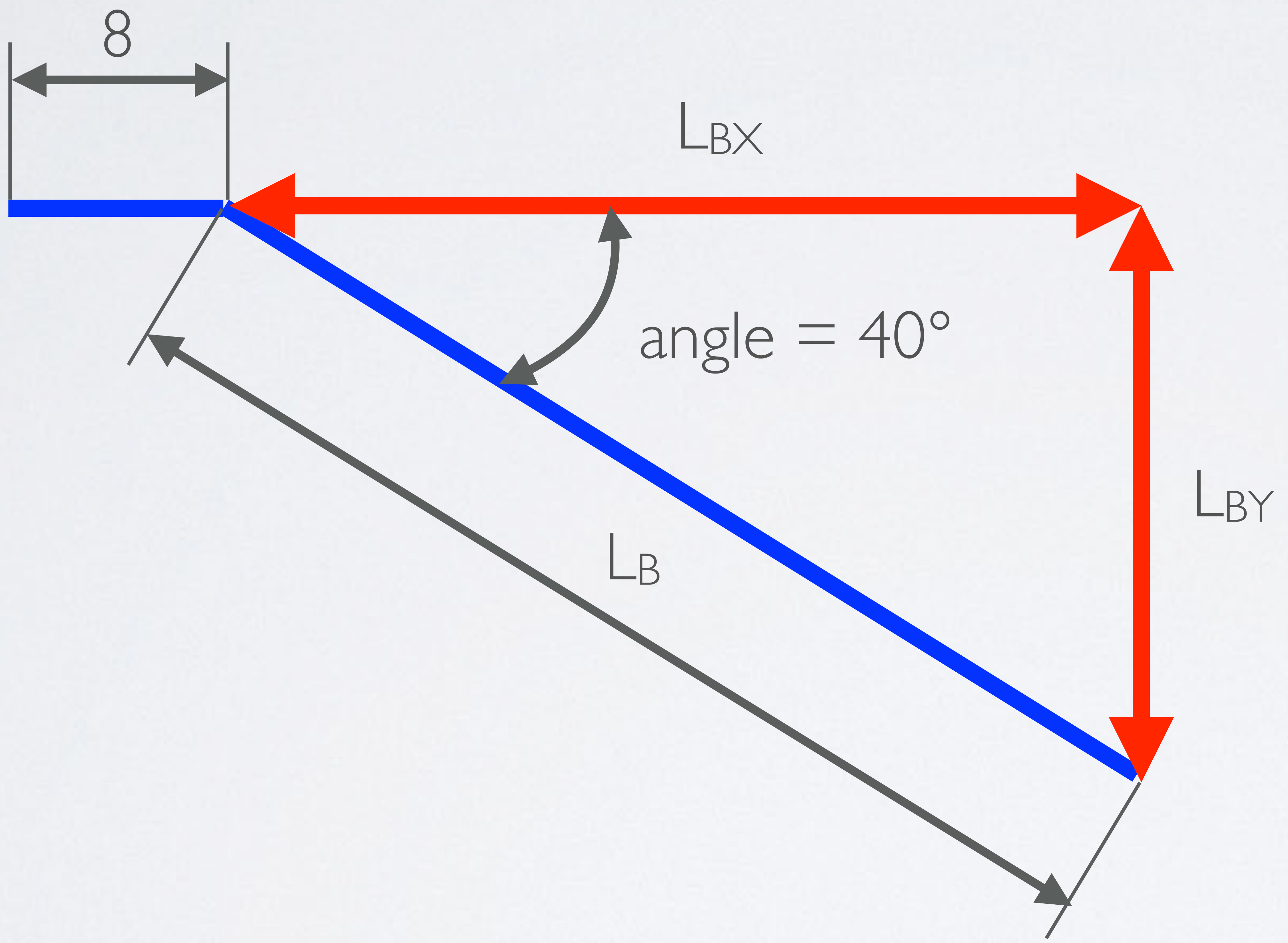
# BUILD A ¼ WAVE GROUND PLANE ANTENNA

- Make the radiating element length 86 mm, instead of 82 mm so it can be tuned using the N1201SA antenna analyser.
- Make the radial element length 90 mm.
- The radial elements are bend down at an angle of 40°, this will change the impedance at the feed point to be around 50Ω.

# BUILD A ¼ WAVE GROUND PLANE ANTENNA



# BUILD A ¼ WAVE GROUND PLANE ANTENNA




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

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

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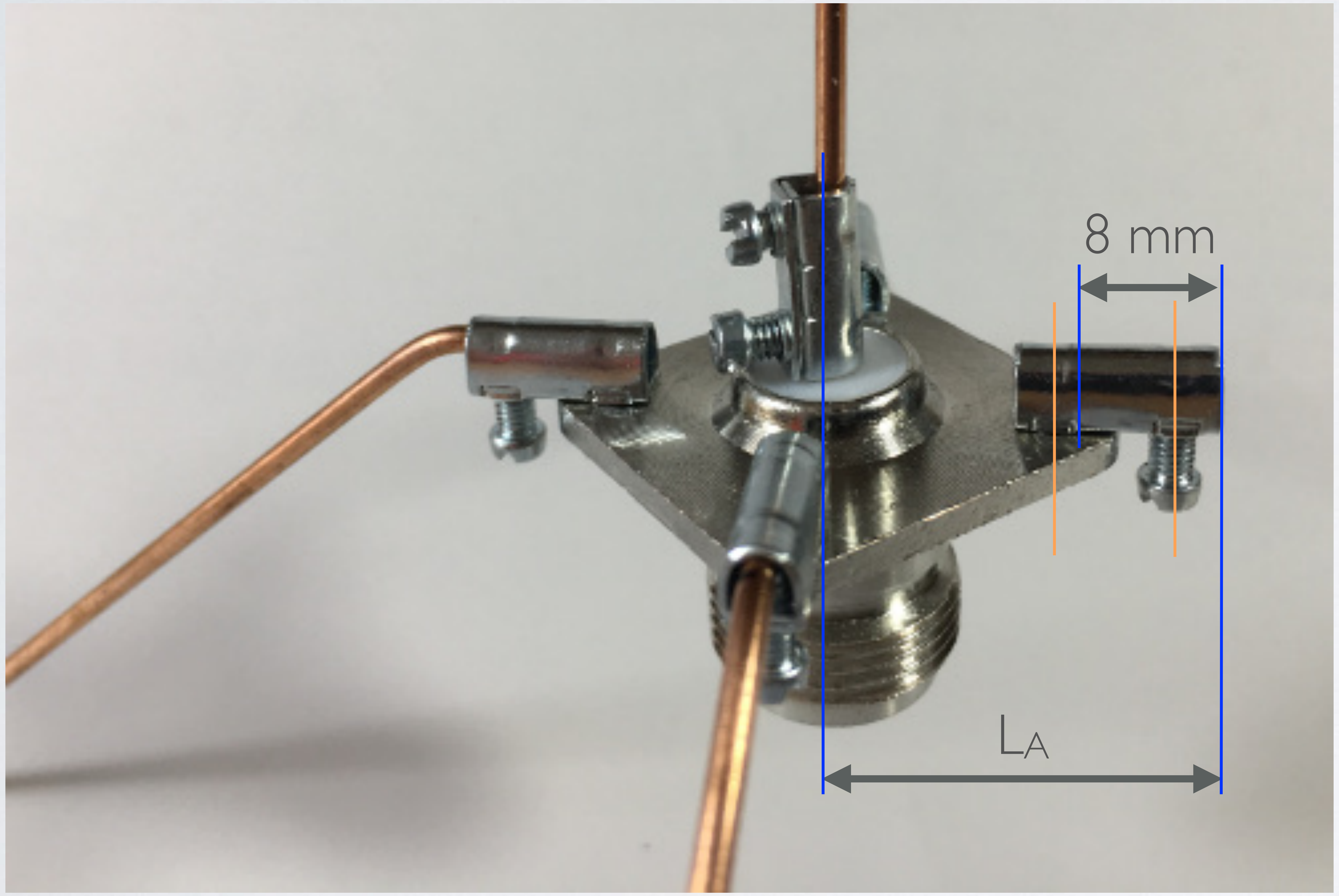
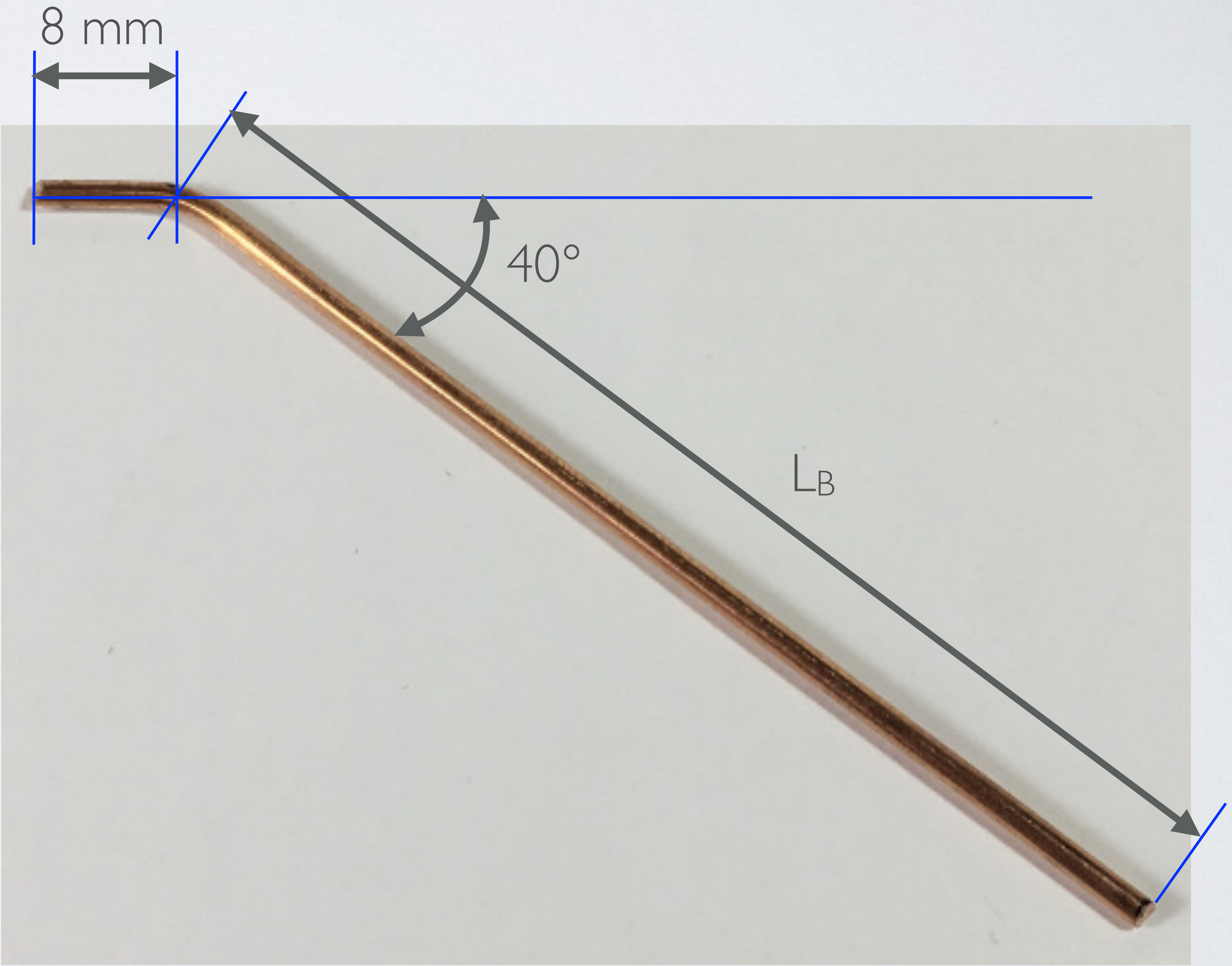


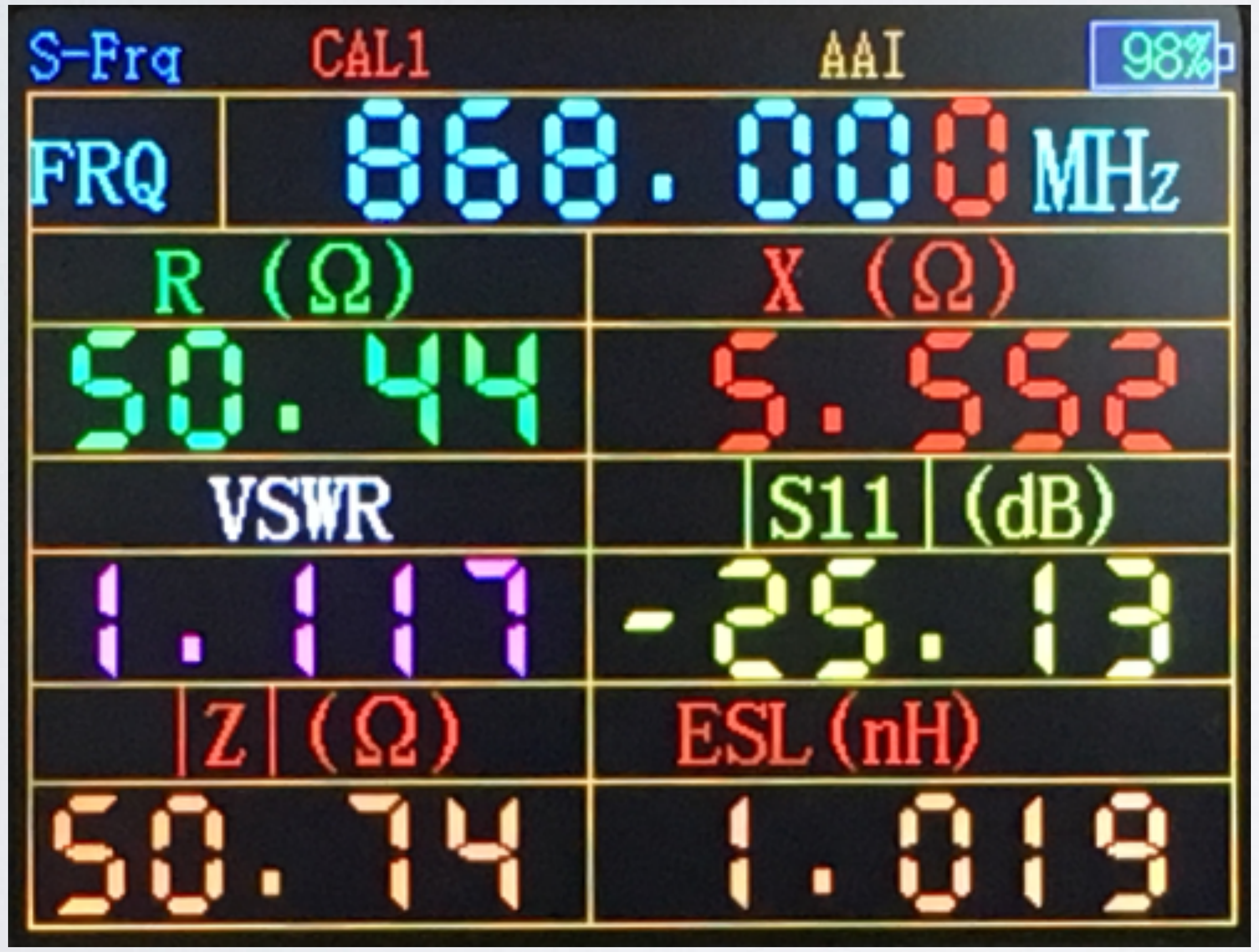
# ATTENTION

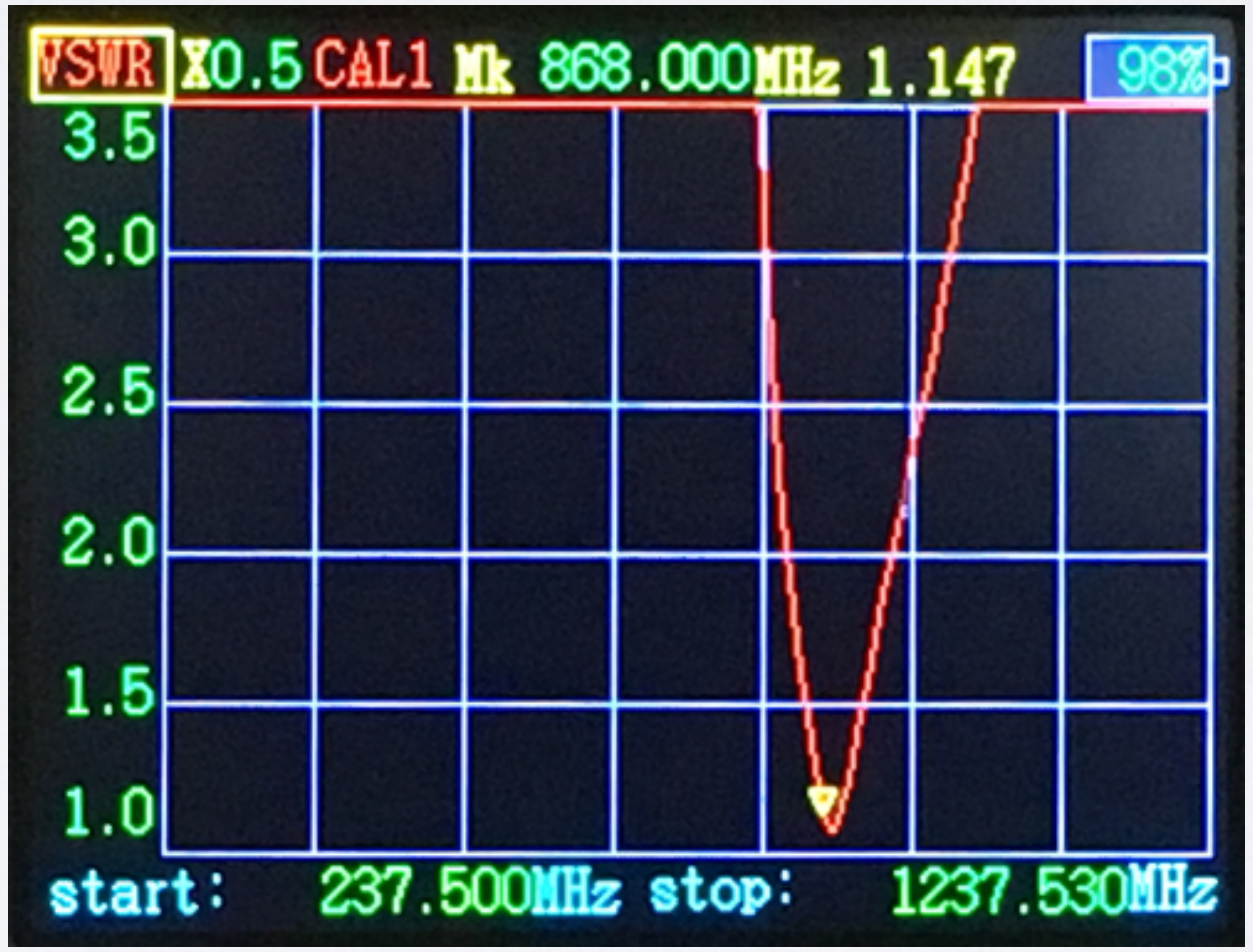
- In the previous slides I have shown how to build a ¼ wave ground plane antenna.
- The demonstrated antenna is NOT intended to be used outdoors.
- The components I have used will not withstand harsh weather conditions. The tiny screws will loosen and the copper wires will bend from wind and other weather conditions.
- The ¼ wave ground plane antenna can be used outdoors but use stronger and tougher components that can withstand harsh weather conditions. For example use large crimp terminal rings, bolts, nuts and washers too firmly attach the radials to the type N connector. Use copper or aluminium tubing instead of wires.

# MEASURING ANTENNA PARAMETERS

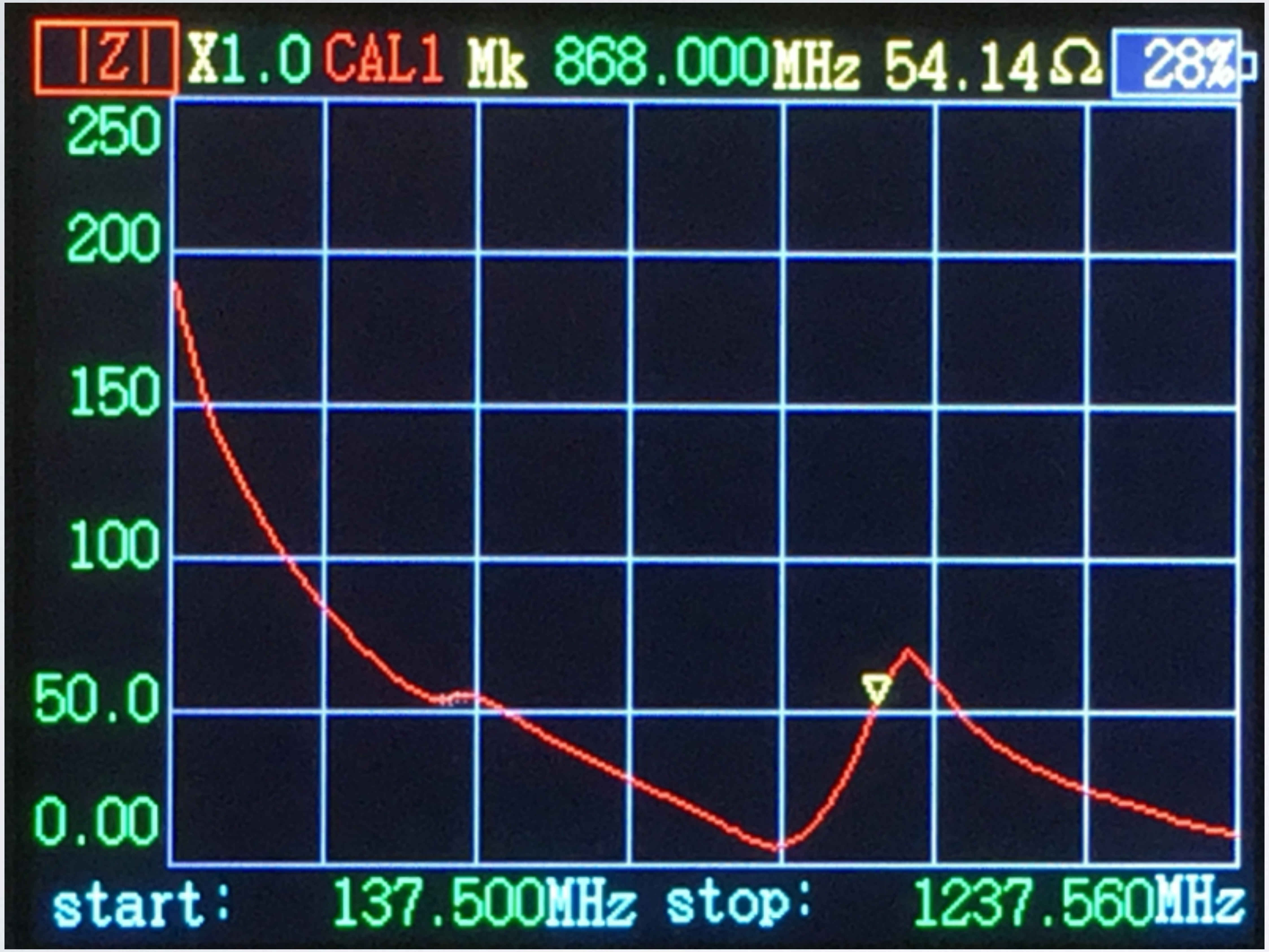
# MEASURED ANTENNA PARAMETERS

- In **MY** situation I got the best antenna performance when $L_{Radiating}$ = 86 mm.
  VSWR ≈ 1.1 ⟵ Good. It is < 2
  Z ≈ 51 Ω ⟵ Good. Should be approx. 50 Ω
  S11 ≈ -25 dB



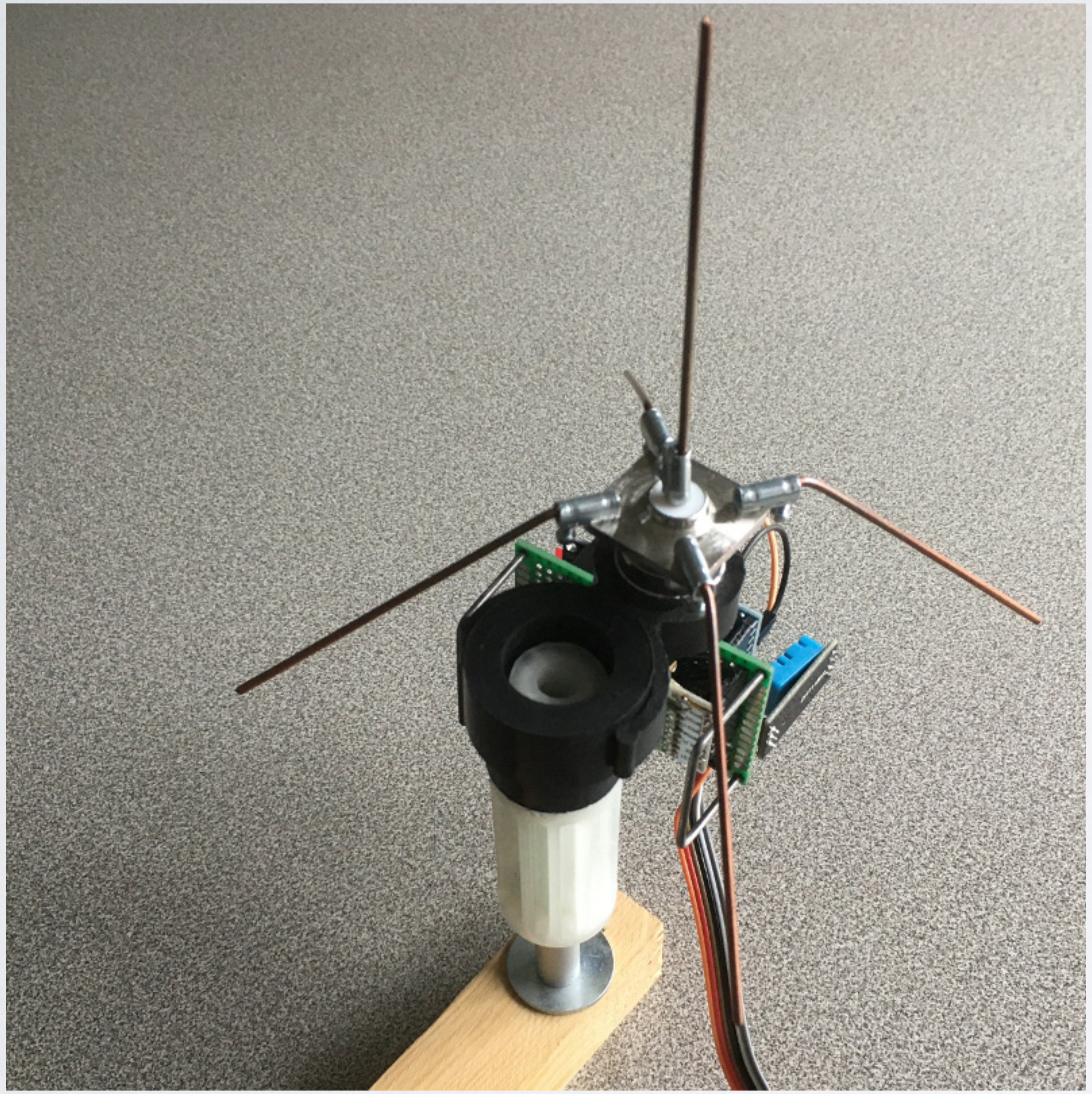

# MEASURED ANTENNA PARAMETERS



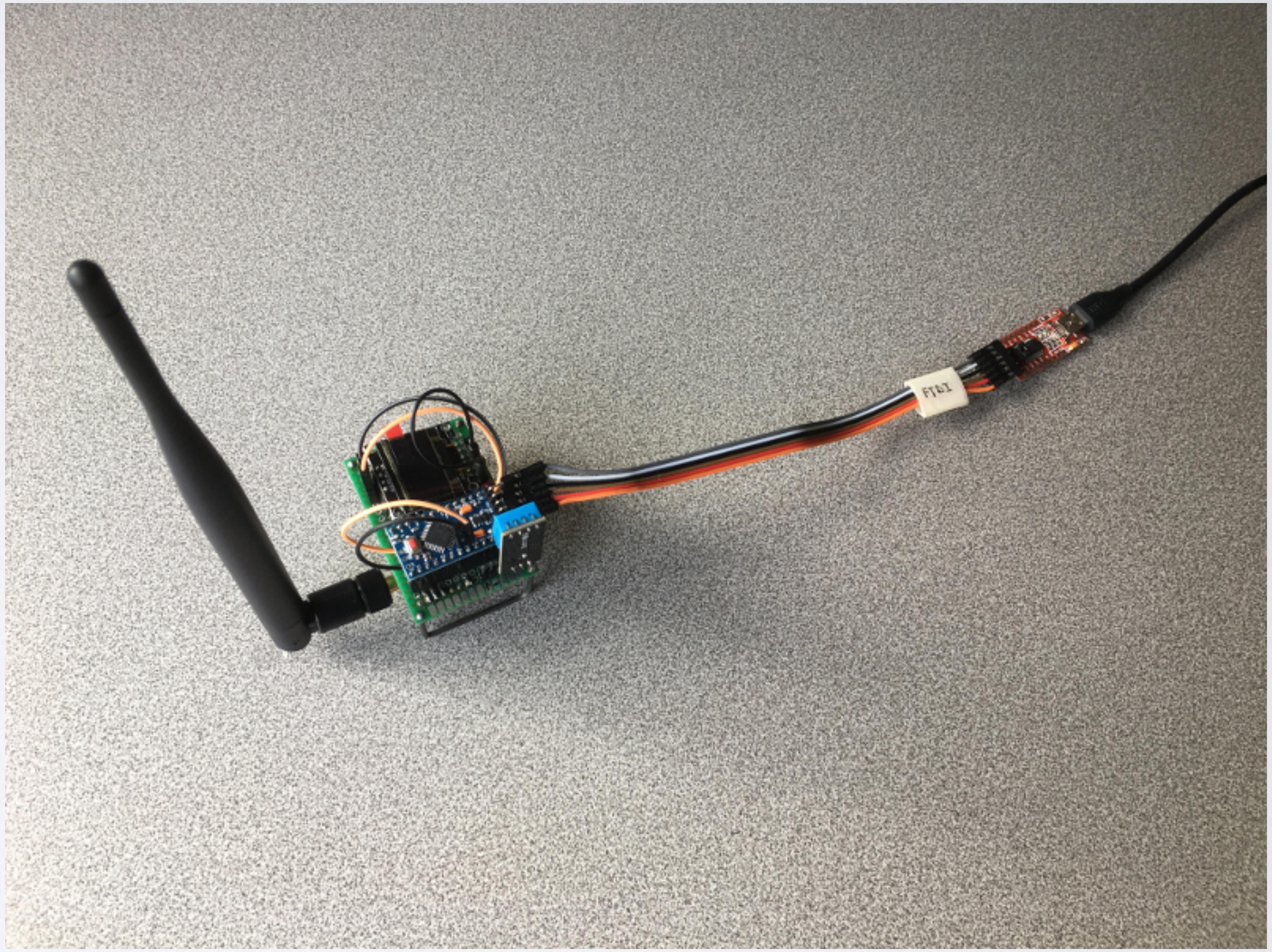
# ANTENNA TEST SETUP

- The ¼ wave ground plane antenna 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

# ANTENNA TEST SETUP

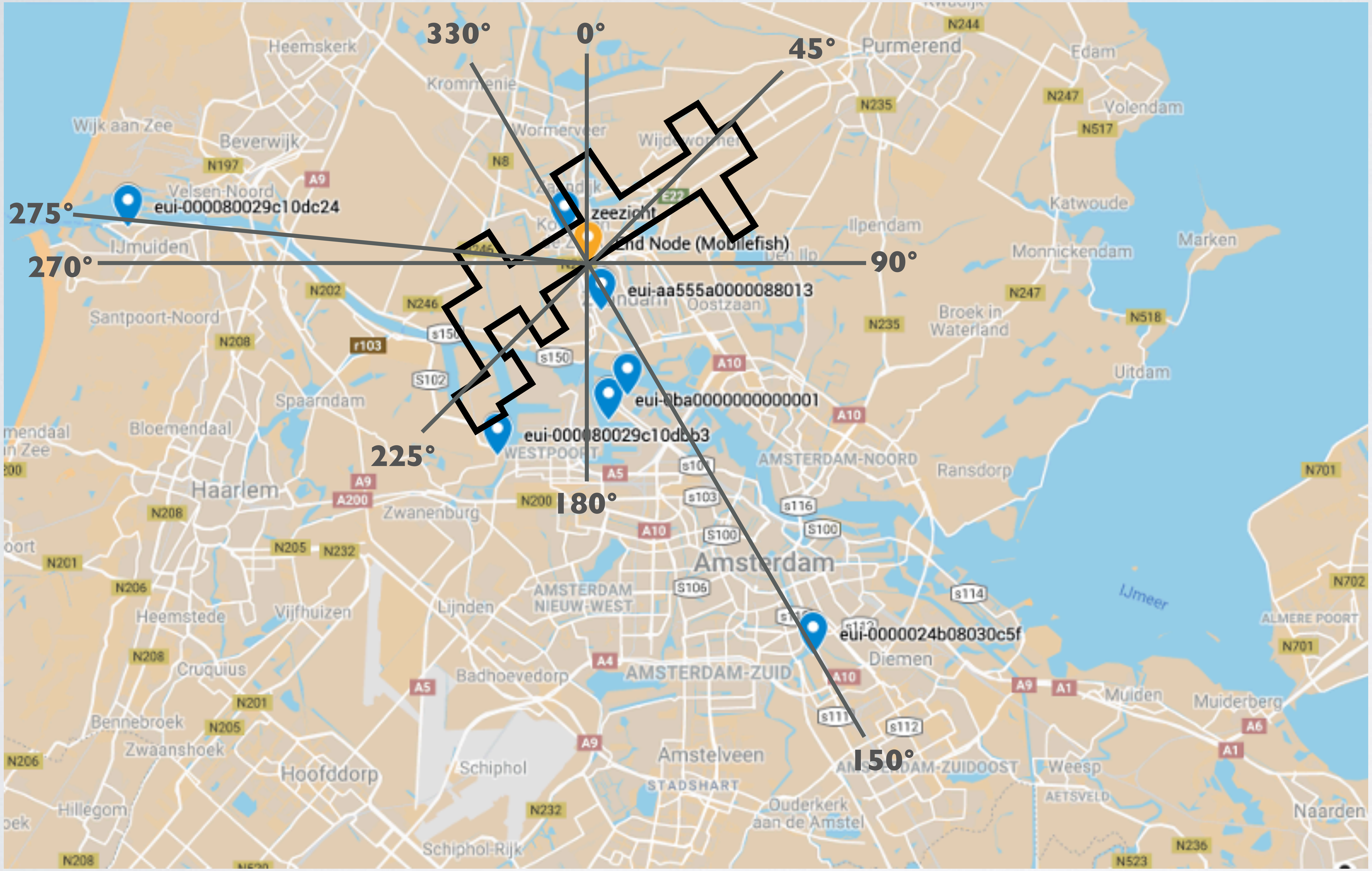


¼ wave ground plane antenna + end node



Sleeve dipole + end node

# 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

# ANTENNA TEST SETUP

- I have NOT modified the end node transmission power when using the ¼ wave ground plane antenna.

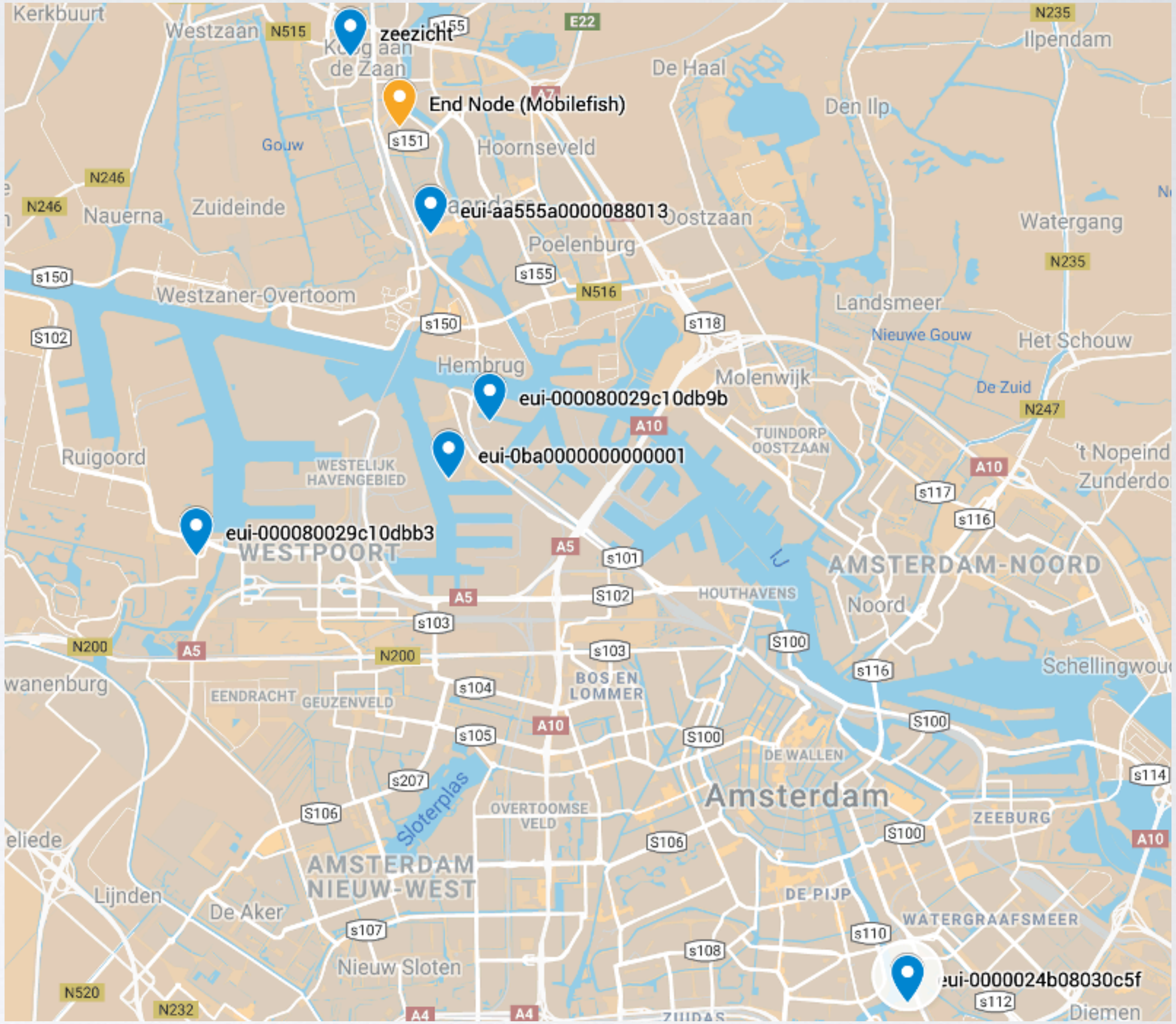
- In my area there are several gateways and I know that these gateways, which are connected to The Things Network, can receive my transmitted data.

- The ¼ wave ground plane antenna 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/quarter_wave_ground_plane_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



# ANTENNA TEST RESULTS

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

| Gateway | Distance from end device [km] | Altitude [m] | ¼ wave ground plane antenna Average RSSI [dBm] | Sleeve dipole Average RSSI [dBm] |
|---|---|---|---|---|
| eui-aa555a0000088013 | 1.57 | 42 | -114.5 * | -117.6 * |
| eui-000080029c10db9b | 4.36 | 30 | -118.6 * | - |
| eui-0ba0000000000001 | 5.02 | 20 | **-116.6** | -118.4 * |
| eui-60c5a8fffe760e60 | 4.15 | 30 | -113.6 * | - |
| eui-dca632fffe43df3e | 0.458 | 10 | **-105.7** | **-105.7** |
| eui-b827ebfffedcc77d | 0.816 | 7 | **-114.8** | -115.4 * |
| eui-000080029c10dc24 | 14.7 | 45 | -120.0 * | -120.0 * |

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

# ANTENNA TEST RESULTS

- If you look at the results you may notice there is no significant difference in the average RSSI values.

- When using the ¼ wave ground plane antenna it took 17.5 minutes to transmit 30 messages.
  When using the sleeve dipole antenna, which is my reference antenna, it took 18.5 minutes to transmit 15 messages.

- The Arduino sketch is configured to transmit 2 messages per minute. In a perfect situation it should take 14.5 to 15 minutes to transmit these 30 messages.

# ANTENNA TEST RESULTS

- So looking at the results I can conclude that my self build ¼ wave ground plane antenna performs the same as the sleeve dipole antenna.