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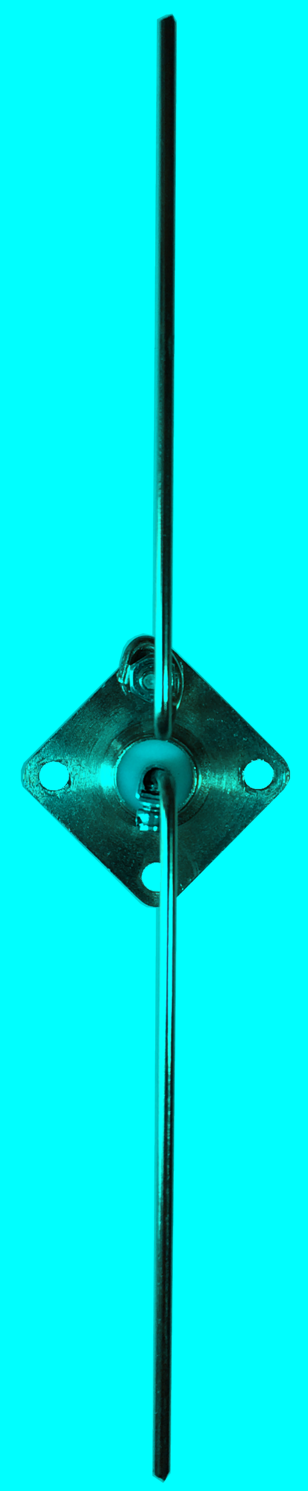
LORA / LORAWAN TUTORIAL 41

Dipole Antenna



v1.0.1

INTRO

- In this tutorial I will explain what a dipole antenna is.

ATTENTION

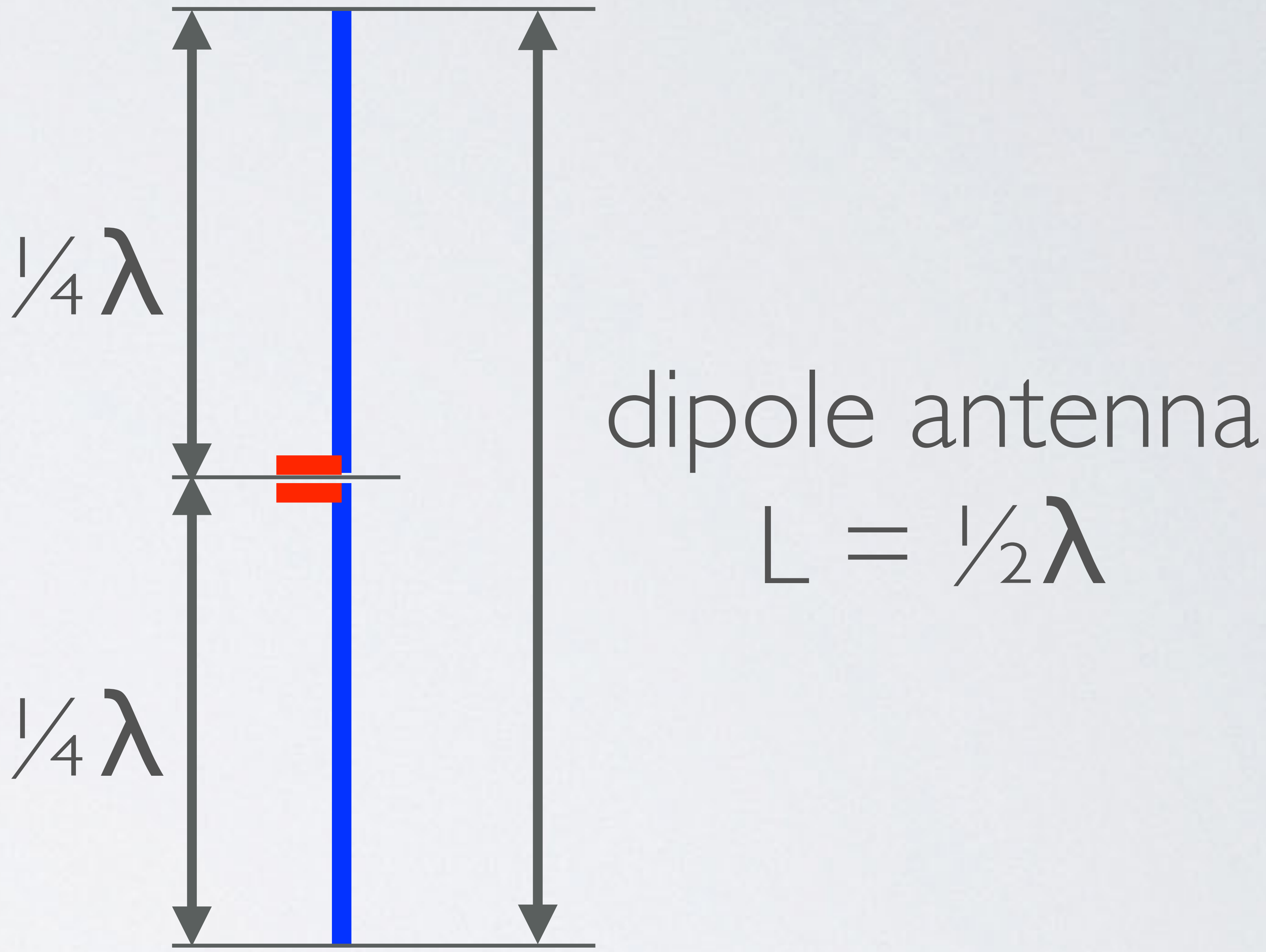
- **The antennas built in this tutorial are intended for test and educational purpose and should be used indoors.**

- **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.**

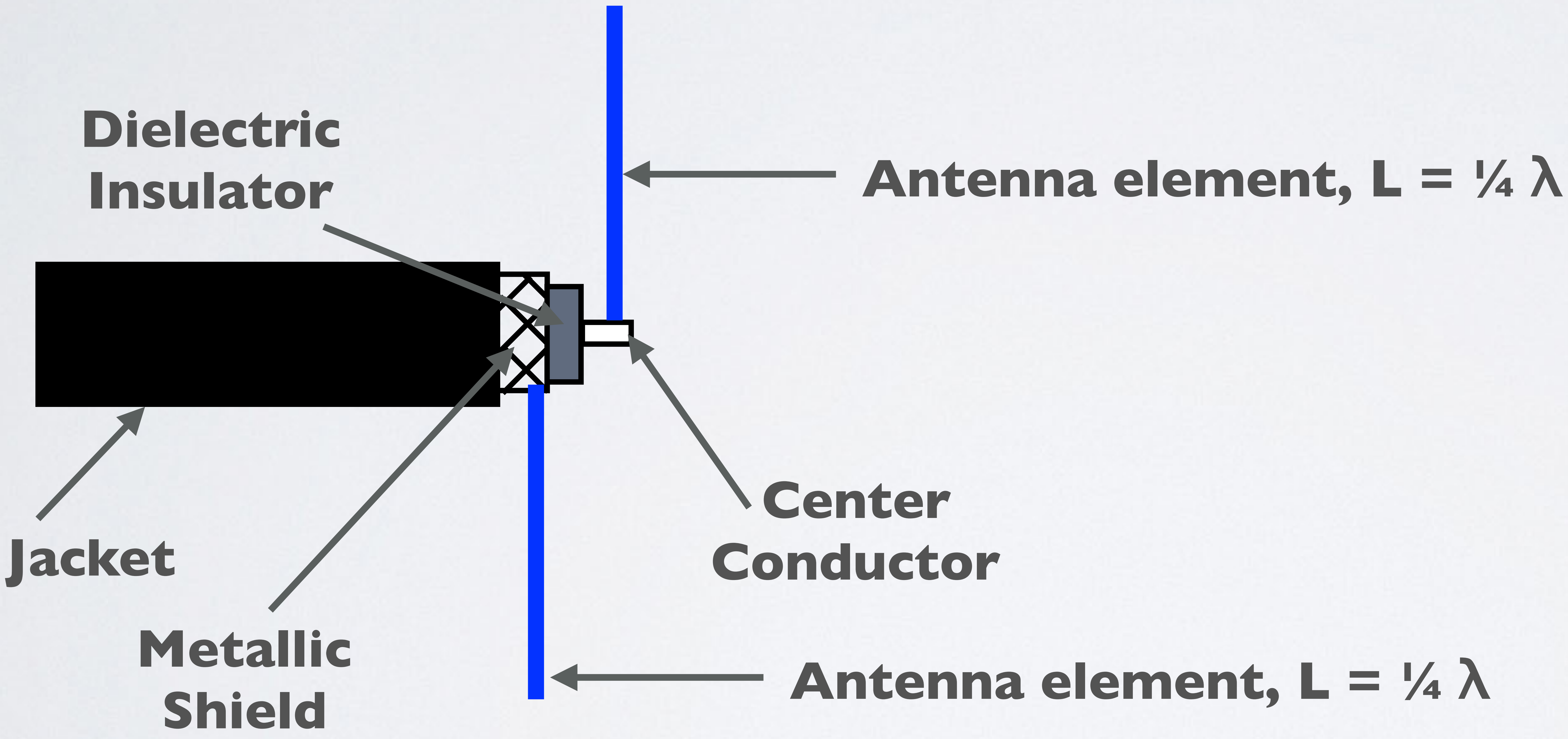
DIPOLE ANTENNA

- A dipole antenna is the simplest and most widely used class of antenna.
- A dipole antenna consists of two identical conductive elements such as copper wires, rods or tubes. The two elements contribute to the radiation.
- If the total length of the dipole is ½ wavelength, than each element has a length of a ¼ wavelength.
- When we speak of a ½λ dipole antenna, the total length of the antenna is a ½λ.

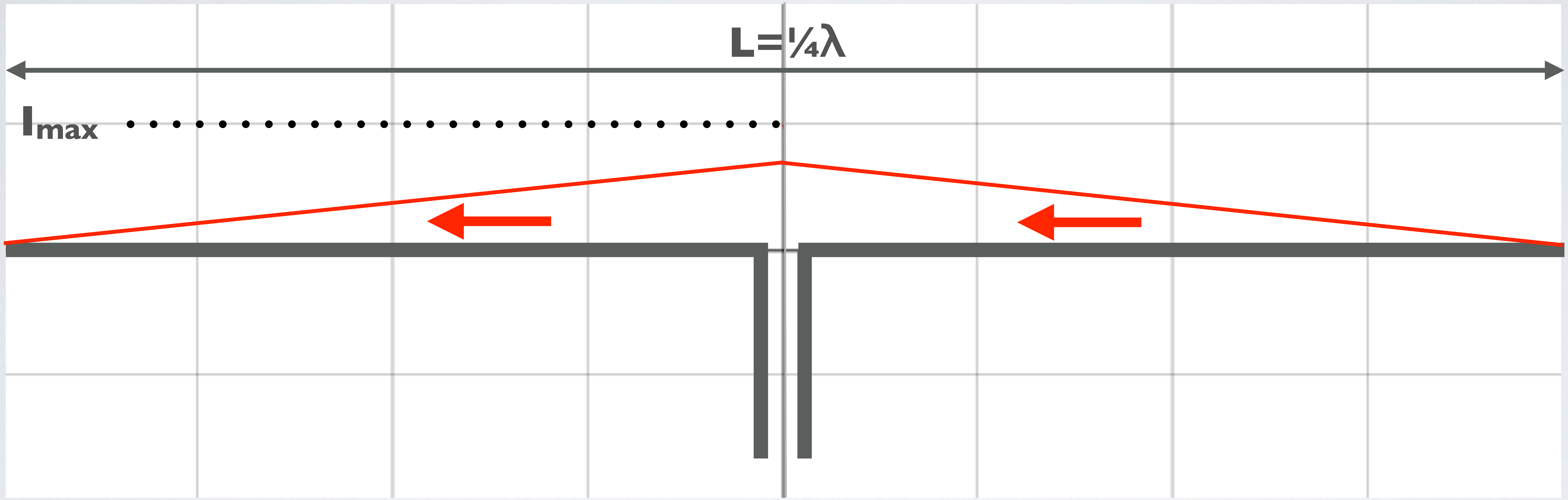


DIPOLE ANTENNA

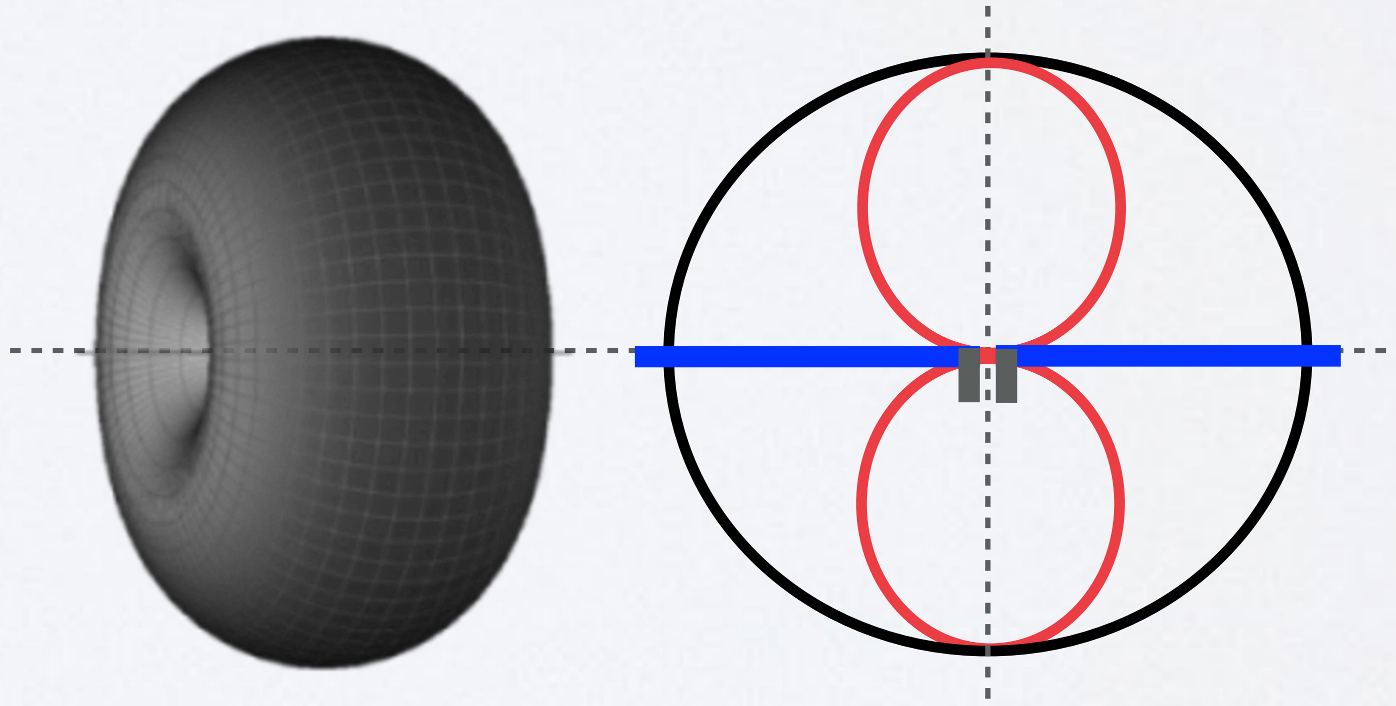
- The construction of a dipole antenna is as follows (simplistic explanation): One element of the dipole antenna is attached to the coax cable centre conductor. The other element is attached to the coax cable metallic shield.



DIPOLE CURRENT DISTRIBUTION

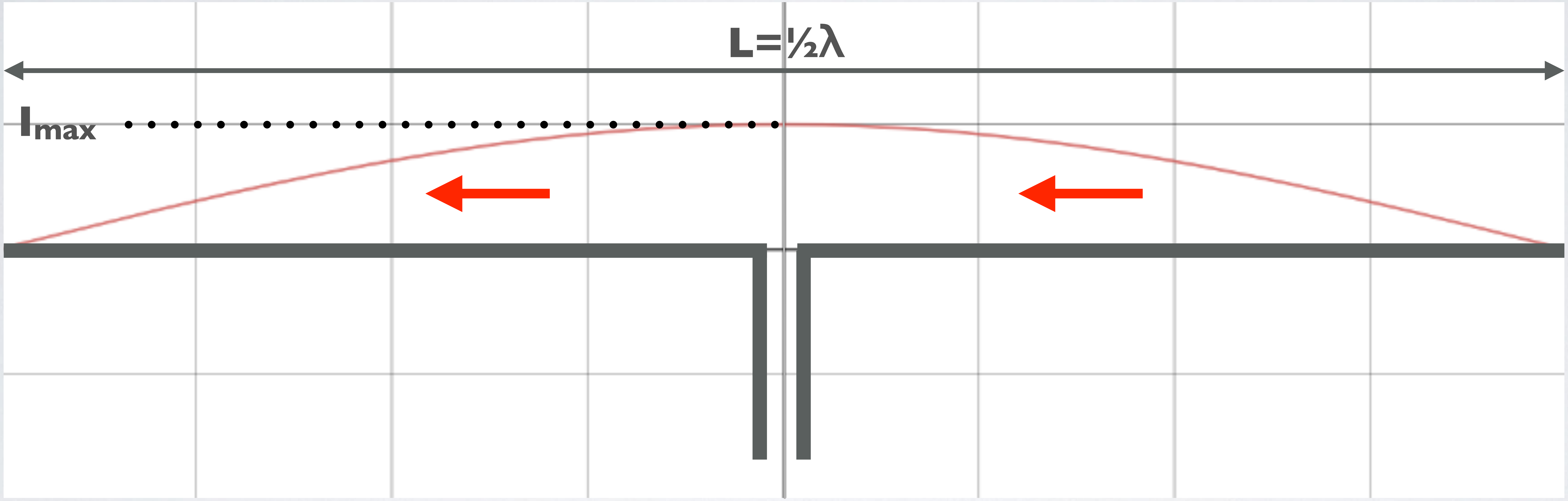


This is called a ¼ wave dipole.
Current flows the same direction,
but the current is not maximum.
This antenna has poor efficiency.

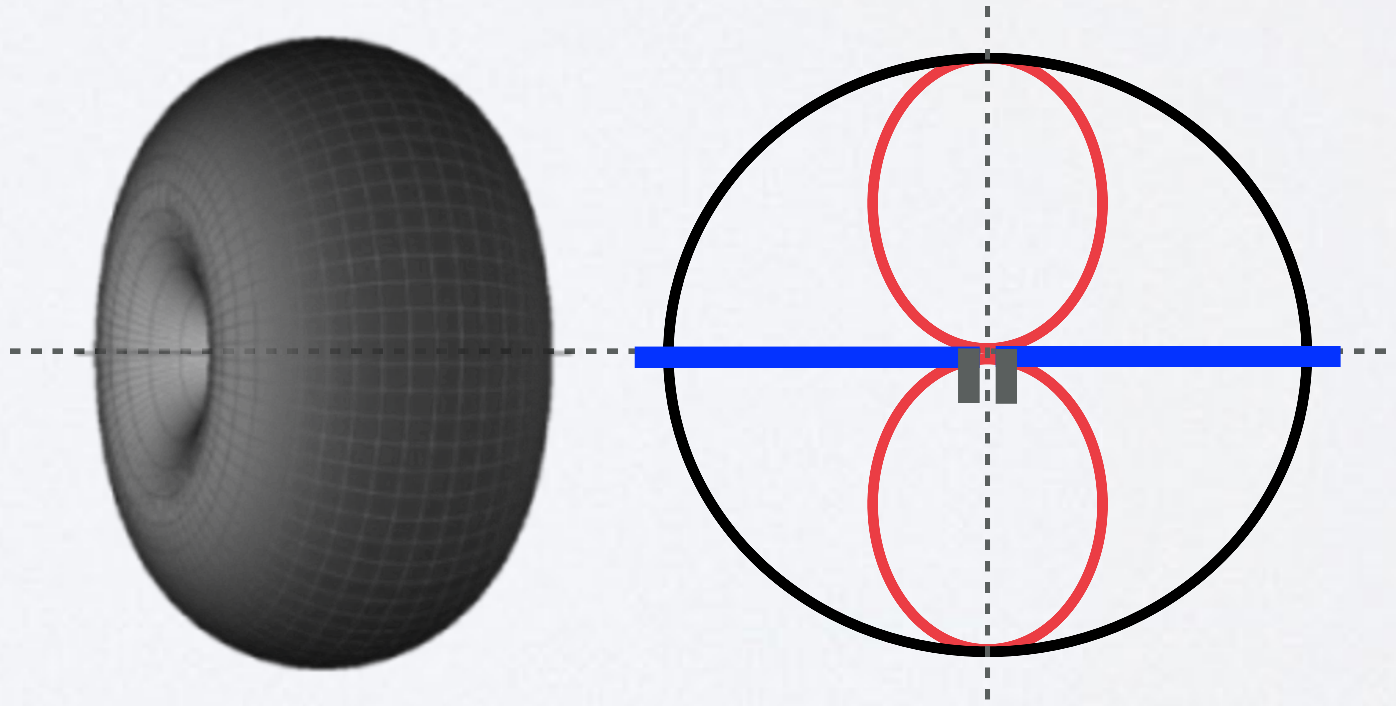


E-plane
Radiation pattern
(simplified)

DIPOLE CURRENT DISTRIBUTION

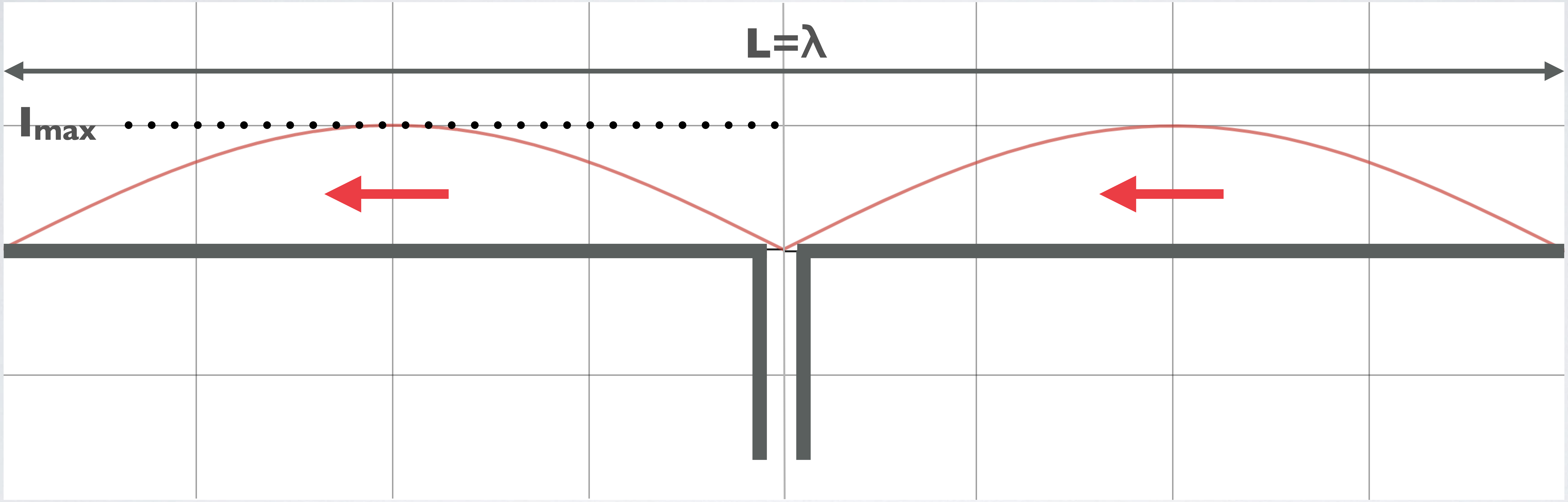


This is called a ½ wave dipole.
Current flows the same direction.
This is a good antenna.

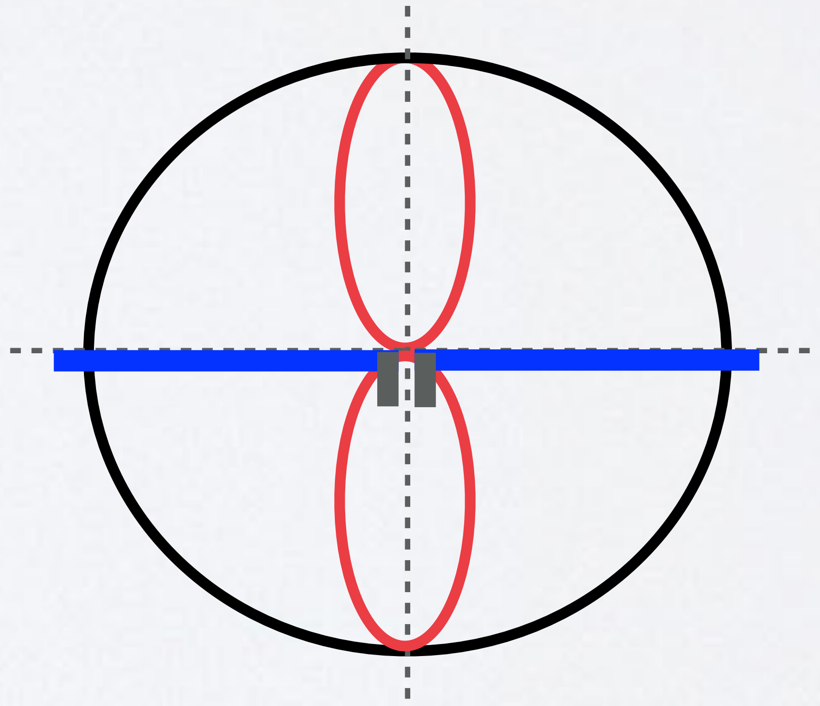


E-plane
Radiation pattern
(simplified)

DIPOLE CURRENT DISTRIBUTION

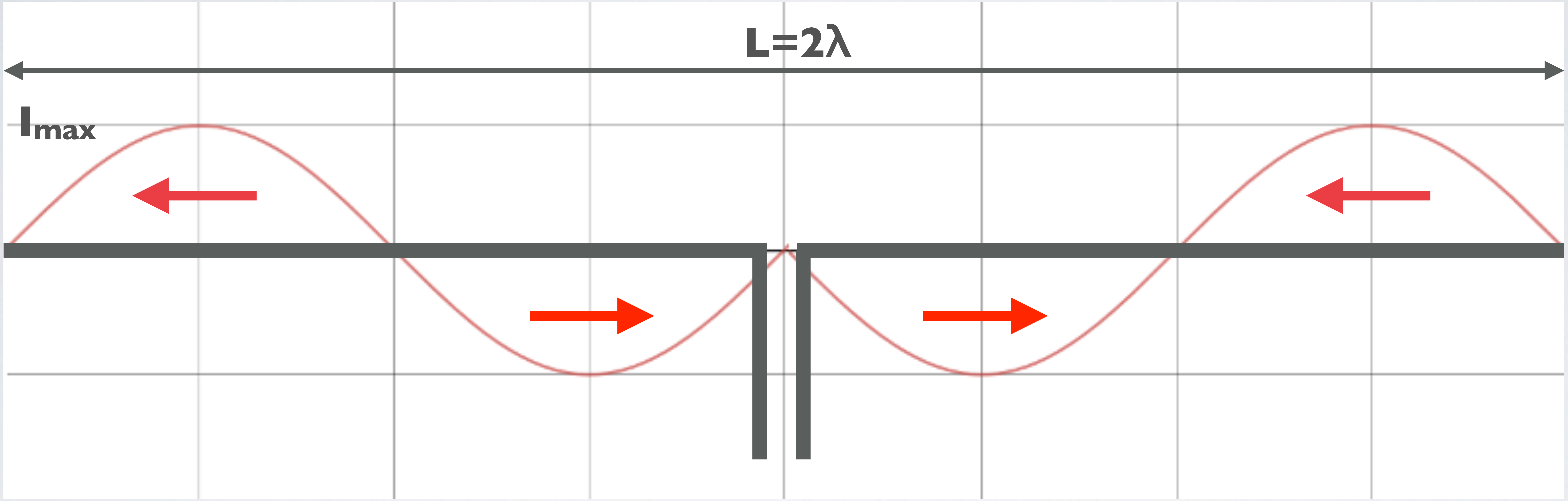


This is called a one wave dipole.
Current flows the same direction.
Radiation pattern is flattened (compared with L= 0.5λ) and dipole is larger. This antenna is not optimal.

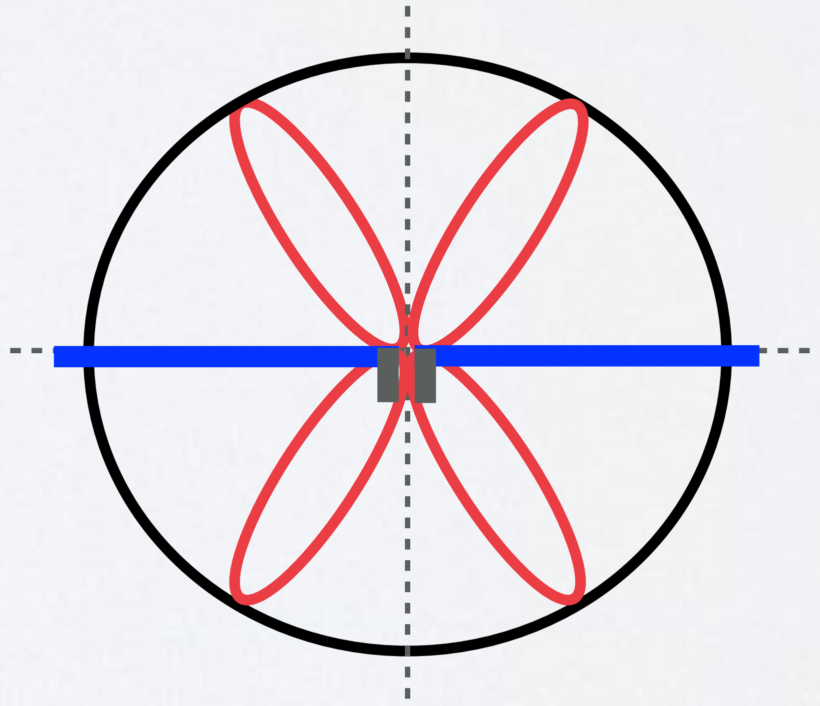


E-plane
Radiation pattern
(simplified)

DIPOLE CURRENT DISTRIBUTION

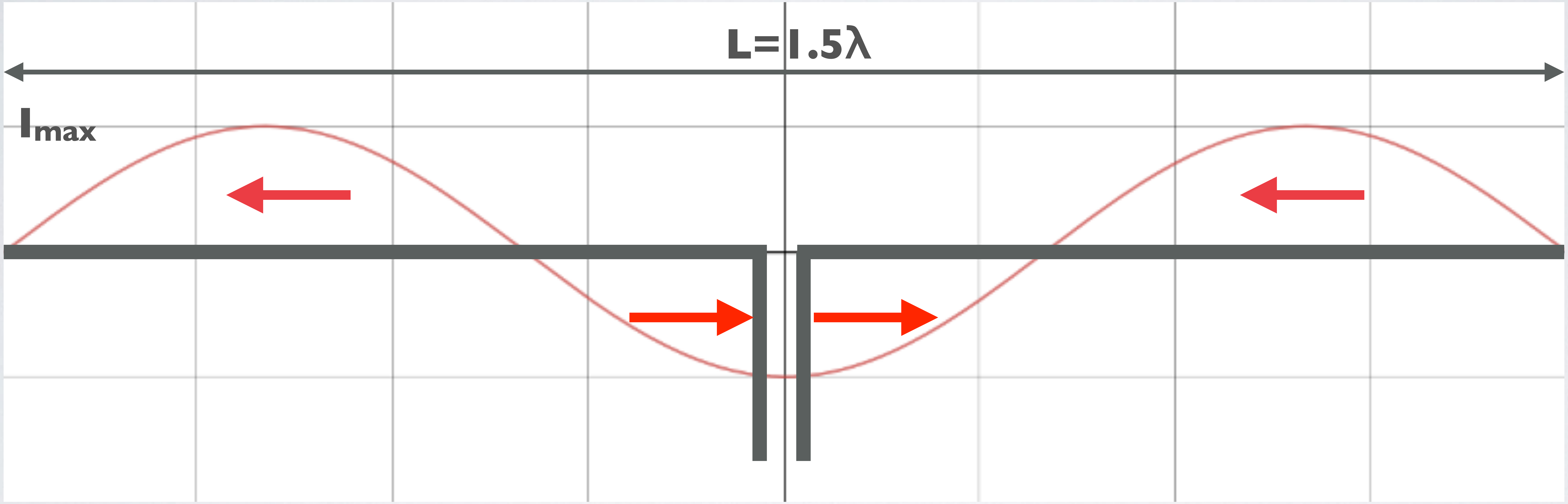


This is called a 2 wave dipole.
Current flows counteract each other.
This antenna is not good.

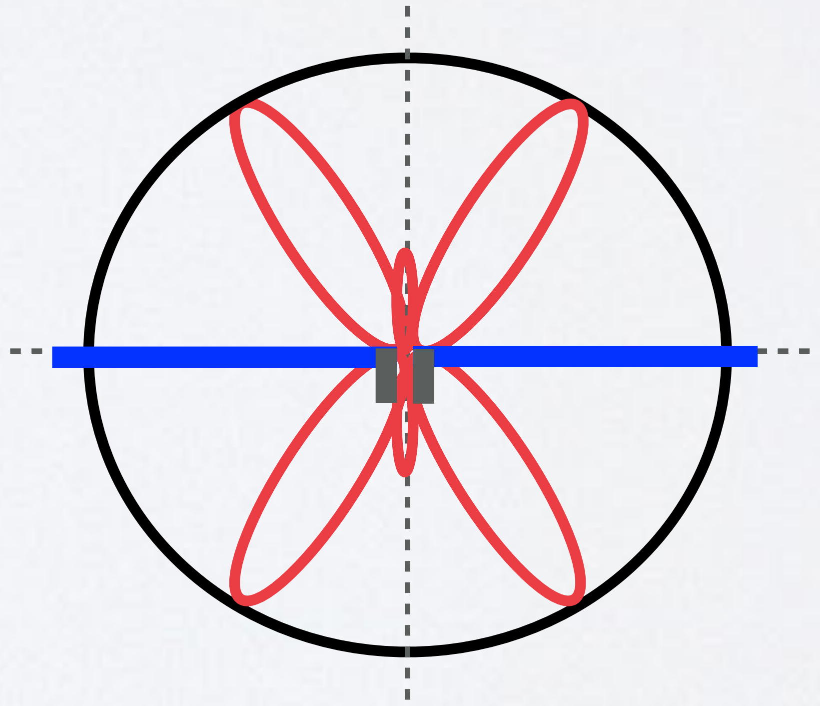


E-plane
Radiation pattern
(simplified)

DIPOLE CURRENT DISTRIBUTION



This is called a 1.5 wave dipole.
Current flows interfere with each other.
This antenna is not good.



E-plane
Radiation pattern
(simplified)

DIPOLE CURRENT DISTRIBUTION

- A nice animation where you can see the radiation pattern vs current distribution when you increase the dipole length: https://youtu.be/edyFGAT_87o

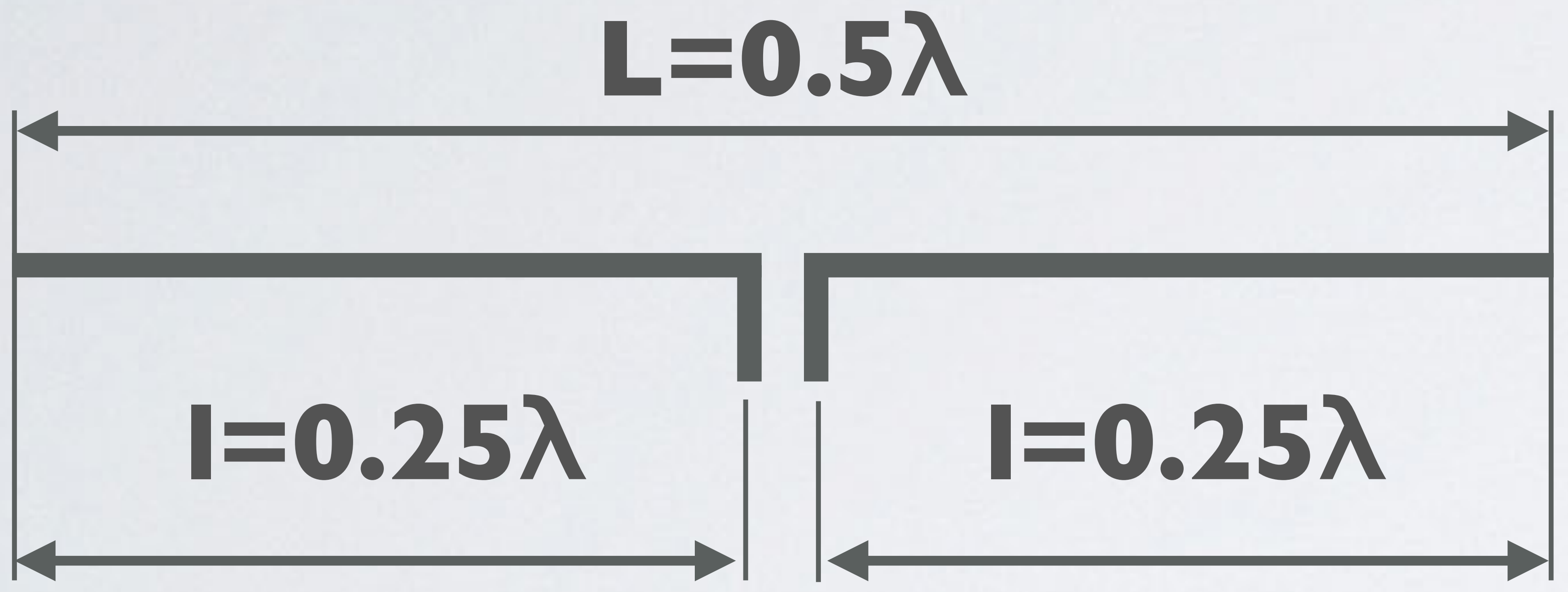
DIPOLE ANTENNA LENGTH

- The equation to calculate the wavelength:
  c = λ x f
  c = speed of light = 299792458 m/s
  λ = wavelength in m
  f = frequency in Hz

- If antenna f = 868 MHz:
  λ = c / f = 299792458 / 868000000 = 0.34538 m = 345.38 mm

DIPOLE ANTENNA LENGTH

- As explained earlier a ½λ dipole is a good antenna.



- This means both elements of the antenna are 0.25 λ in length.
- If f = 868 MHz and λ = 345.38 mm, L= 0.5 x 345.38 = 172.69 mm
- Do not forget the velocity factor.
  If the dipole is made of stainless steel (VF=0.9): l = 0.9 x 172.69 = 155 mm

1/2 WAVE DIPOLE ANTENNA GAIN

- A ½λ dipole antenna has a power gain of 1.64 (or 2.15 dBi) over an isotropic antenna (see tutorial 39).

- At its feed point ½λ dipole antenna has an impedance consisting of 73 Ω resistance (R) and a reactance of 42.5 Ω (X).

DIPOLE ANTENNA

This is a dipole antenna.
When using this antenna make sure it is vertically oriented.
Most gateway antenna's are vertical polarised.

This is a sleeve dipole antenna.
Will be discussed in detail in tutorial 43.

1/2 WAVE DIPOLE ANTENNA

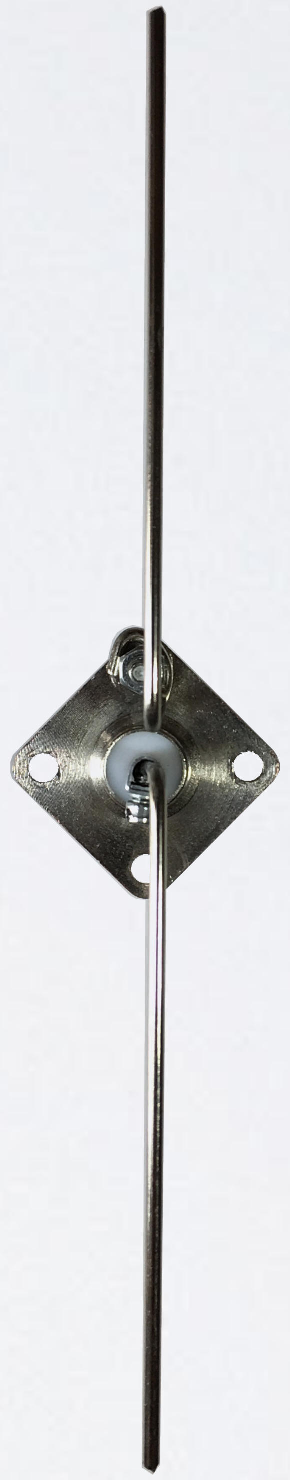
- Here is one way to build a ½λ dipole antenna but without a balun.
  In many practical situations it is possible to operate a dipole satisfactorily without the use of a balun, but there may be a slight increased risk of interference if one is not used. I only use this dipole antenna for education / test purpose.

- 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

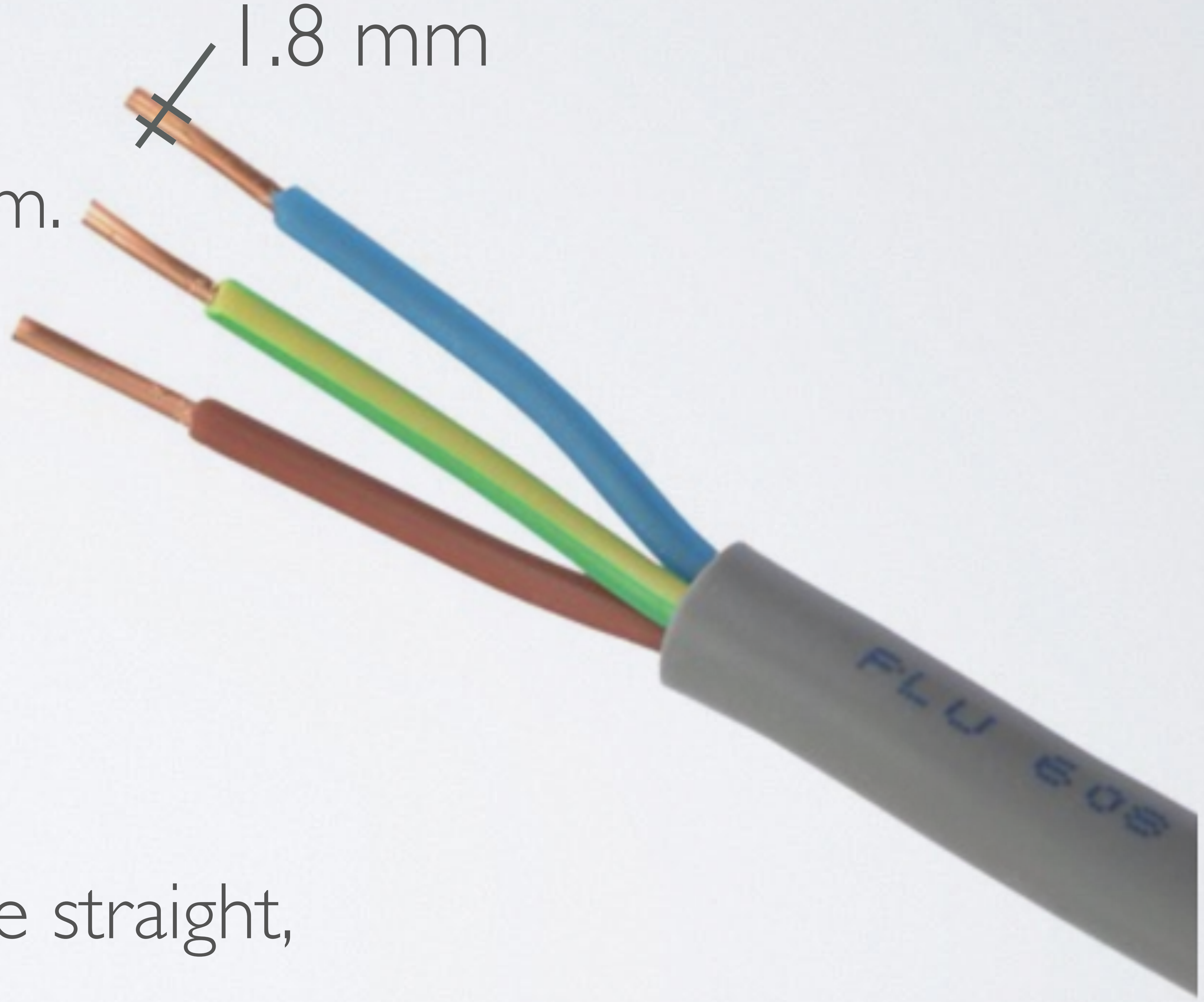

1/2 WAVE DIPOLE ANTENNA

- The two antenna wires are from an umbrella.
  These wires are made from stainless steel (called ribs).



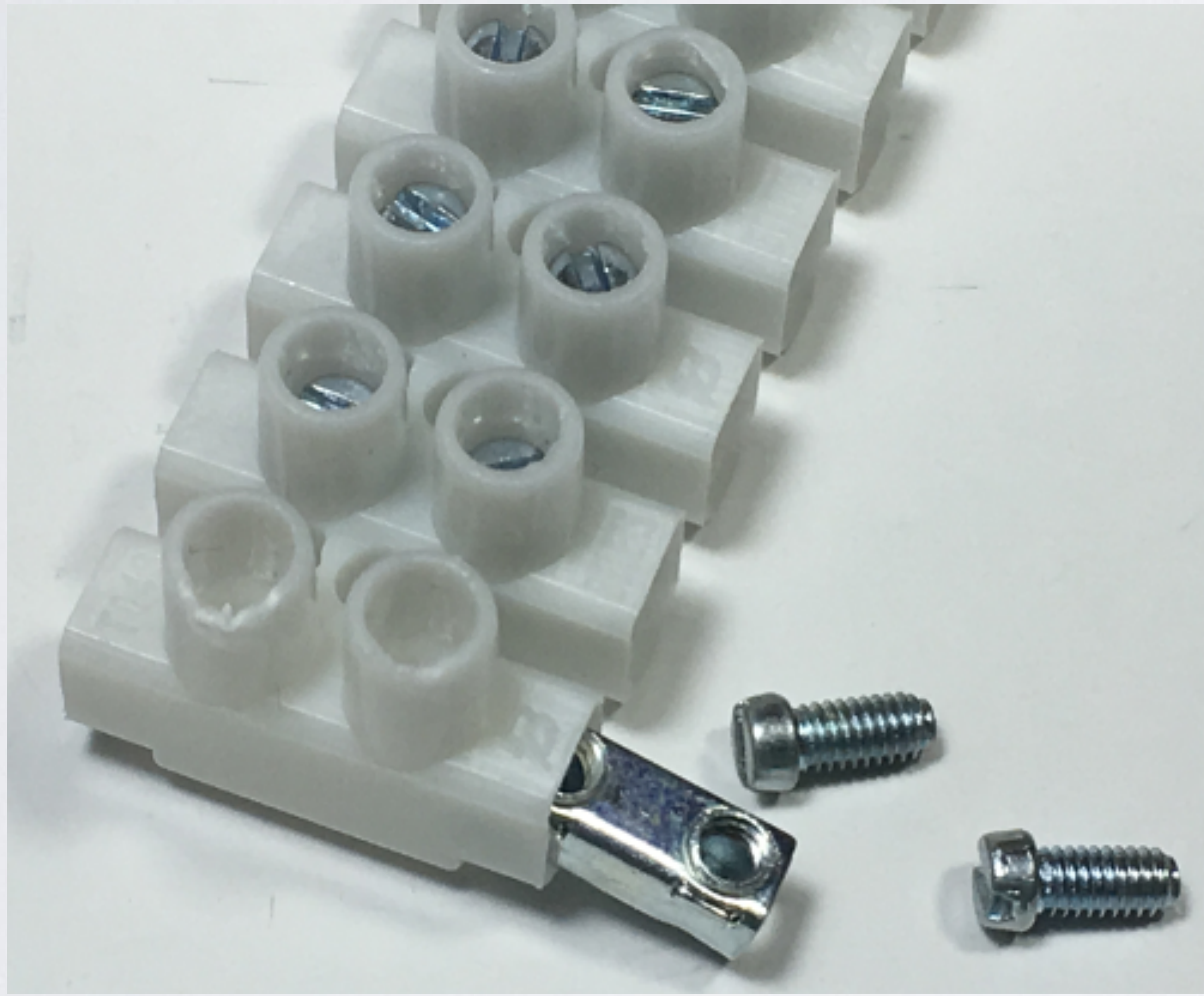
1/2 WAVE DIPOLE ANTENNA

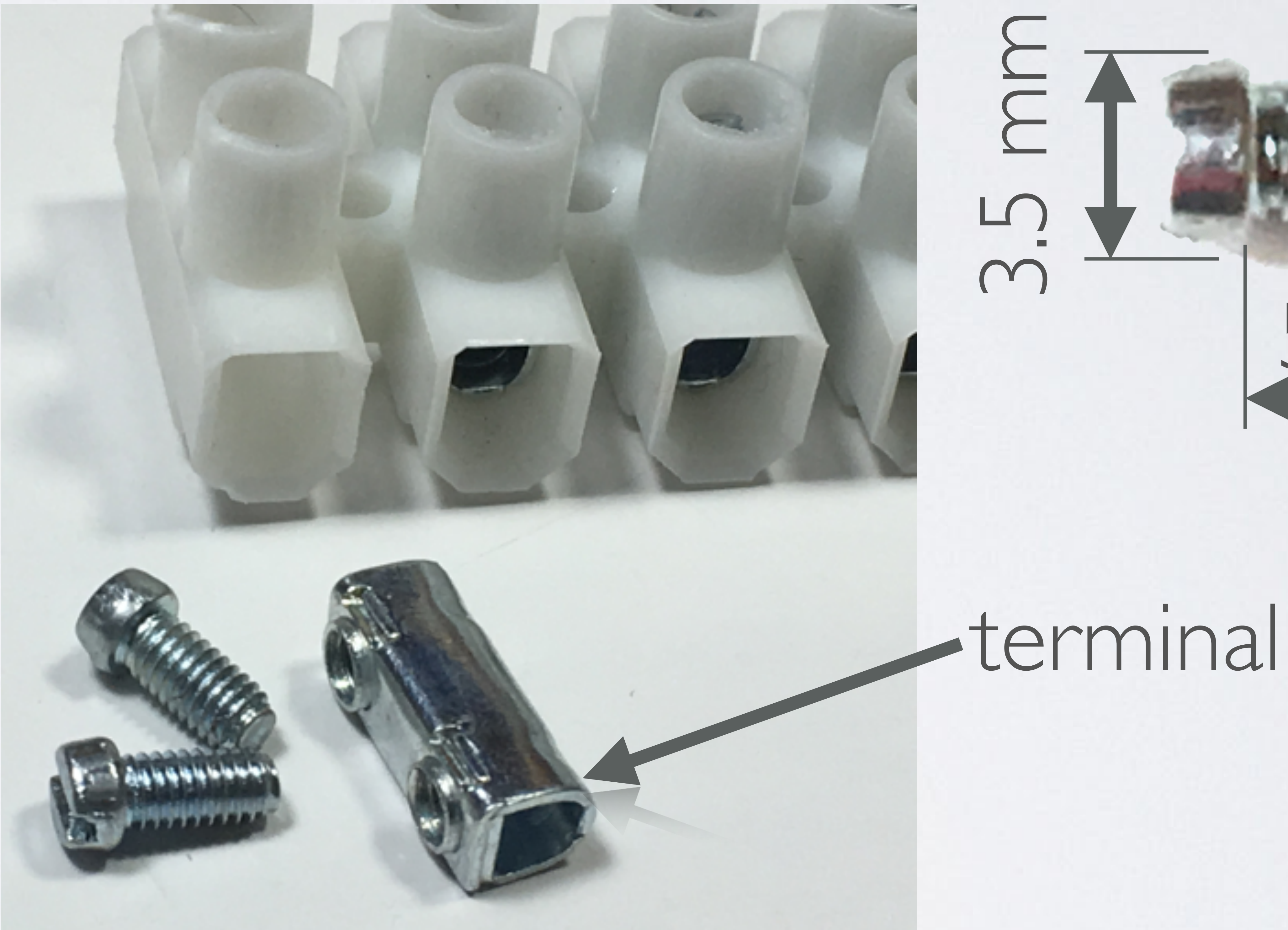
- Instead of umbrella wires you can use electrical wires, but I prefer stainless steel wires because it does not bend easily compared to copper wires:
  - Outdoor cable XMVK 3x2.5 mm^2 grey.
    The copper wire has a diameter of 1.8 mm.
    Only 1 meter is needed.
    Cost: € 1.75 per meter
  - The electrical 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, but the wire diameter will decrease.

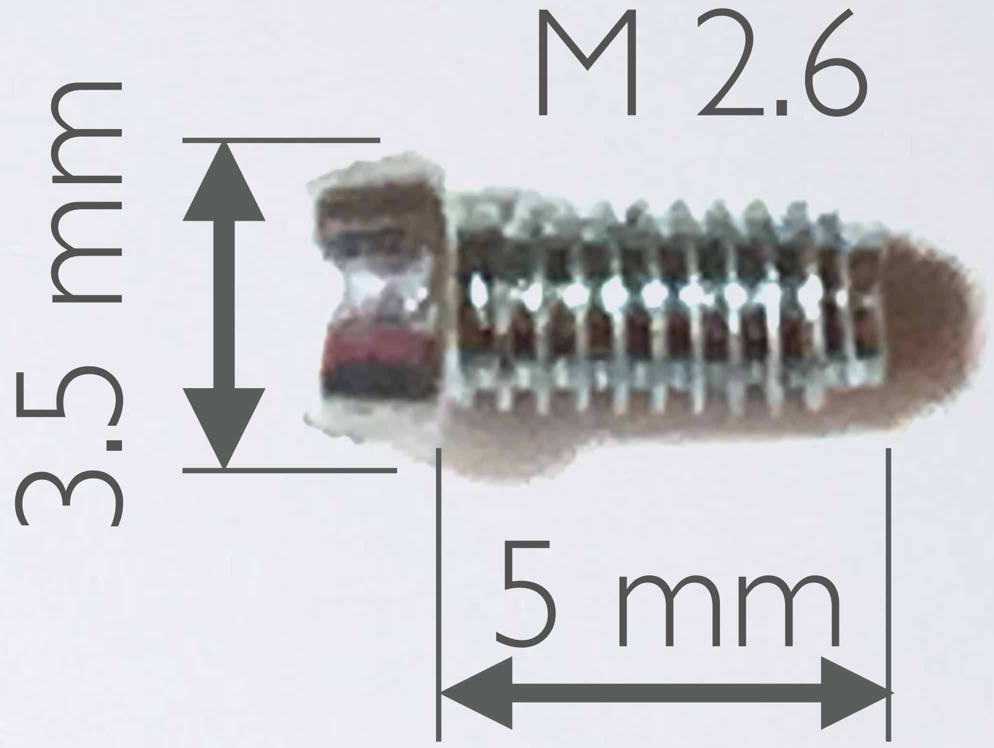


1/2 WAVE DIPOLE ANTENNA

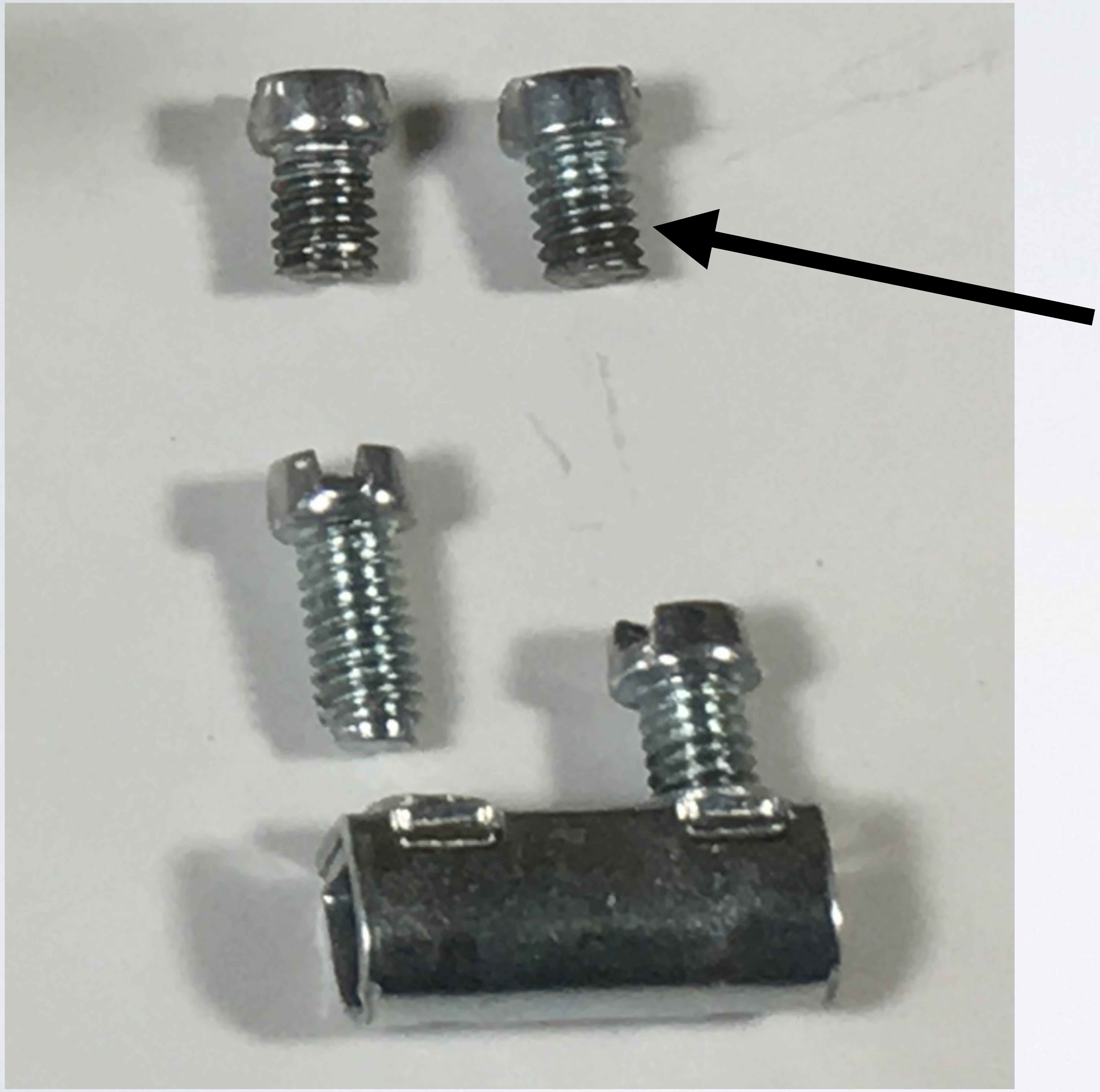
- Terminal strip block 1.5-4.0 mm²
  To be used for wires with a diameter of 1.38 mm - 2.26 mm
  Cost: € 1.98 (2 strips, each strip has 12 terminals)





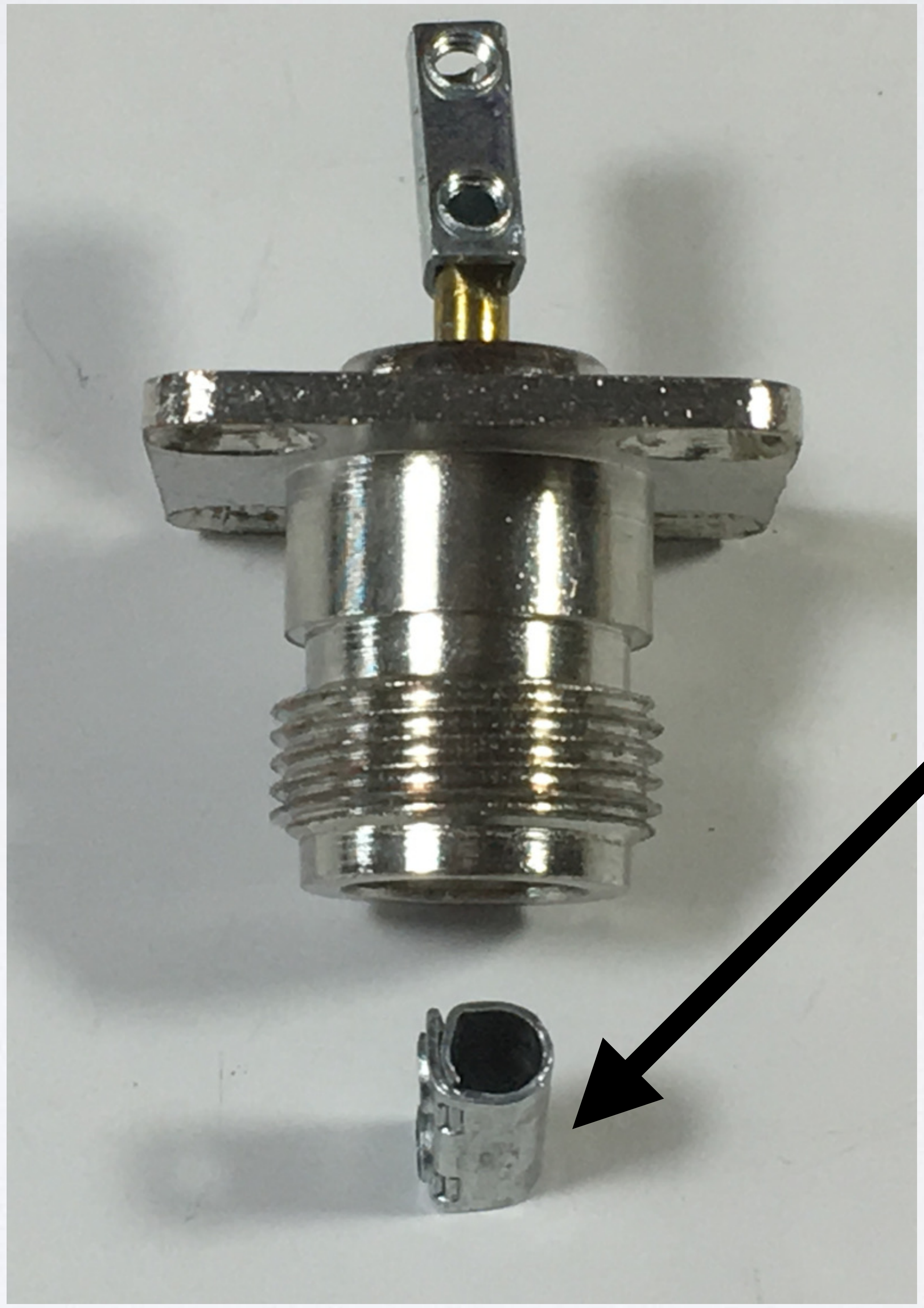


1/2 WAVE DIPOLE ANTENNA



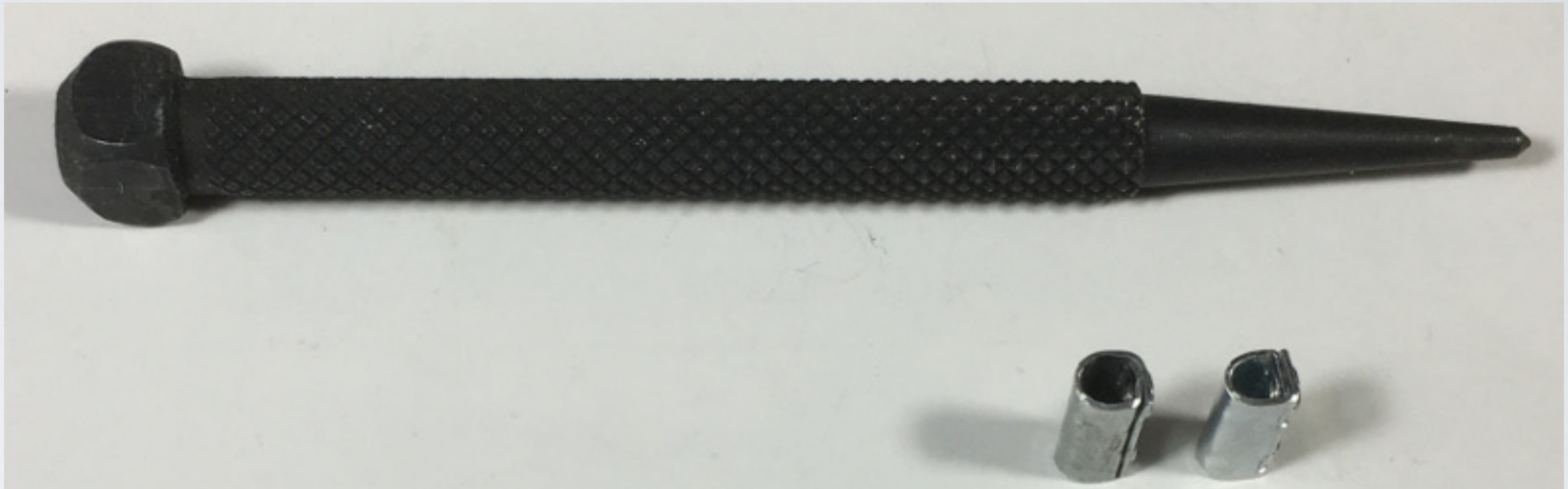
Cut the screws in half, so they will not stick out too much.

1/2 WAVE DIPOLE ANTENNA



Enlarge the hole of a terminal.

1/2 WAVE DIPOLE ANTENNA



Use a punch to enlarge the hole of a terminal.

1/2 WAVE DIPOLE ANTENNA

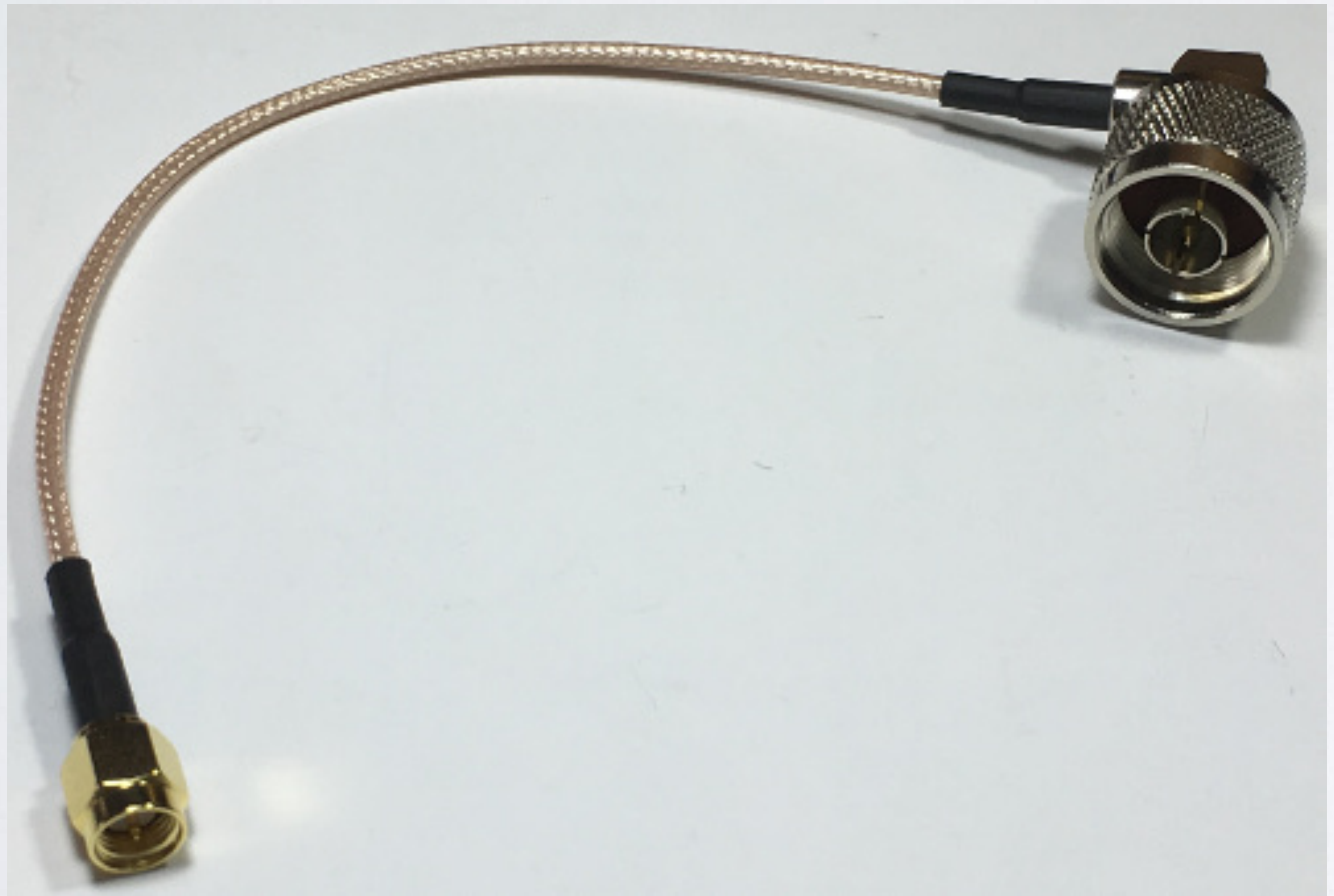
- Bolt: M4x10
  Nut: M4
  Metal washer 7.8 x 4.4 x 0.5 mm (outer diameter, inner diameter, thickness)
  Cost: unknown

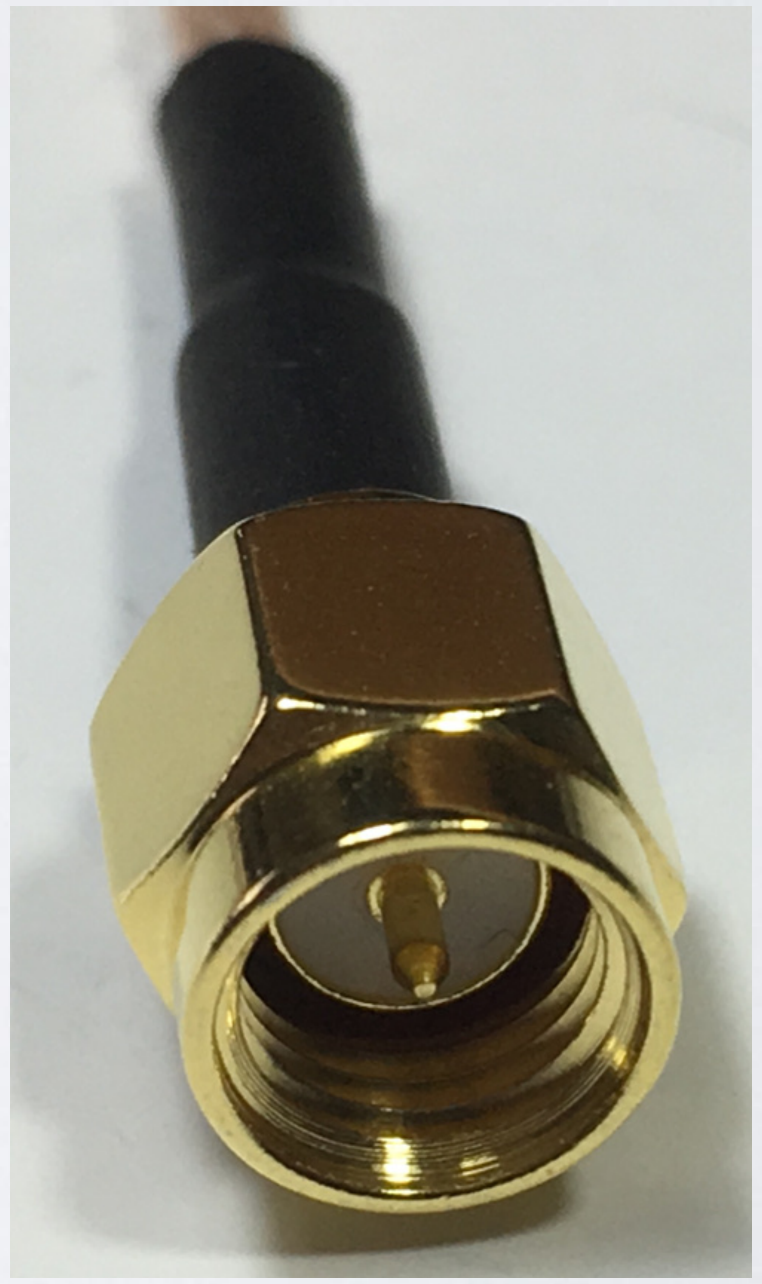
1/2 WAVE DIPOLE ANTENNA

If you use an M4 bolt, enlarge the hole diameter from 3.5 mm to 4.5 mm.

1/2 WAVE DIPOLE ANTENNA

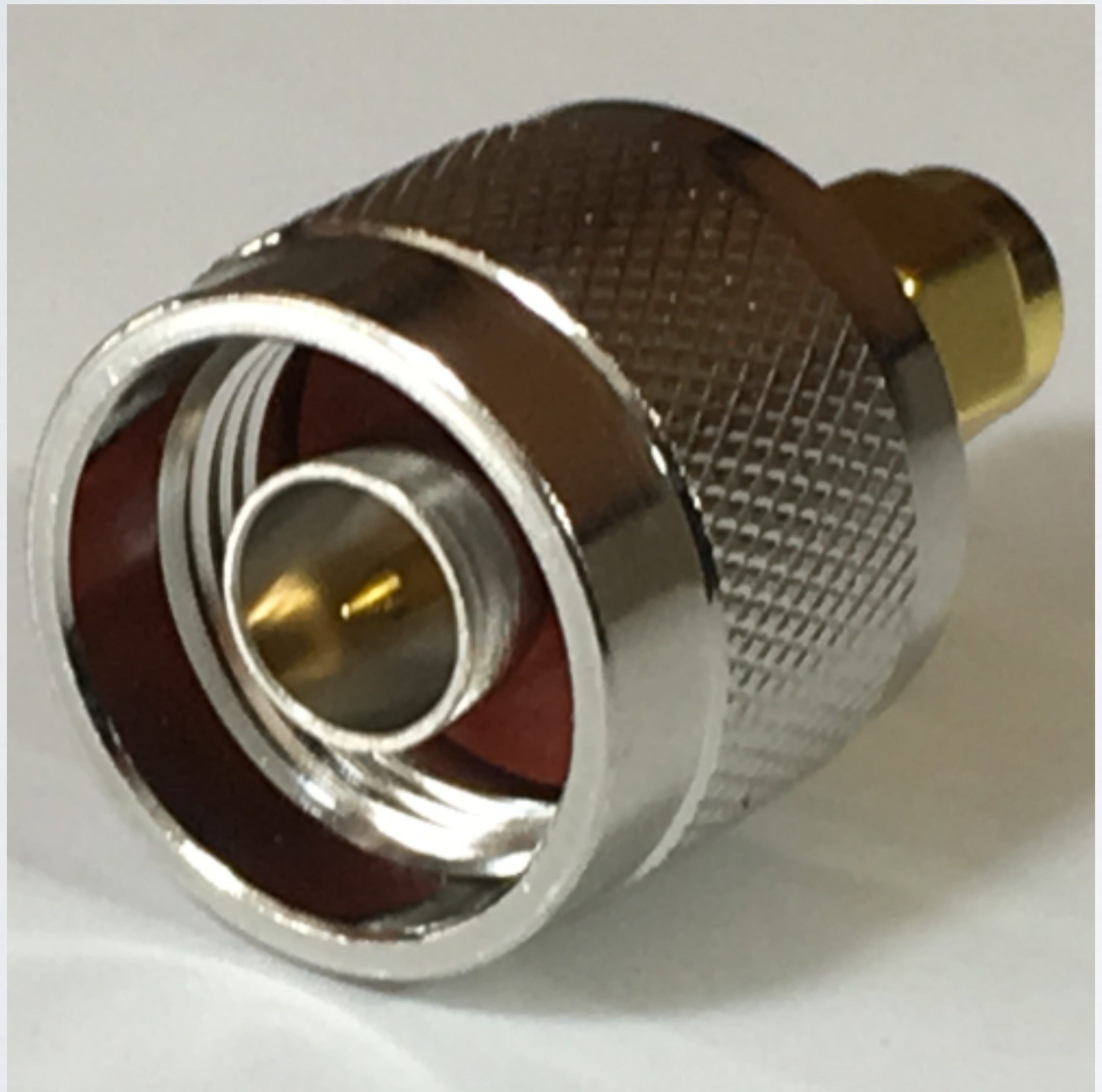
- RF coaxial cable RG316, length 20 cm with type N male plug right angle to SMA male connector.
  Impedance: 50Ω
  Coax: RG316
  Cost: € 3.39

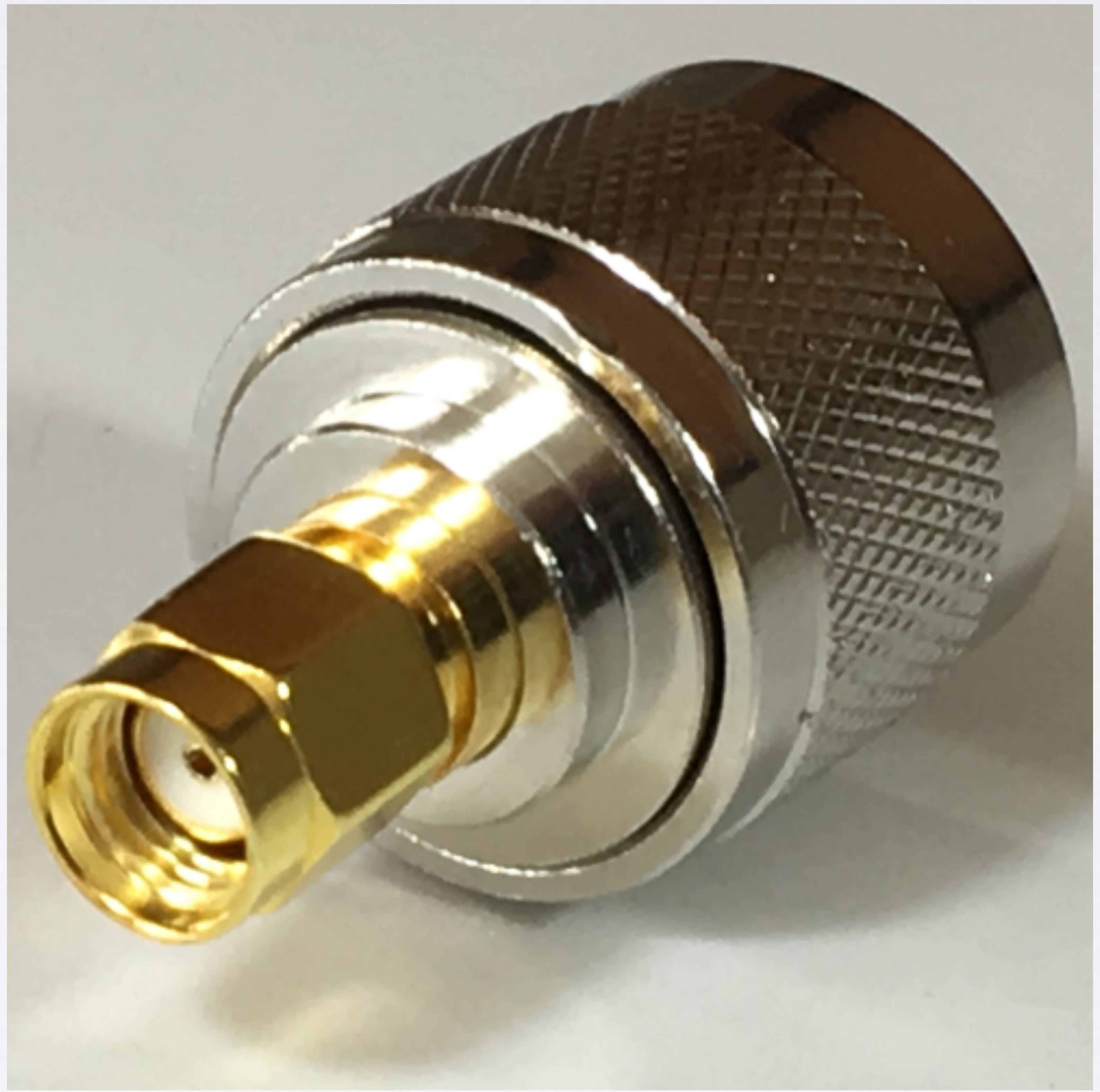




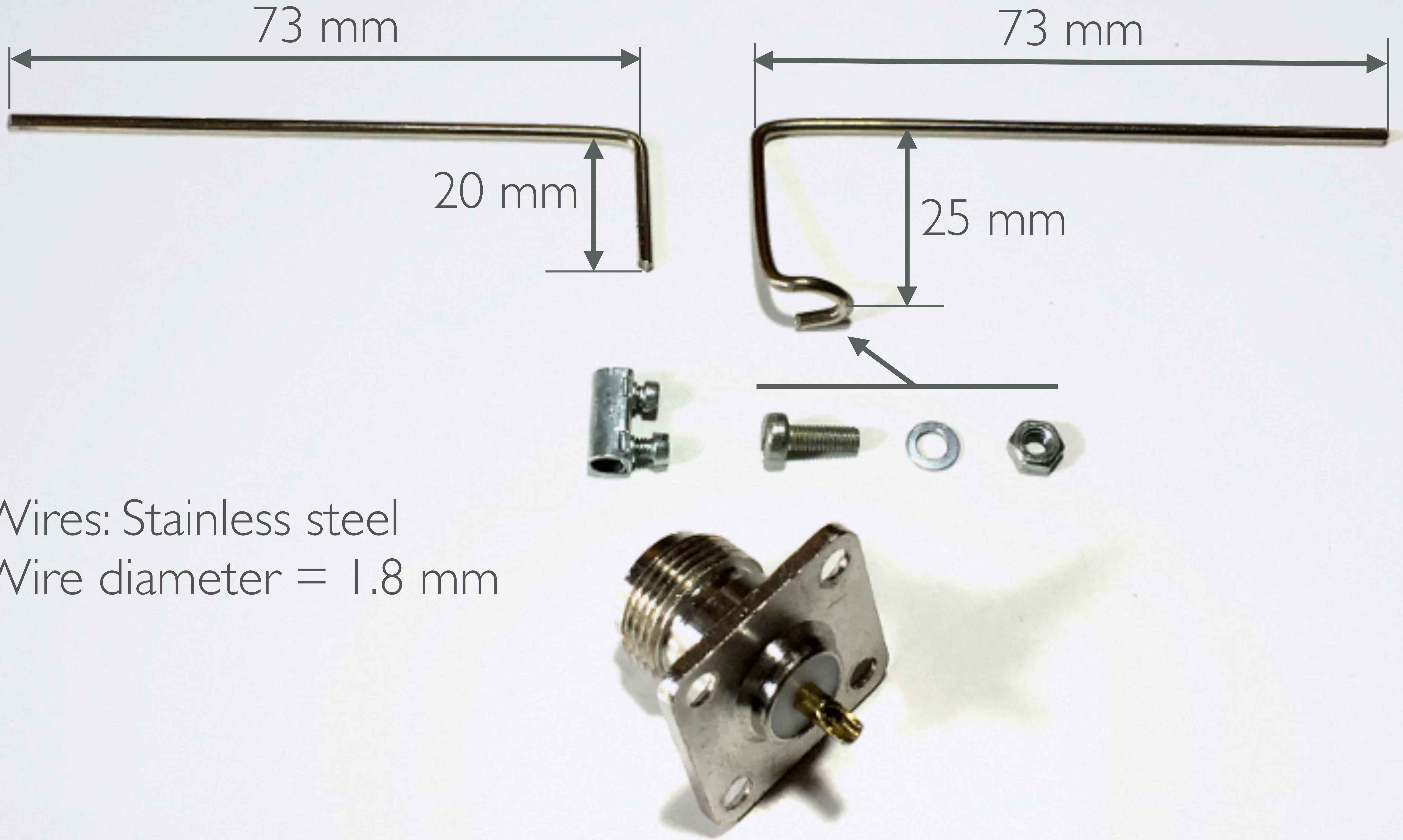
1/2 WAVE DIPOLE ANTENNA

- Type N male to RP-SMA male plug adapter coaxial cable connector.
  Impedance: 50Ω
  Cost: € 1.44



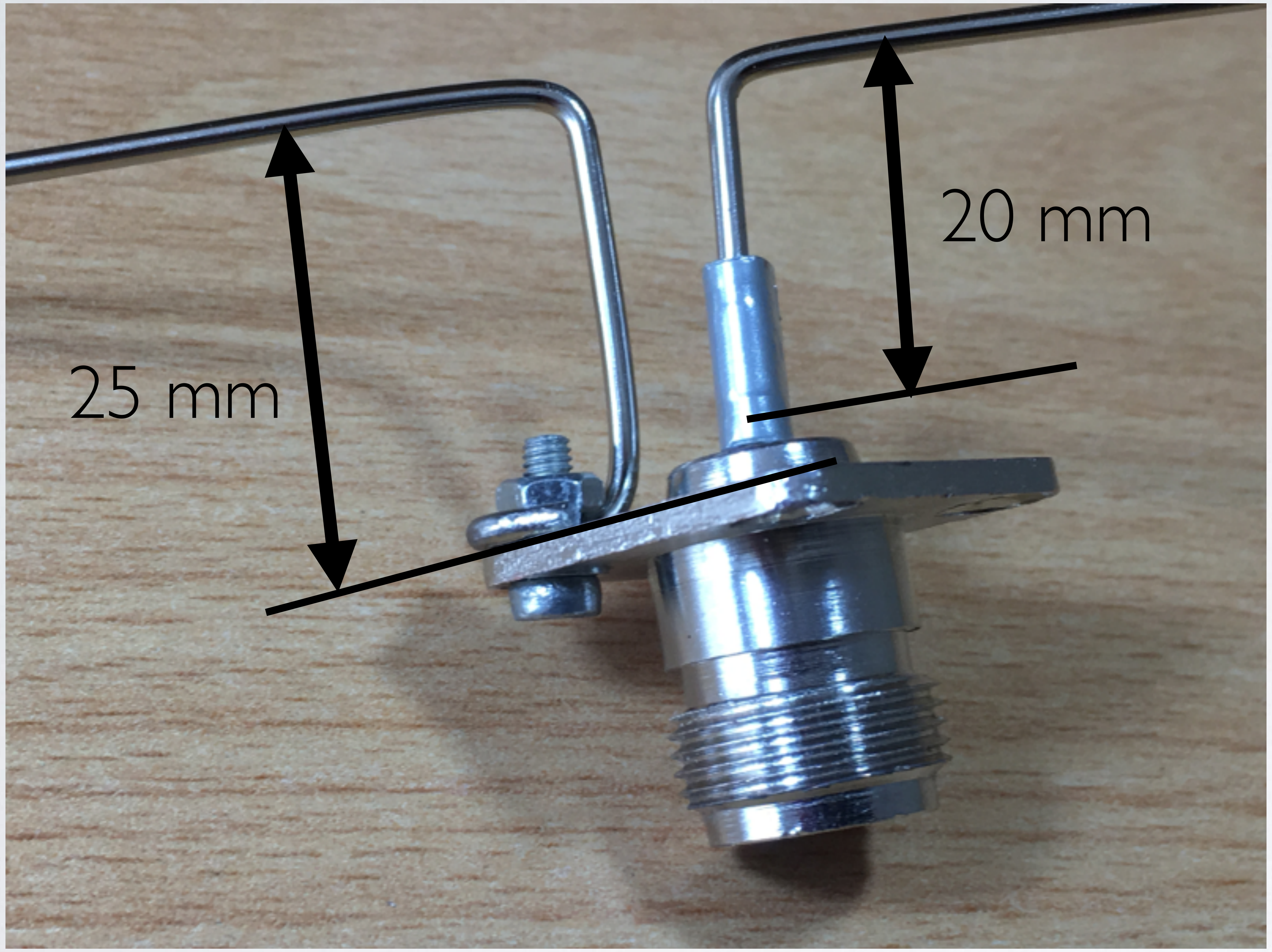


1/2 WAVE DIPOLE ANTENNA

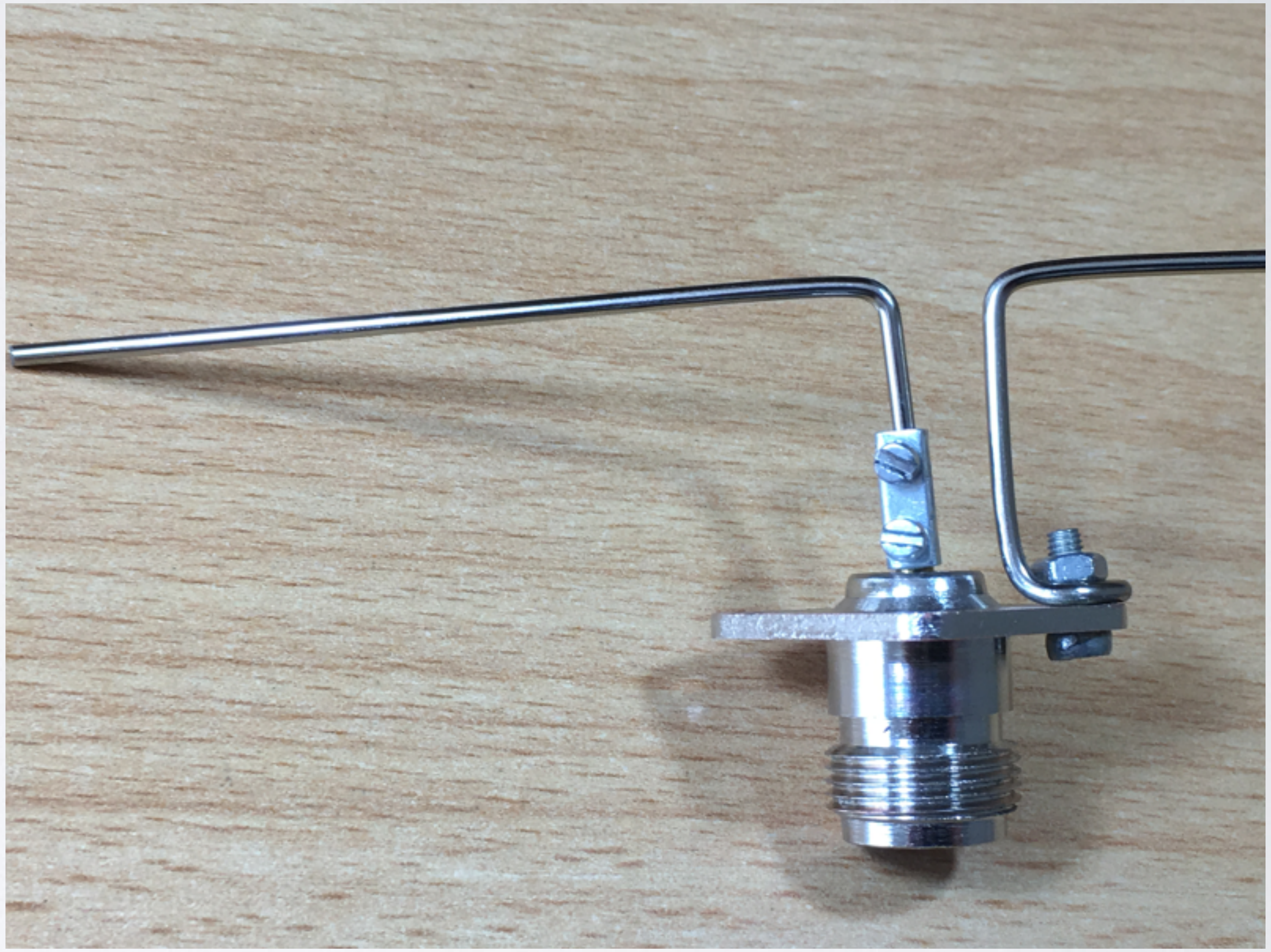


Wires: Stainless steel
Wire diameter = 1.8 mm

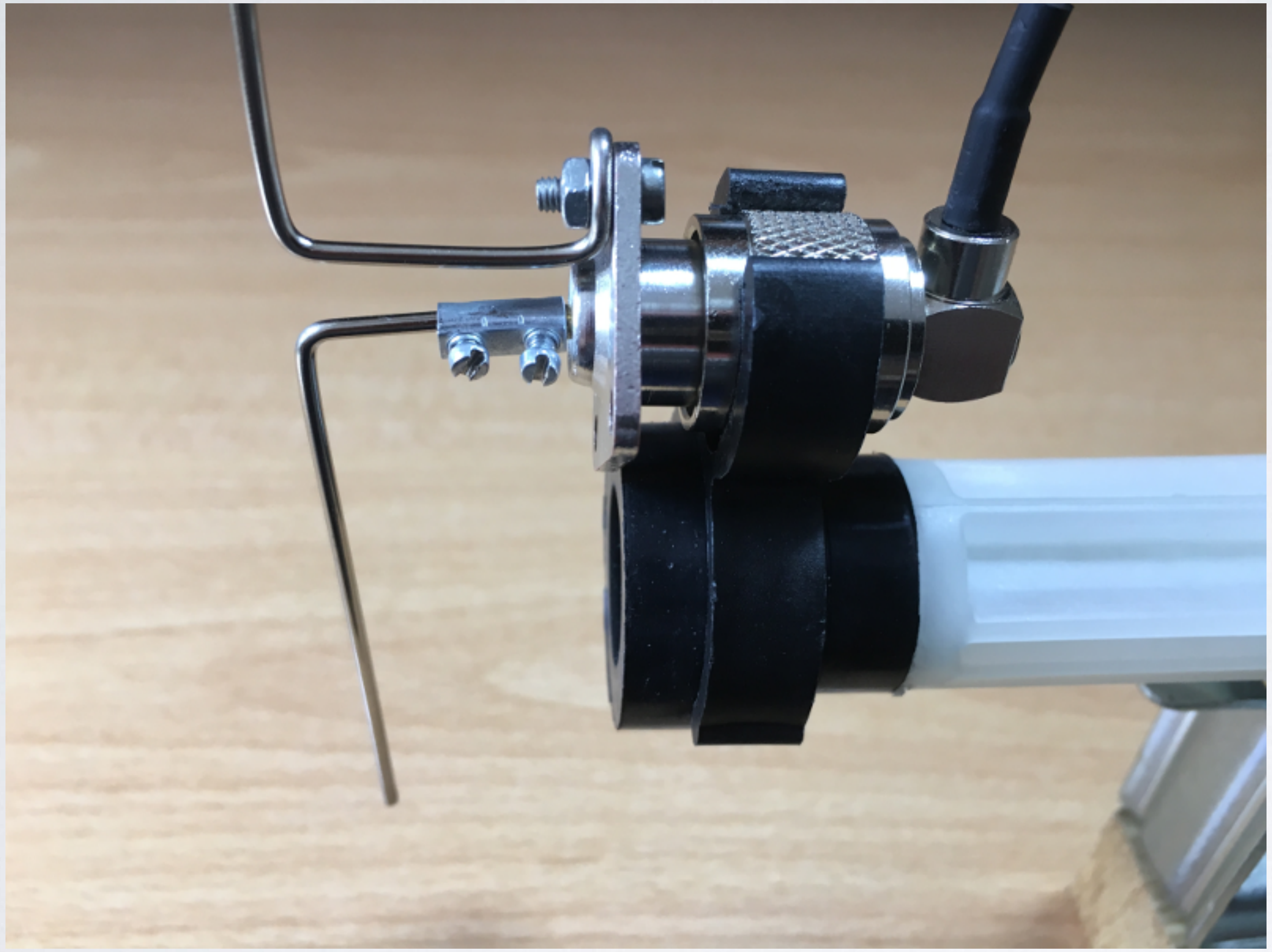
1/2 WAVE DIPOLE ANTENNA

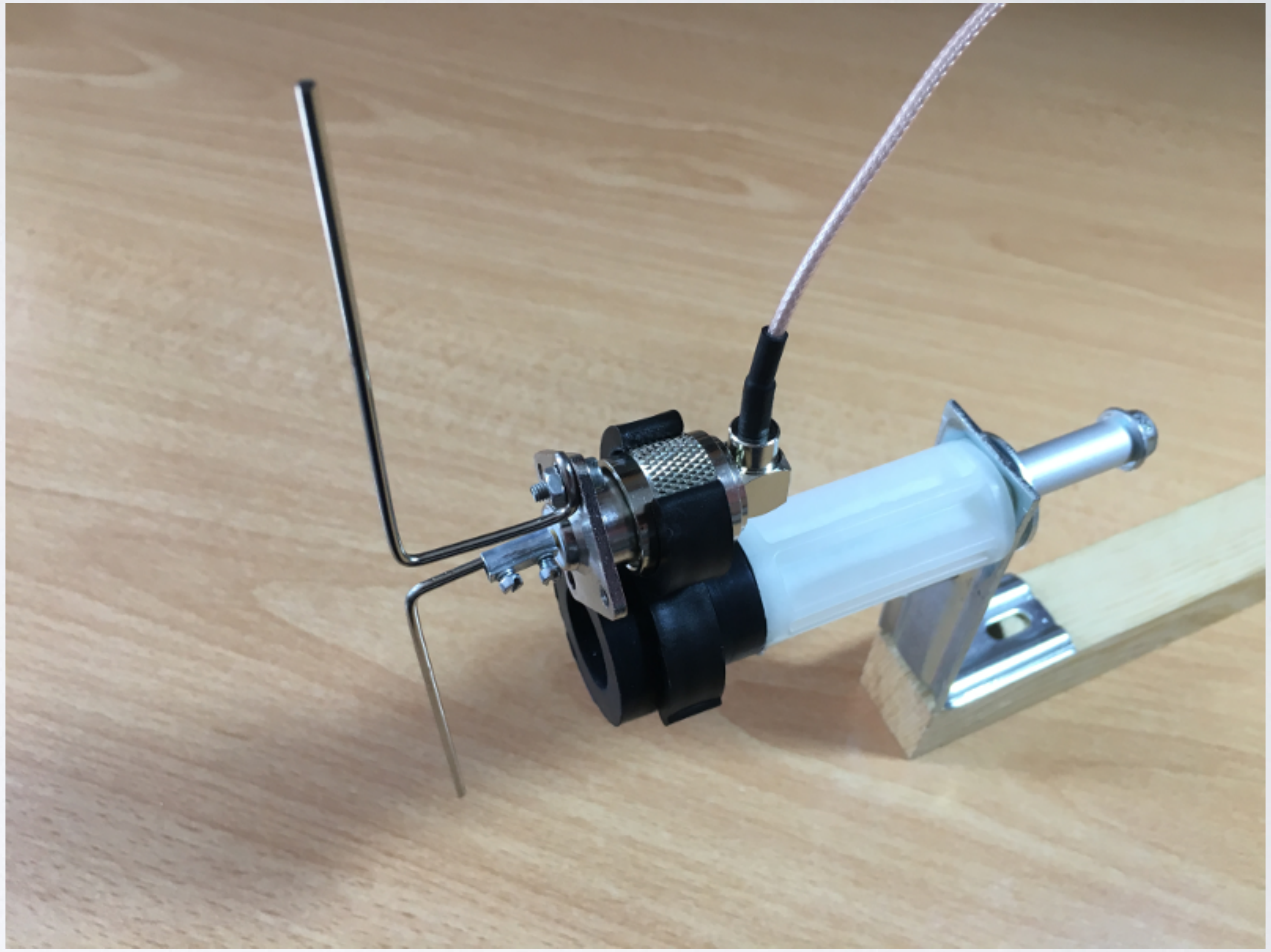


1/2 WAVE DIPOLE ANTENNA

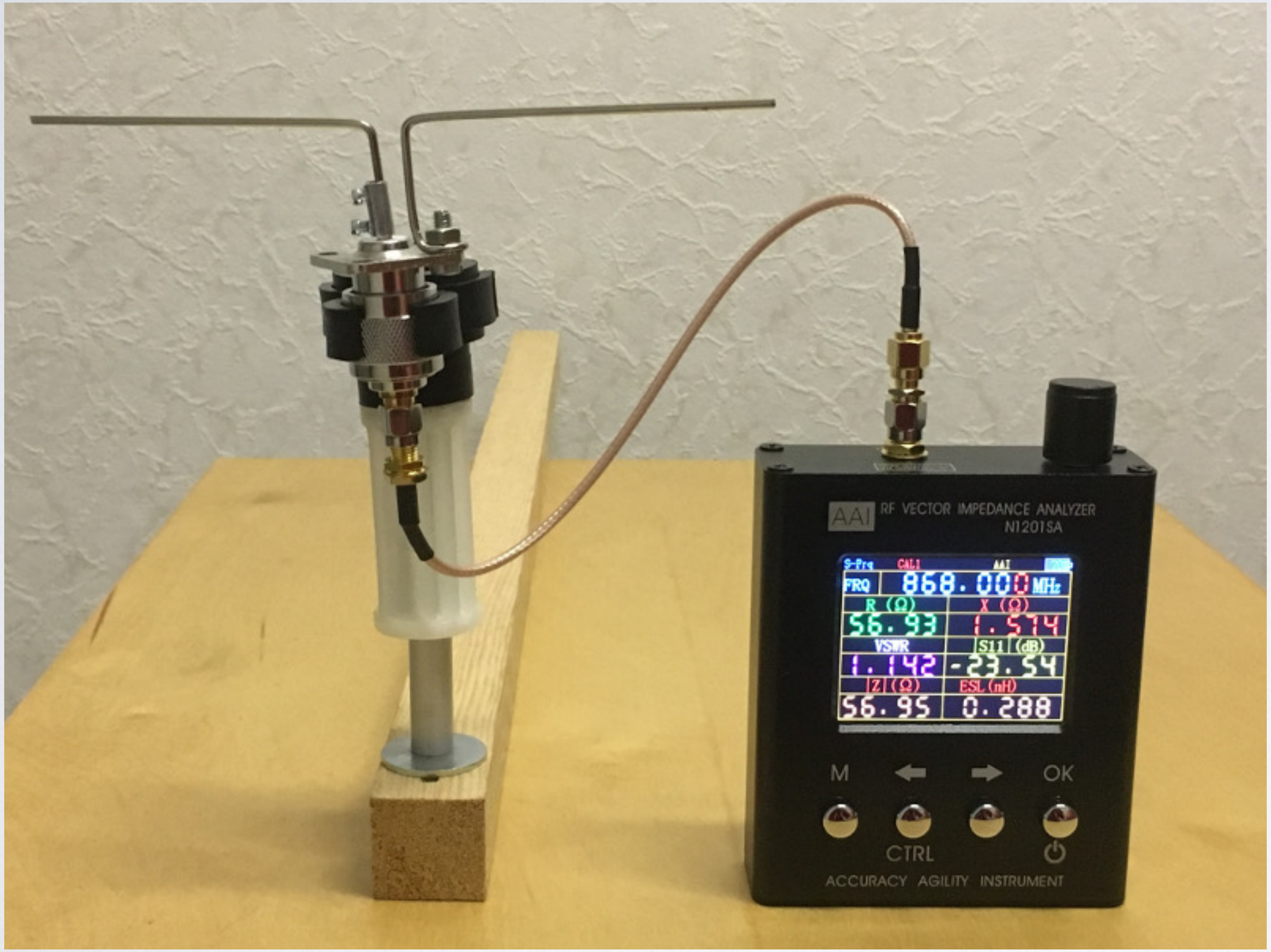


1/2 WAVE DIPOLE ANTENNA





1/2 WAVE DIPOLE ANTENNA



Dipole and antenna analyser connected by a coax cable.

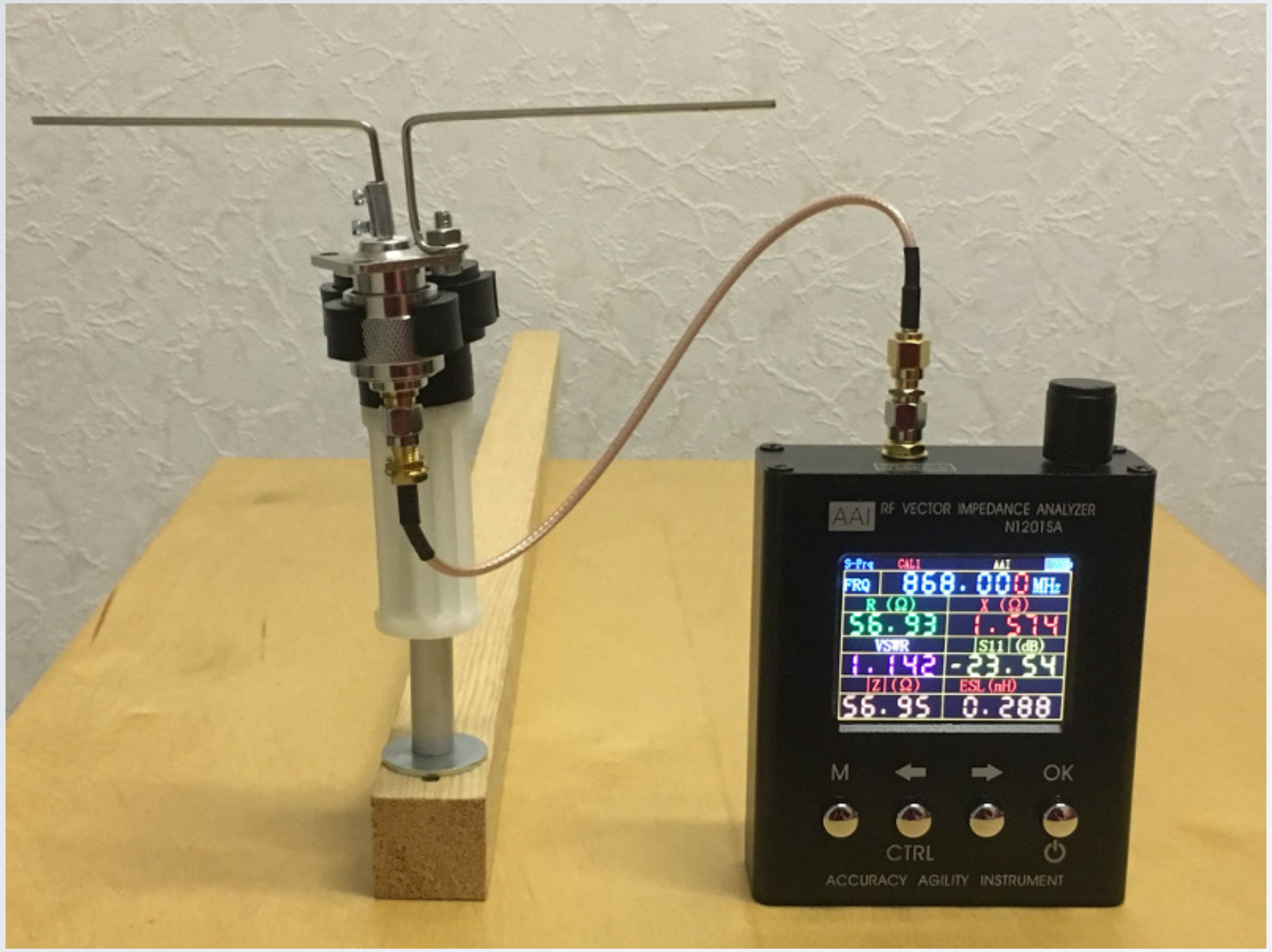
VSWR = 1.142

1/2 WAVE DIPOLE ANTENNA

Dipole and antenna analyser connected to each other without using a coax cable.

VSWR = 1.327

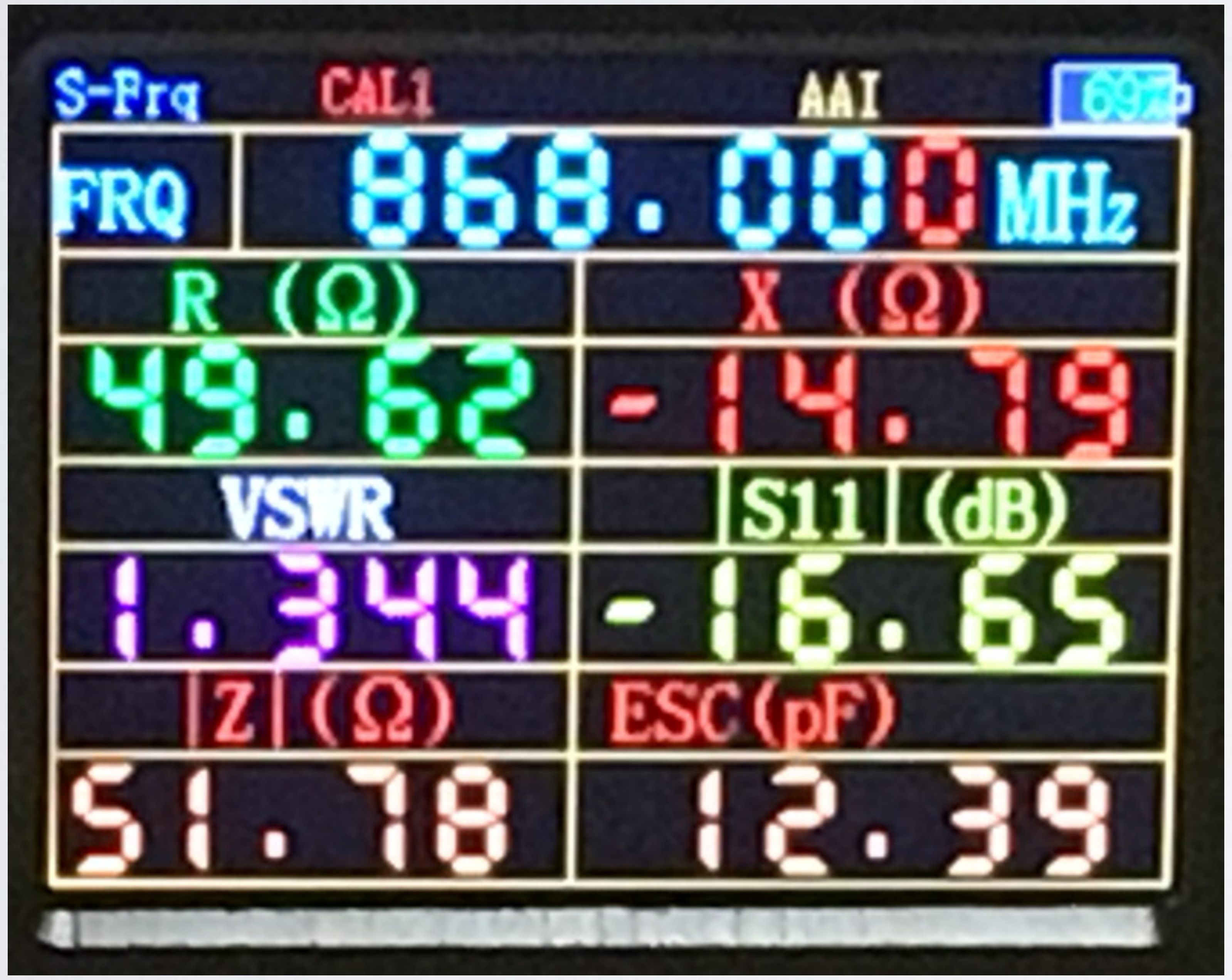
1/2 WAVE DIPOLE ANTENNA



It is recommended to connect the antenna directly to the antenna analyser without using a coax cable. A cable may influence the measurements.

MEASURED ANTENNA PARAMETERS

- In **MY** situation I got the following results:
  VSWR ≈ 1.3 ← Good. It is < 2
  Z ≈ 52Ω ← Good. Should be approx. 50Ω
  S11 ≈ -17 dB



Dipole and antenna analyser connected to each other without using a coax cable.

MEASURED ANTENNA PARAMETERS

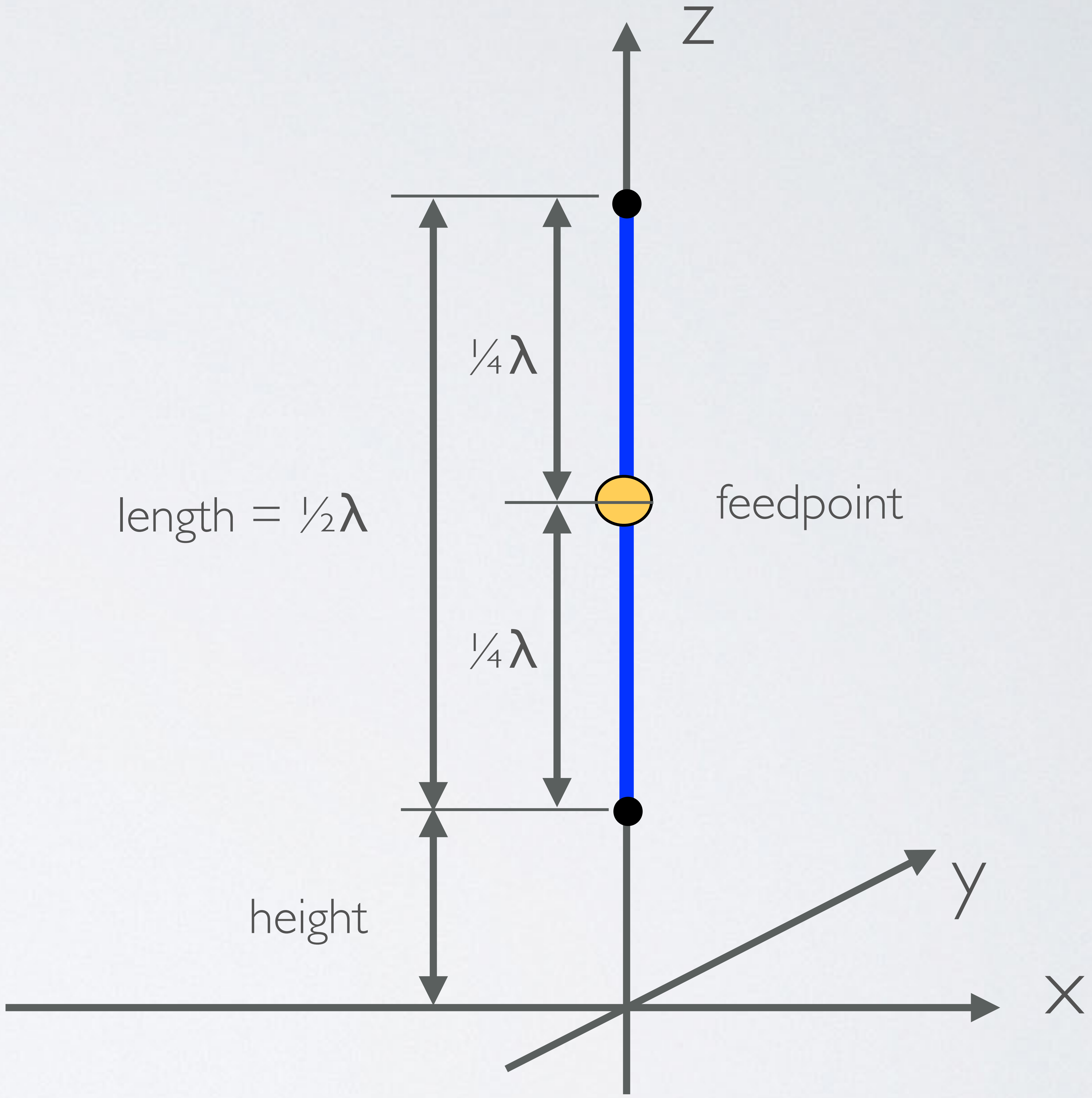
mobilefish.com

ANTENNA MODELLING 4NEC2

- Antenna parameters:
  f = 868 MHz
  wire material = stainless steel
  wire diameter = 1.8 mm
  wire radius = 0.9 mm = 0.0009 m
  height = 11 m
  length = 0.155 m
  ground type: real ground
  (City industrial area)

- Length = 0.155 m, VSWR=1.67

- Antenna model optimised:
  Length = 0.160 m, VSWR = 1.43



Coordinates in meters

ANTENNA MODELLING 4NEC2

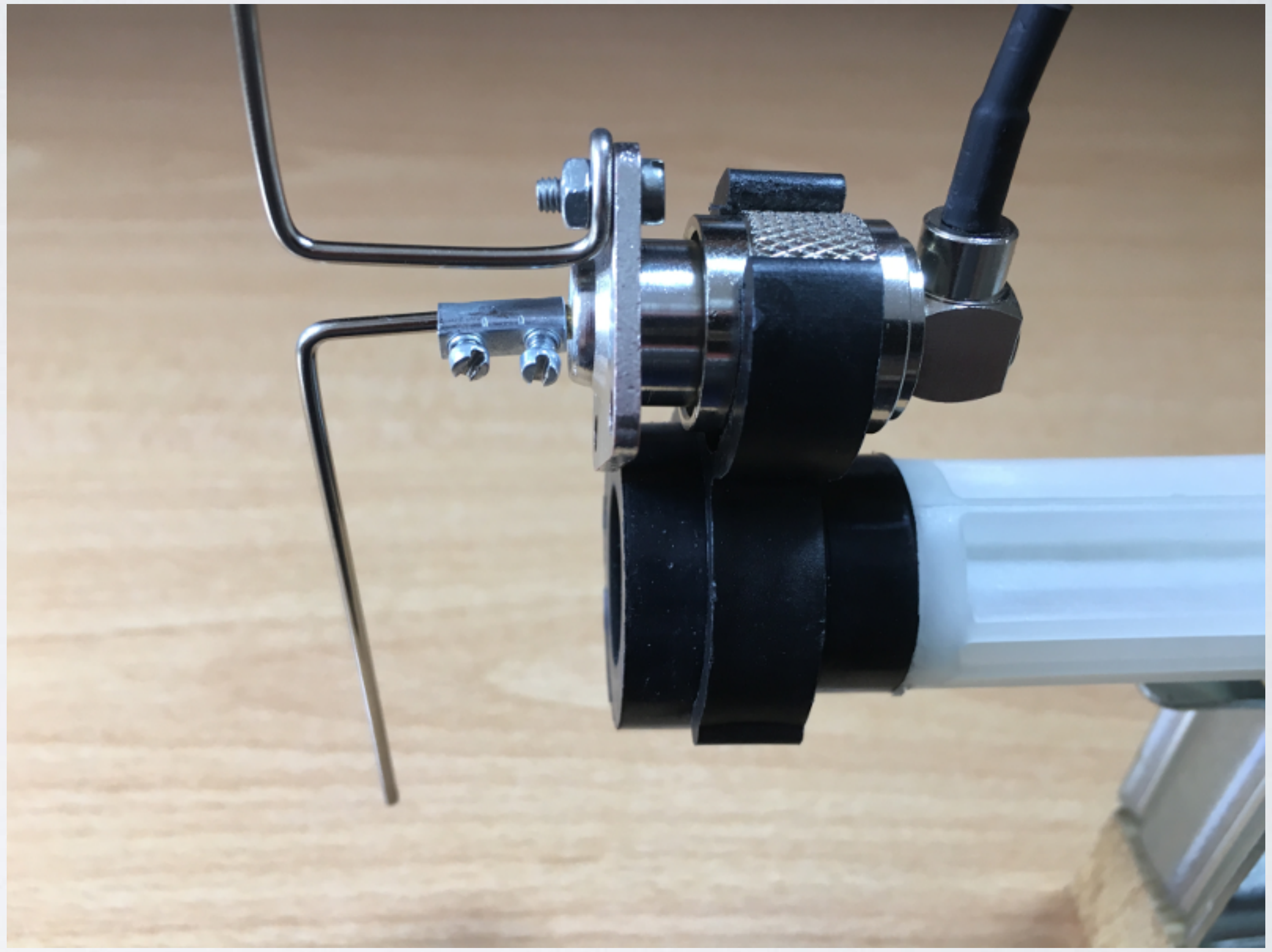
- 4NEC2 card deck: https://www.mobilefish.com/download/lora/dipole_vertical_868mhz_4nec2.nec.txt
- Note: Initially the length was set to 0.155 m then I used the 4NEC2 optimising functionality to improve the design. The optimised length = 0.160 m.

ANTENNA MODELLING 4NEC2

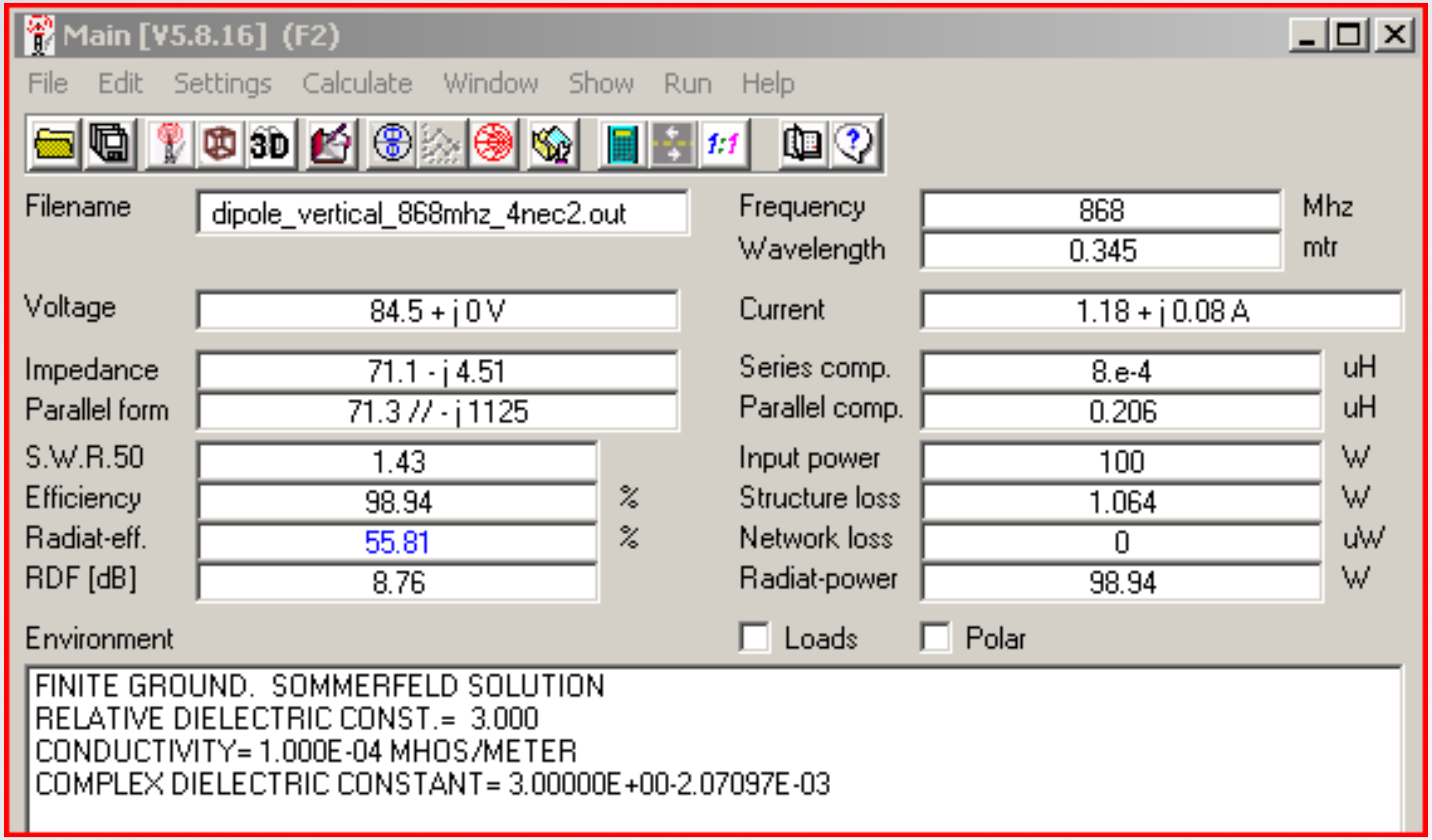
- The 4NEC2 model element length = 160 mm.

- The real ½λ dipole antenna length = 146 mm (= 2 x 73 mm).
  I used the N1201SA Vector Impedance Analyser to tune the antenna.

- Why this discrepancy?
  The real antenna is not 100% accurately modelled in the 4NEC2 program.
  Think of the gap between the elements, terminal with screws, the type N female chassis.
  All these influences the antenna behaviour.

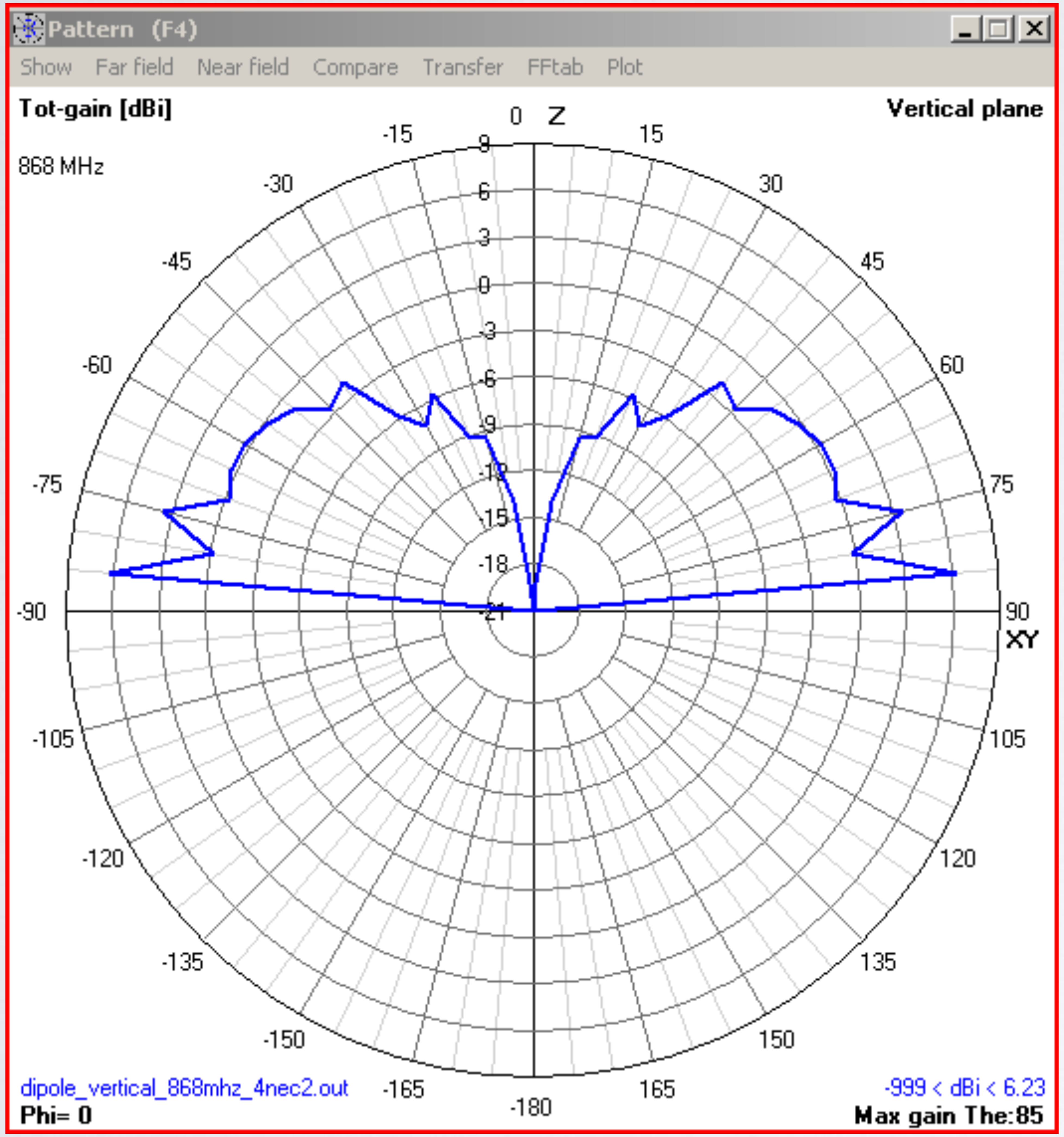


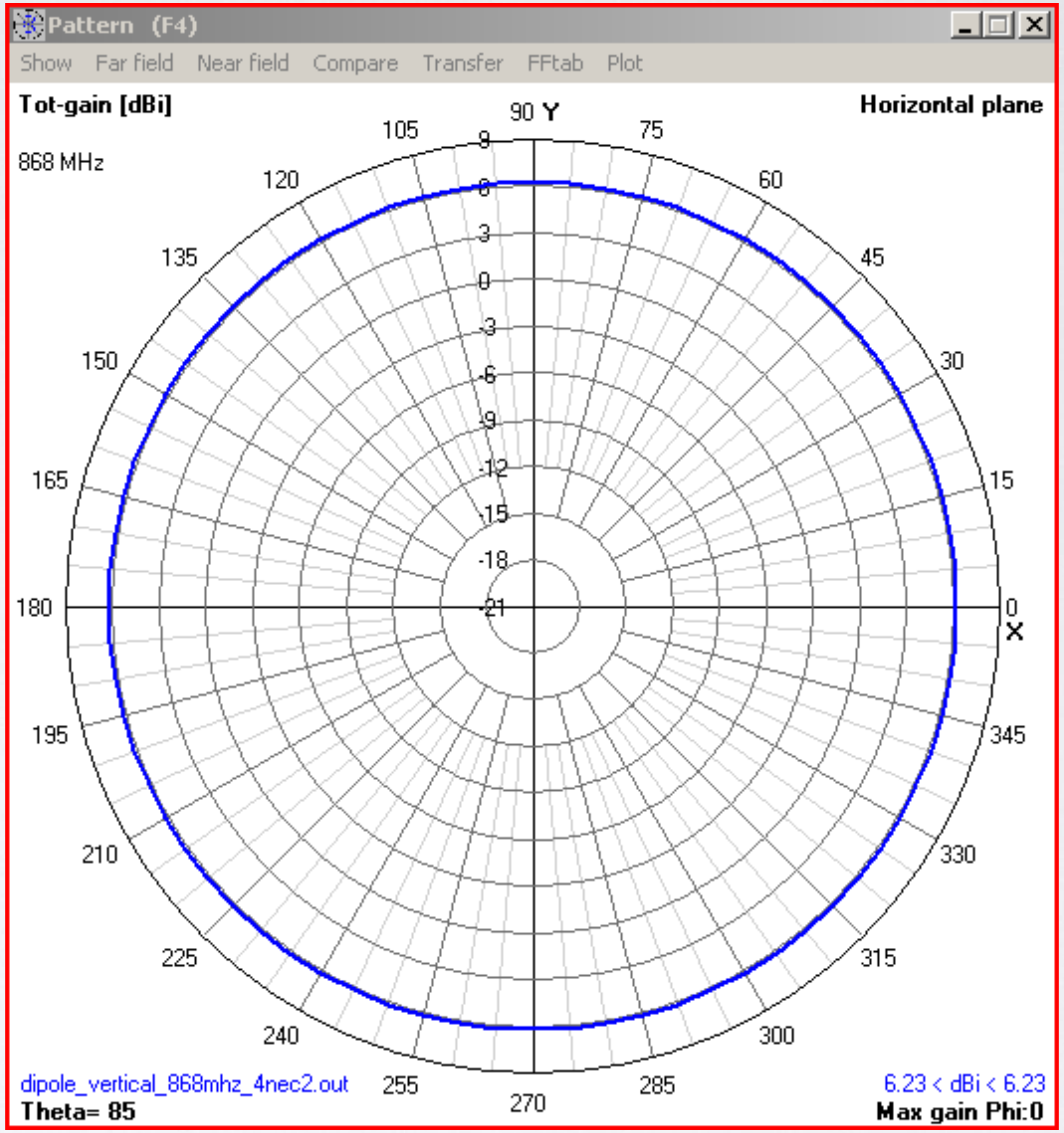
ANTENNA MODELLING 4NEC2



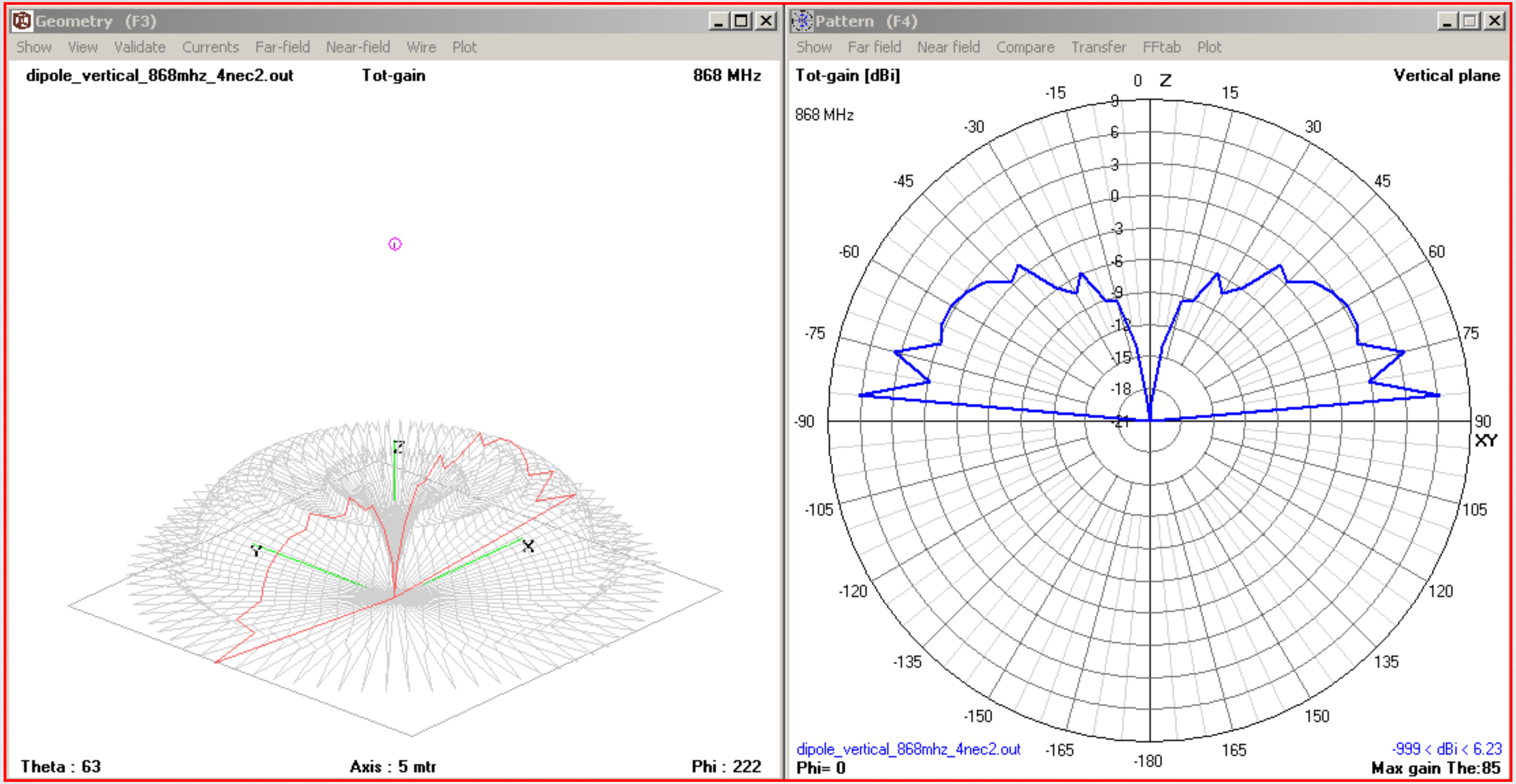
length = 0.160 m

ANTENNA MODELLING 4NEC2

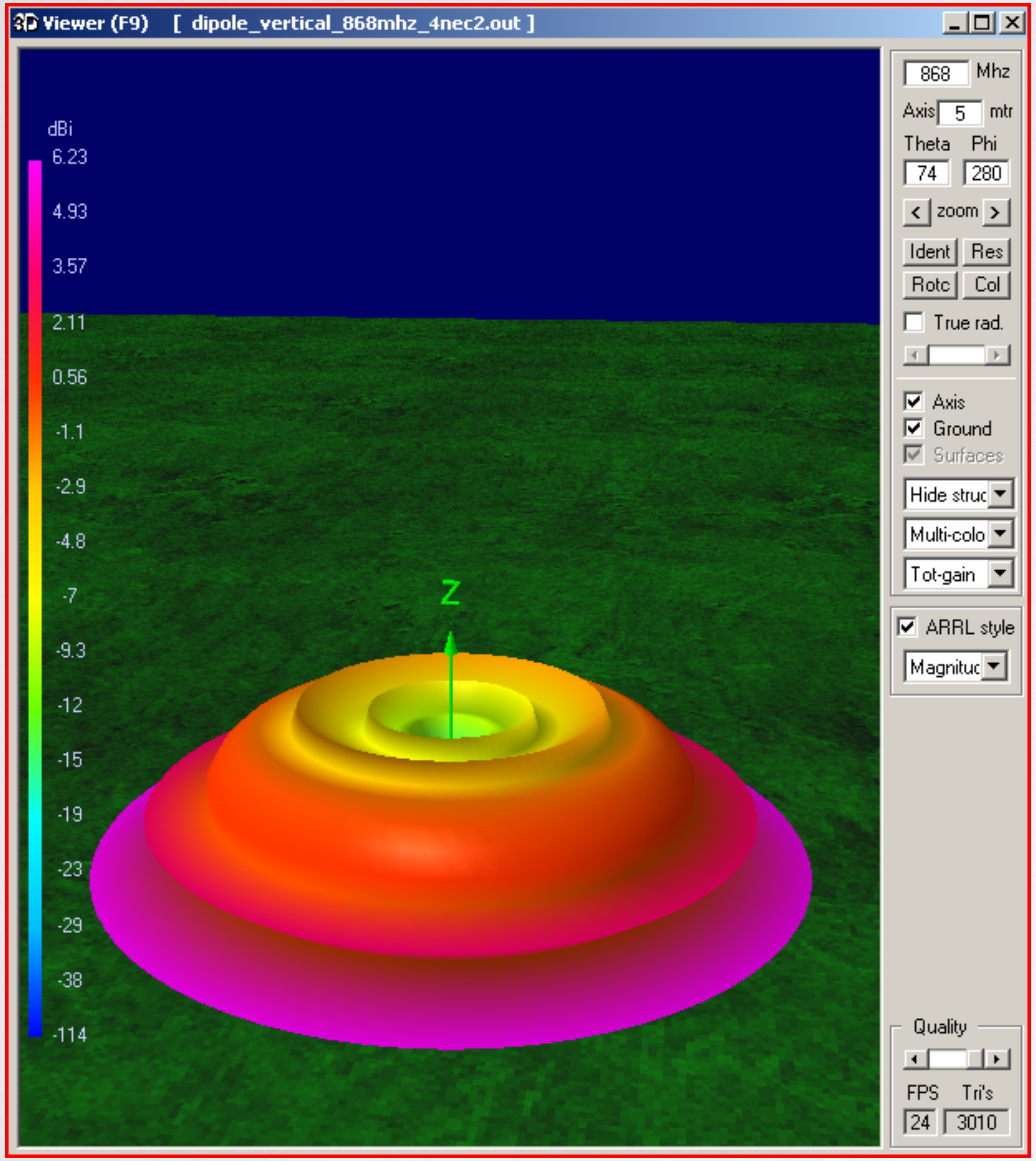




ANTENNA MODELLING 4NEC2



ANTENNA MODELLING 4NEC2

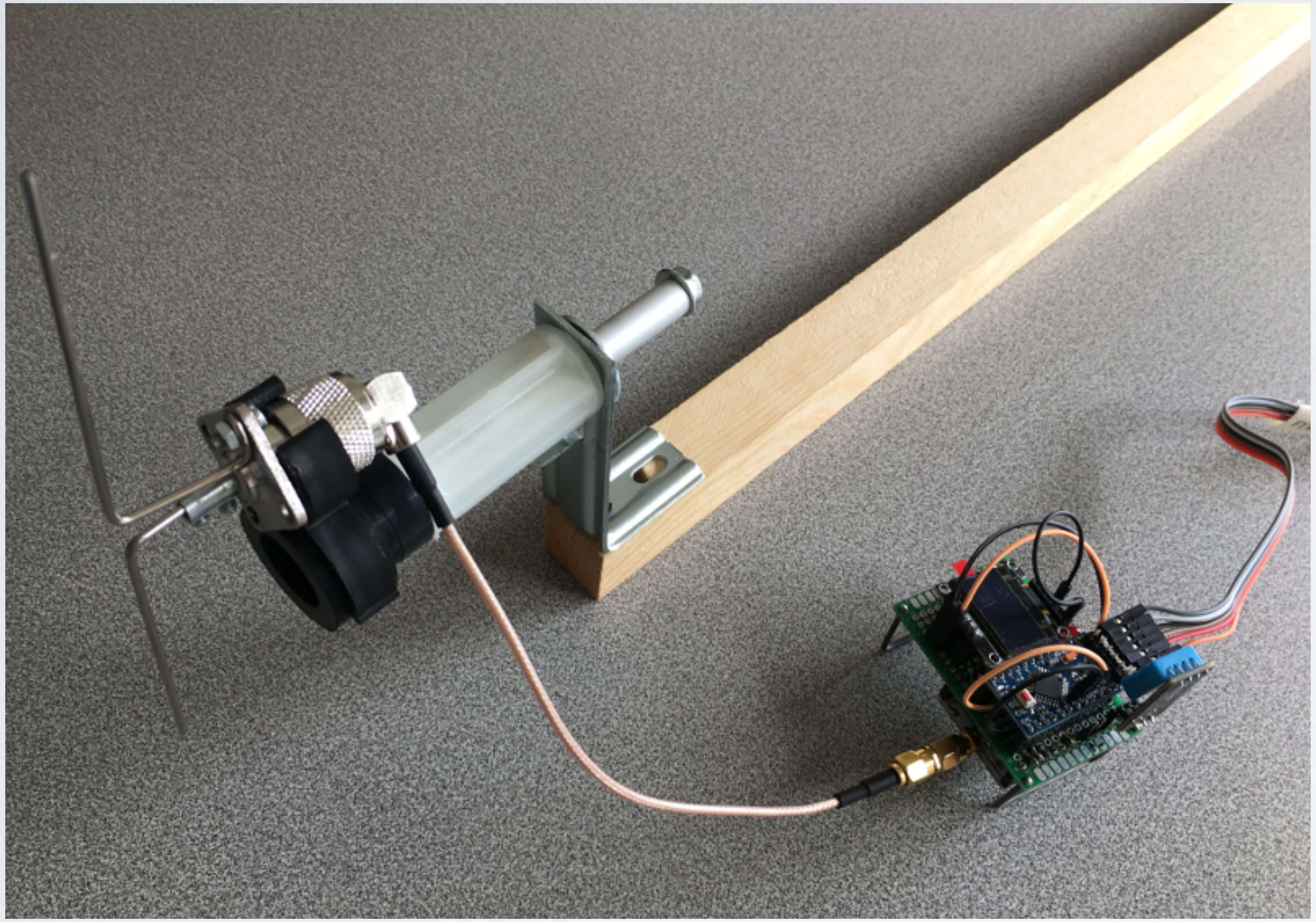


- Please be aware that the generated radiation patterns are merely a ROUGH indication how the real dipole antenna behaves.
- As explained earlier the real ½λ dipole is not 100% accurately modelled.
- If you want accurate radiation patterns of real antennas than the antenna radiation patterns measurements should be performed in an anechoic chamber.

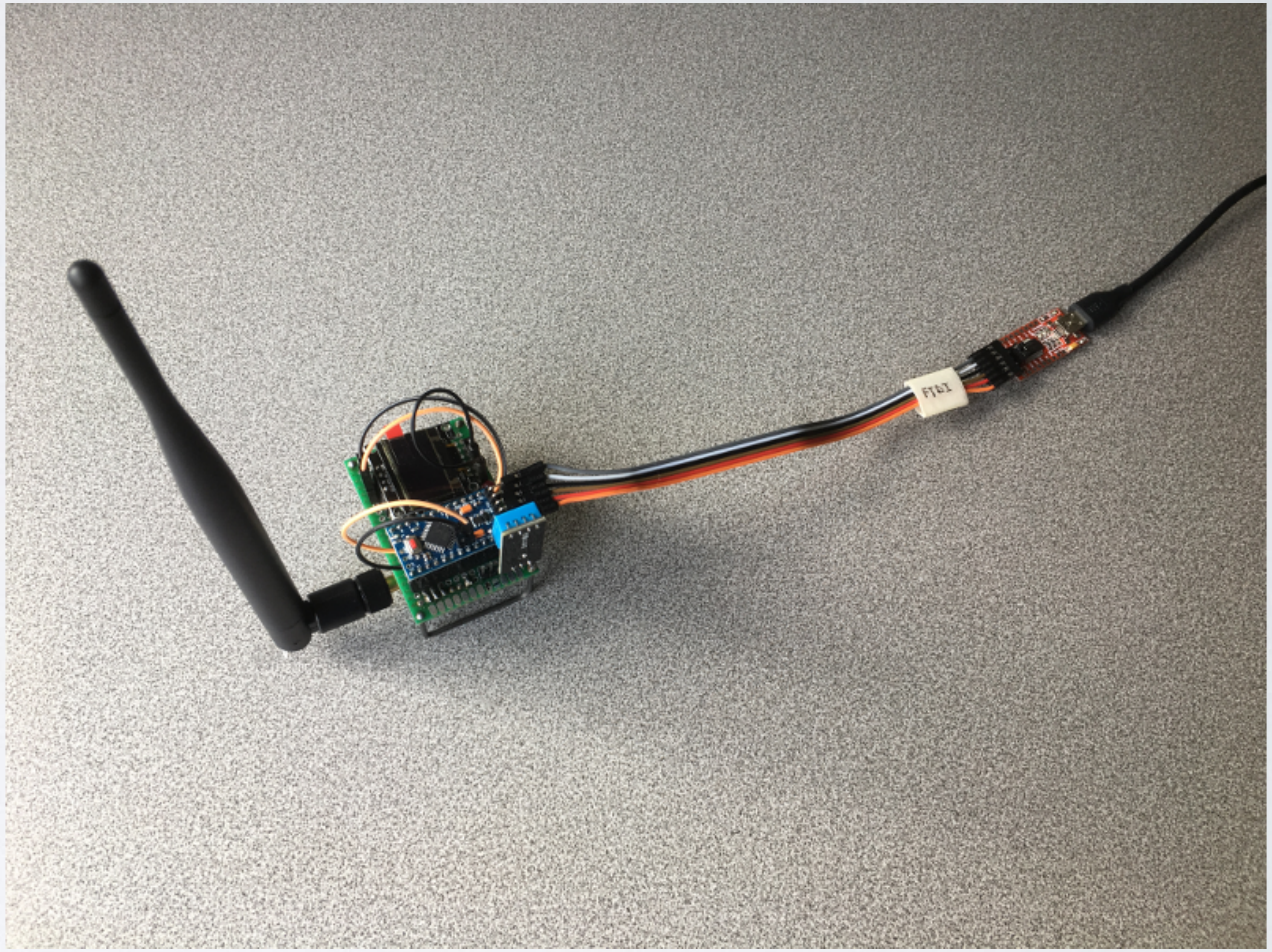
ANTENNA TEST SETUP

- The ½λ dipole 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

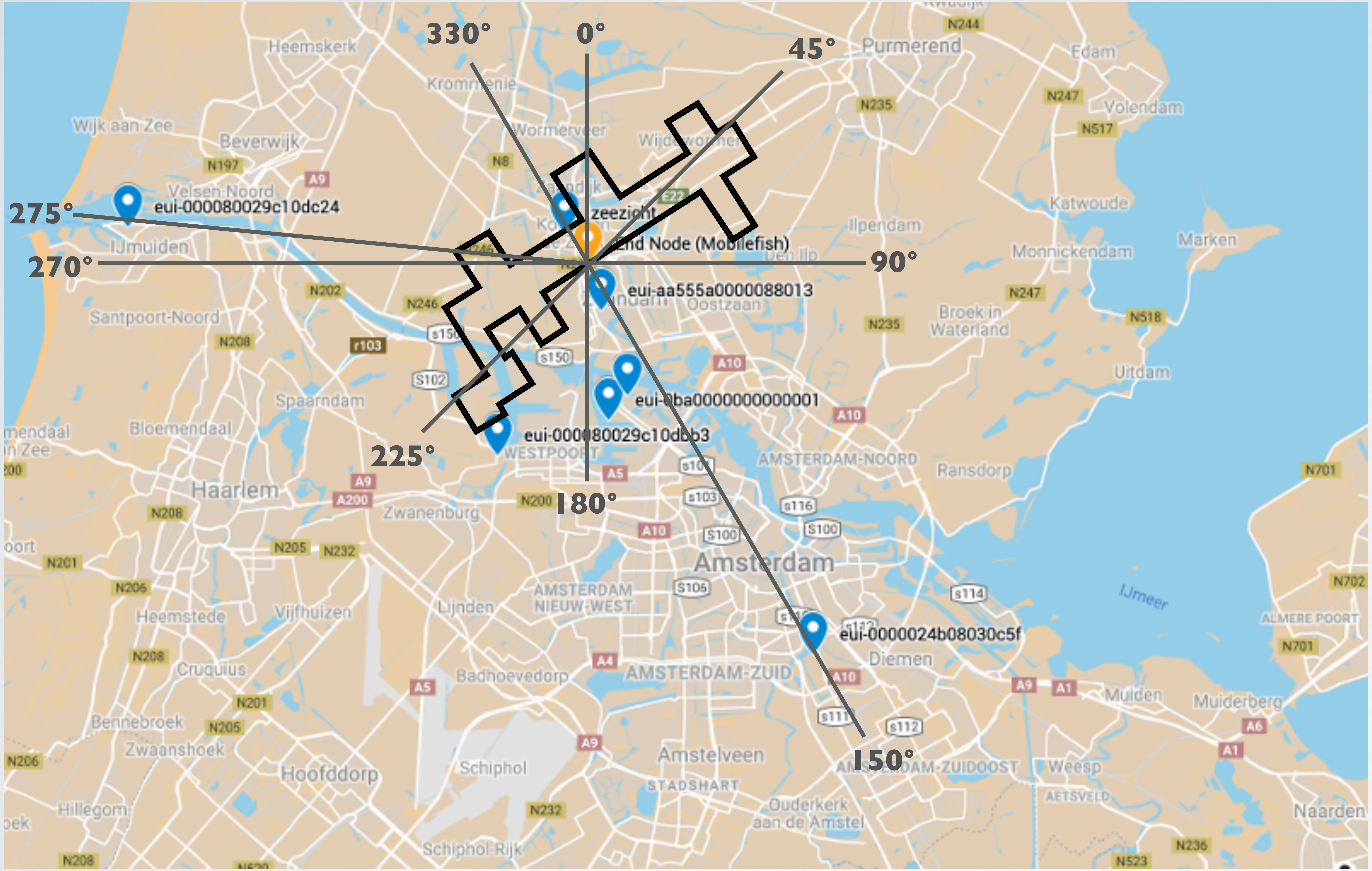


½λ dipole and end node connected by a coax cable



Sleeve dipole and 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

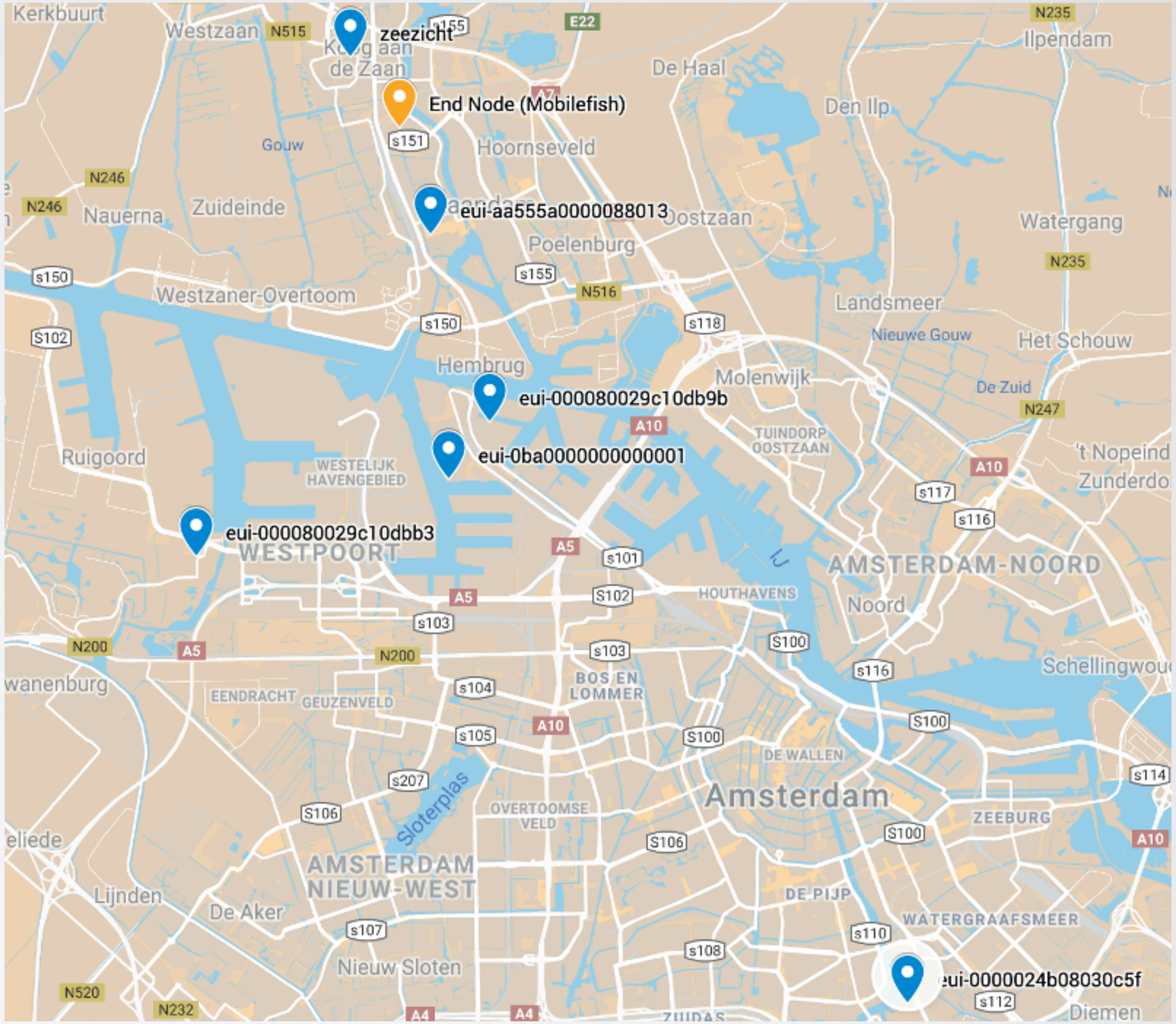
Location B, facing West and North. Altitude = ~11m

ANTENNA TEST SETUP

- I have NOT modified the end node transmission power when using the ½λ dipole 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 ½λ dipole antenna is attached to an end node at location A and transmitted data and I have done the same with a 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/dipole_test_results.txt

ANTENNA TEST RESULTS

- Several nearby gateways were able to receive my transmitted sensor data, see: https://drive.google.com/open?id=18SKbHVElFHU6YjzYpgZL98vuHcmV4OPQ&usp=sharing



ANTENNA TEST RESULTS

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

Gateway	Distance from end device [km]	Altitude [m]	½λ dipole Average RSSI [dBm]	½λ dipole Average SNR [-]	Sleeve dipole Average RSSI [dBm]	Sleeve dipole Average SNR [-]
eui-aa555a0000088013	1.57	42	**-118.6**	**-4.67**	**-118.1**	**-4.3**
eui-0000024b08030c5f	14.4	20	-116 *	-8.5*	-	
eui-000080029c10dc24	14.7	45	-		-120.3 *	-7.025 *
eui-000080029c10db9b	4.36	30	-		-120 *	

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

ANTENNA TEST RESULTS

- If you only look at the eui-aa555a0000088013 gateway results you may notice there is no significant difference in the average RSSI and SNR values.

- But if you look at the time it took to transmit 15 messages there is a difference.

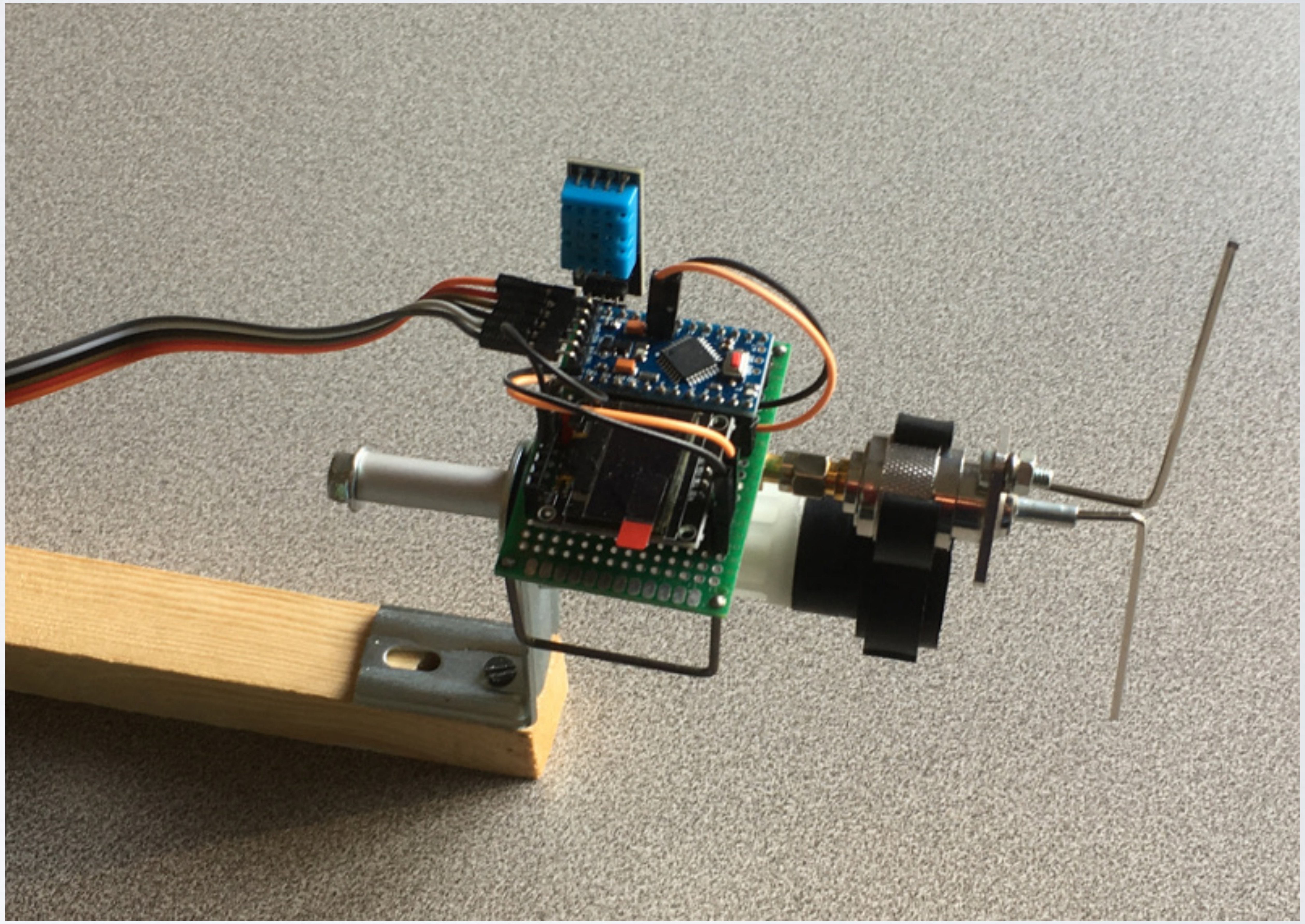
- When using the ½λ dipole antenna it took 18 minutes to transmit 15 messages. When using the sleeve dipole antenna, which is my reference antenna, it took 10 minutes to transmit 15 messages.

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

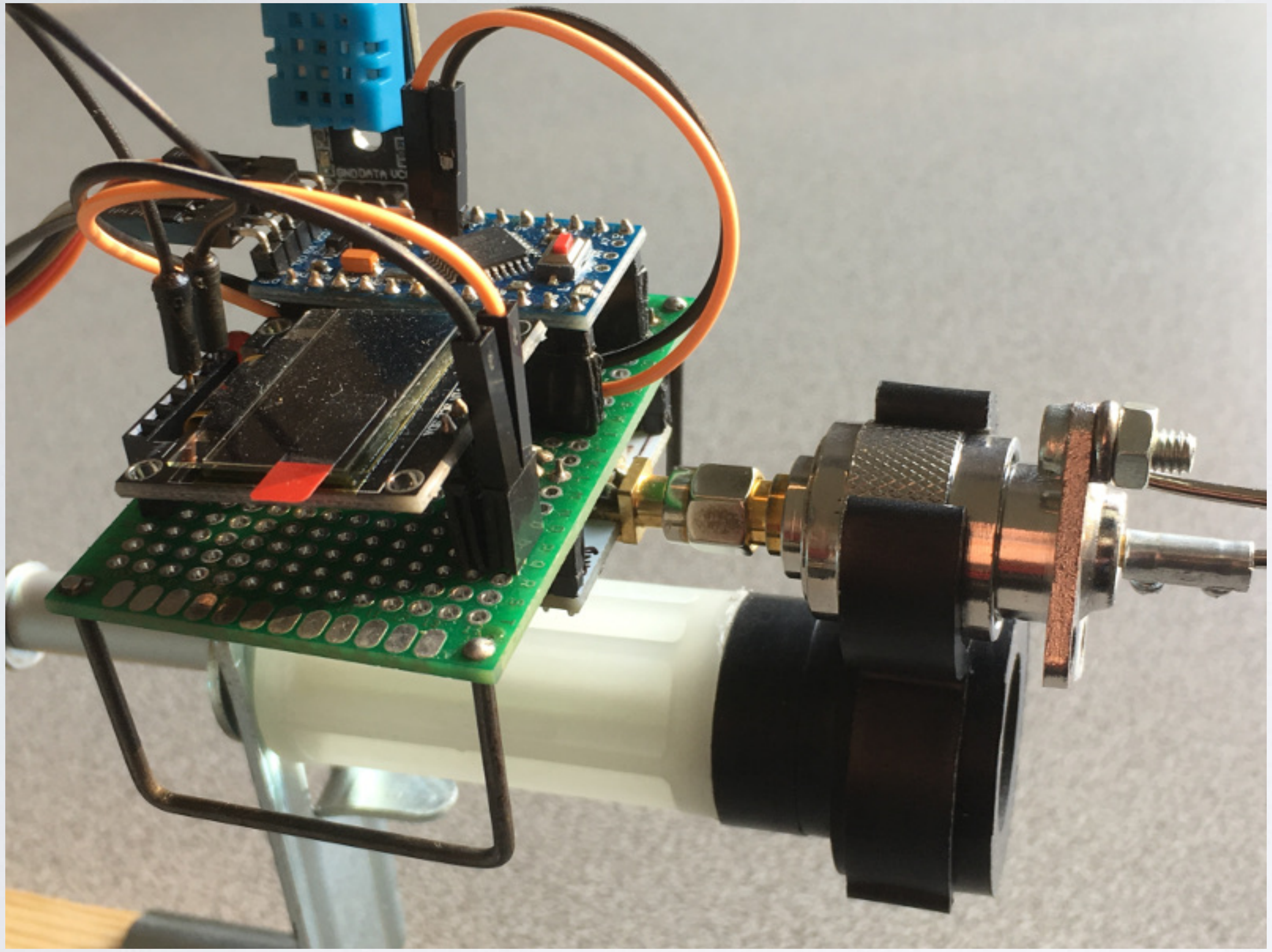
ANTENNA TEST RESULTS

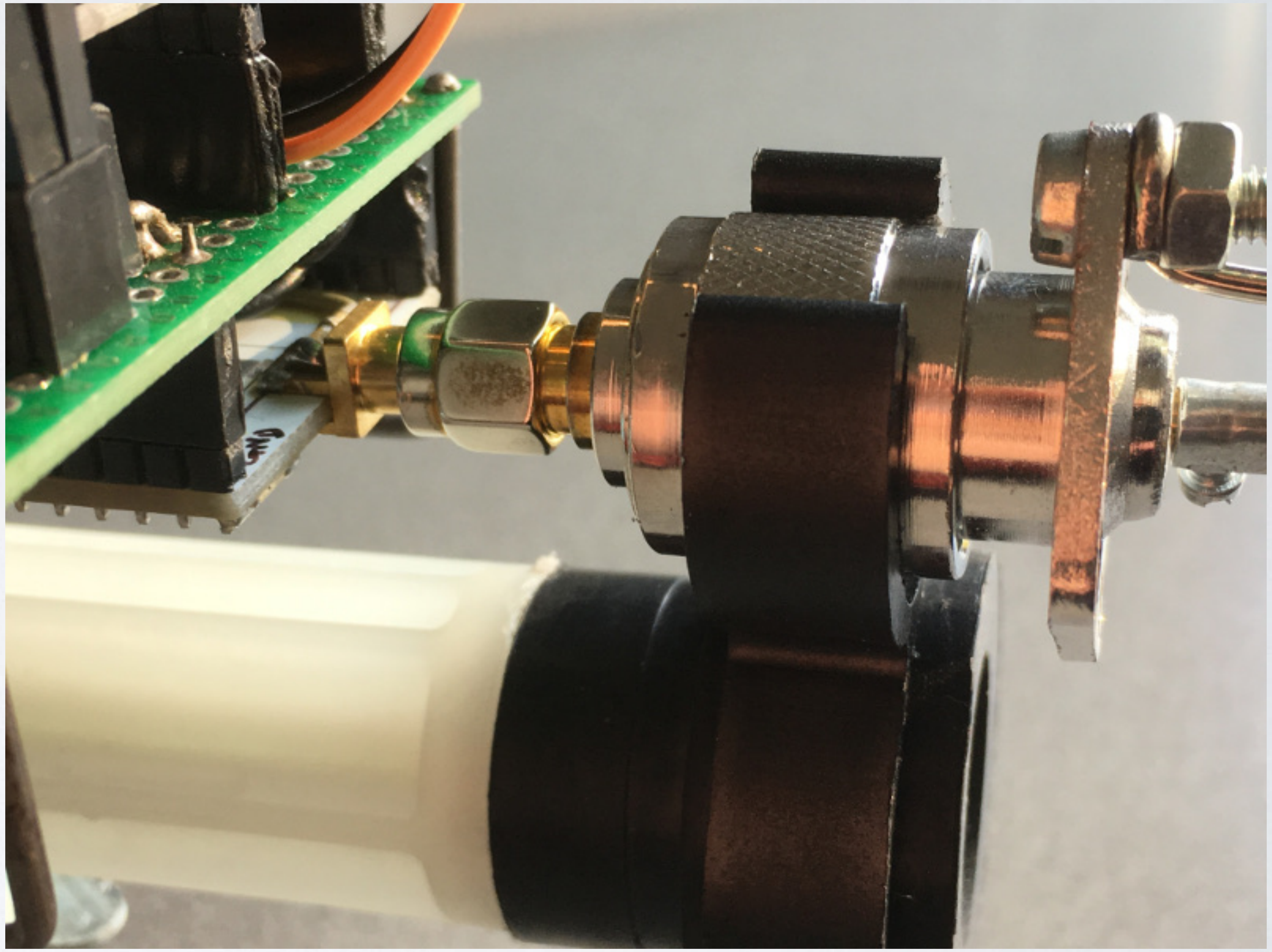
- The problem might be caused by the RF coaxial cable with type N male plug right angle to SMA male connector.

- I have conducted another test whereby the ½λ dipole antenna is directly connected to the end device. No coax cable is used.



ANTENNA TEST RESULTS





ANTENNA TEST RESULTS

- Again the same tests were conducted using the same ½λ dipole antenna and sleeve dipole antenna at location A.

- Two messages per minute were transmitted and both logged data can be found at: https://www.mobilefish.com/download/lora/dipole_test_results2.txt

- Note: The tests were conducted approximately 1.5 months later.

ANTENNA TEST RESULTS

- End node tx power = 14 dBm
  Data from: dipole_test_results2.txt

Gateway	Distance from end device [km]	Altitude [m]	½λ dipole Average RSSI [dBm]	½λ dipole Average SNR [-]	Sleeve dipole Average RSSI [dBm]	Sleeve dipole Average SNR [-]
eui-aa555a0000088013	1.57	42	-117 *	-8.8 *	-	-
eui-000080029c10db9b	4.36	30	-121 *	-8 *	-	-
eui-0ba0000000000001	5.02	20	**-119.2**	**-5.46**	**-119.4**	**-6.9**
eui-60c5a8fffe760e60	4.15	30	-113 *	-5 *	-113.6 *	-5.42 *
eui-dca632fffe43df3e	0.458	10	**-104.8**	**4.81**	**-104.9**	**4.37**
eui-b827ebfffedcc77d	0.816	7	-114 *	-9.2 *	-	-

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

ANTENNA TEST RESULTS

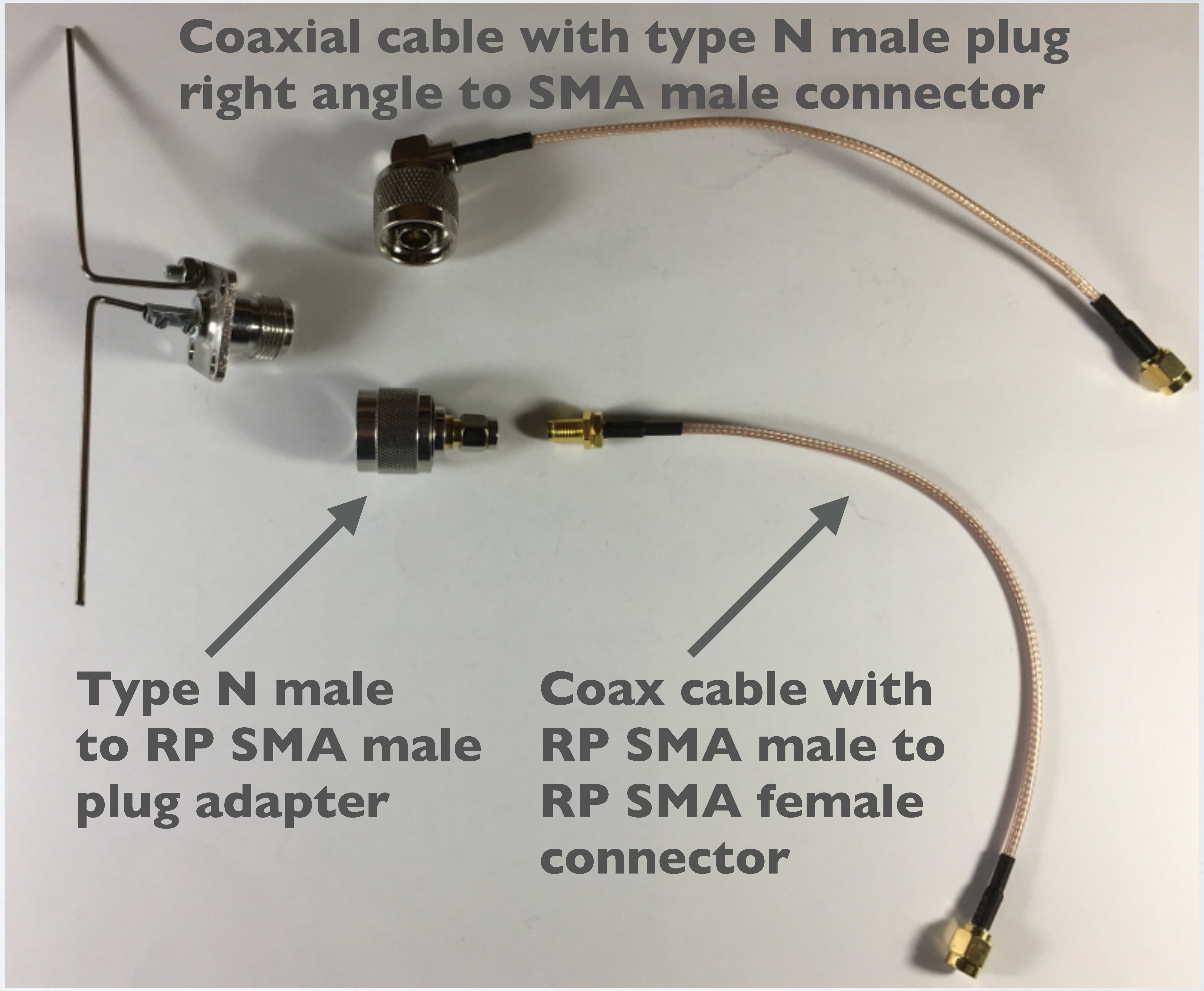
- If you only look at the eui-0ba0000000000001 and eui-dca632fffe43df3e gateway results you may notice there is no significant difference in the average RSSI and SNR values.

- Also if you look at the time it took to transmit 15 messages there is no large difference.

- When using the ½λ dipole antenna it took 11.5 minutes to transmit 15 messages. When using the sleeve dipole antenna, it took 12.5 minutes to transmit 15 messages.

ANTENNA TEST RESULTS

- The RF coaxial cable with type N male plug right angle to SMA male connector is probably not working correctly.
- I have replaced it with another setup.
- Now it took 9 minutes to transmit 15 messages.

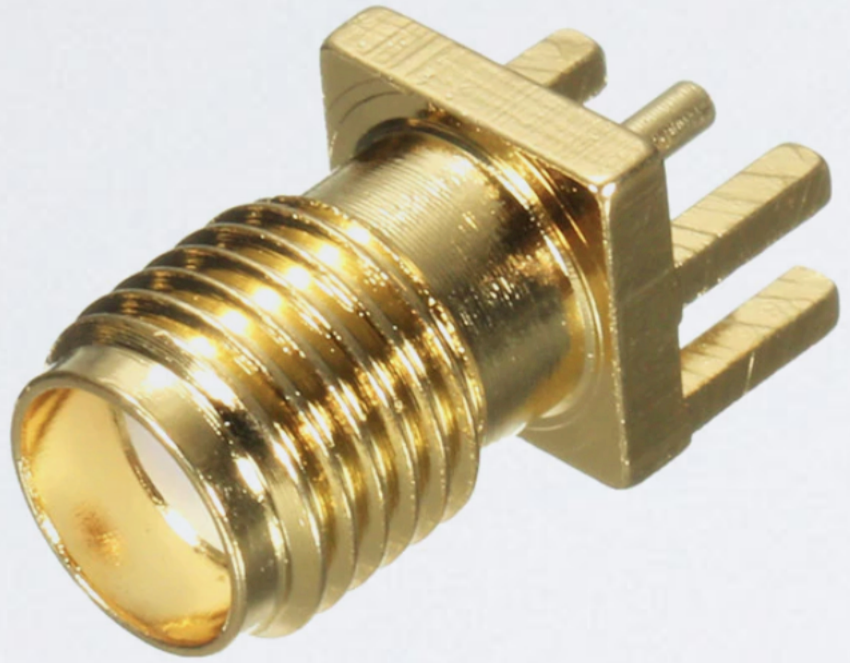


ANTENNA TEST RESULTS

- Looking at the results I can conclude that my self build ½λ dipole antenna performs the same as the purchased sleeve dipole antenna.

1/2 WAVE DIPOLE ANTENNA WITH LESS PARTS

- The simplest way to build an ½λ dipole antenna:



SMA female edge PCB straight mount