



Laboratory of Electronics Antennas and Telecommunications



https://github.com/FabienFerrero/Antenna_Radiation_Measurement

Low-cost Antenna Radiation Measurement

Fabien Ferrero



Outline

- Why antenna measurement are needed ?
- Antenna characteristics
- How to measure an antenna ?
- First solution with Spectrum Analyser
- Second solution with RSSI
- Conclusion and perspectives

Why do I need antenna measurement ?

- To see if my antenna prototype work
- To optimize my antenna geometry or matching network
- To see if my antenna is sensitive to the environment
- To compare different antennas or to find an optimal position
- To verify if my device respect the certification

Why do I need antenna measurement ?

- To see if my antenna prototype works
 - Low accuracy
- To optimize my antenna geometry or matching network
 - Medium accuracy (relative measurement)
- To see if my antenna is sensitive to the environment
 - Medium accuracy (relative measurement)
- To compare different antennas or to find an optimal position
 - Medium accuracy (relative measurement)
- To verify if my device respect the certification
 - High accuracy (absolute results)

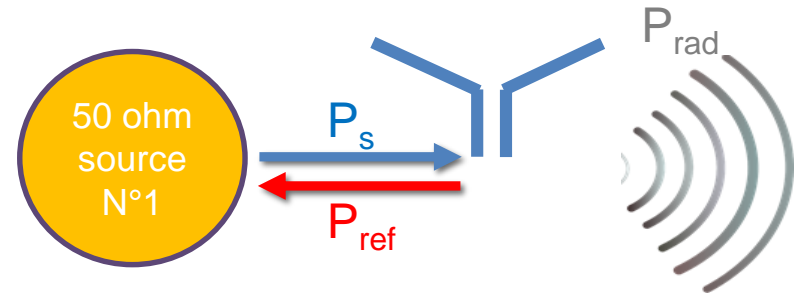
Antenna performance indicator

■ Some definitions :

- P_s : Power from the source
- P_{ref} : Power reflected by the antenna
- P_{rad} power radiated by the antenna

■ Antenna Performance Indicator

- Reflection coefficient
 - S_{11} is usually plotted in dB scale
 - S_{11} criteria from -10 dB to -6dB (90% to 75% transmitted power)
- Total Efficiency
 - Include **matching** and **radiation loss**
 - Can be plotted in linear or dB scale
 - 30-70% classically observed
- Gain
 - Include **matching, radiation loss, polarization** and **directivity**
 - Plotted in dBi
 - $U(\theta, \varphi)$ is the radiation intensity in a given direction



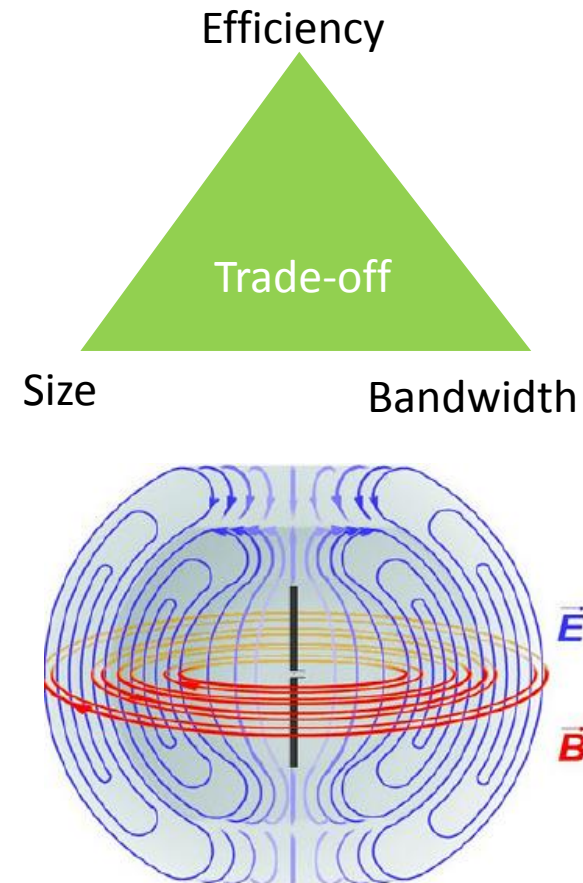
$$|S_{11}|^2 = P_{ref}/P_s$$

$$\eta_t = P_{rad}/P_s$$

$$G(\theta, \varphi) = \frac{U(\theta, \varphi)}{P_s/4\pi}$$

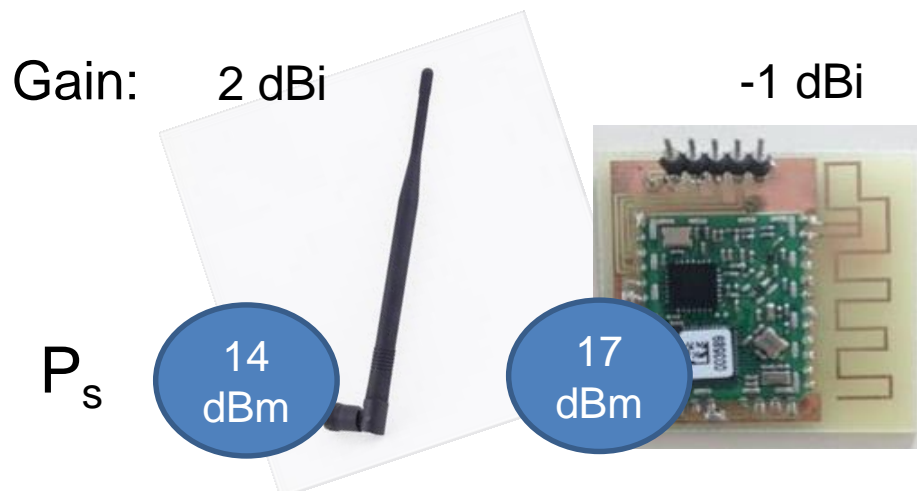
Antenna key parameters

- Antenna is a resonant structure :
 - Input impedance is changing with frequency
 - Limited frequency bandwidth
 - Miniature antenna can have a low efficiency due to metallic or dielectric losses
- Antenna is an open structure
 - Compare to electronic components, antenna is strongly influenced by its surrounding environment
 - For integrated antenna, the electromagnetic wave is generated by the antenna and by the terminal ground plane
- Small antenna has to be carefully tuned



Certification process

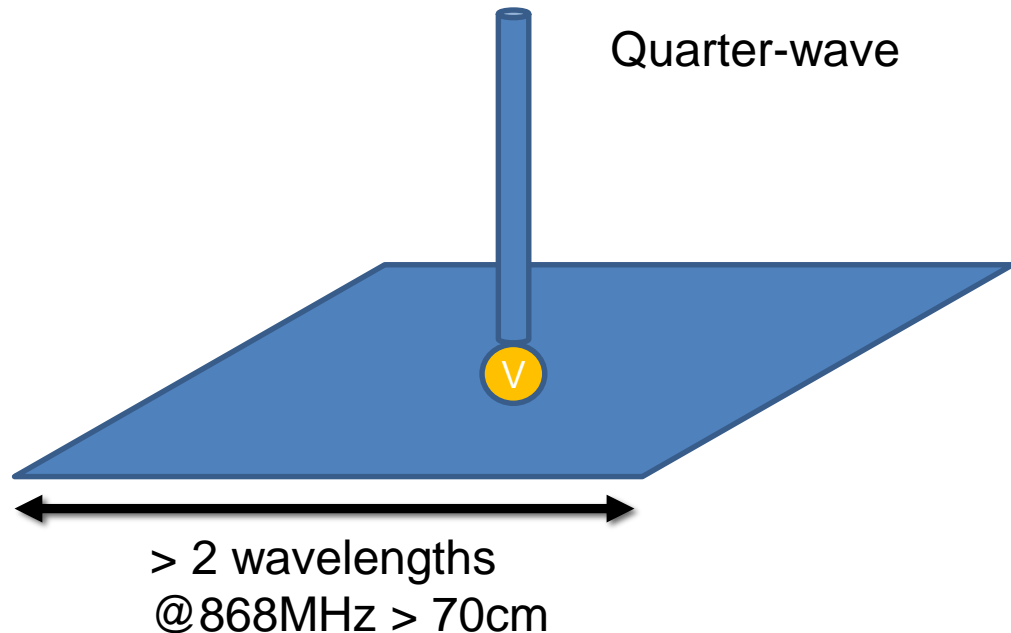
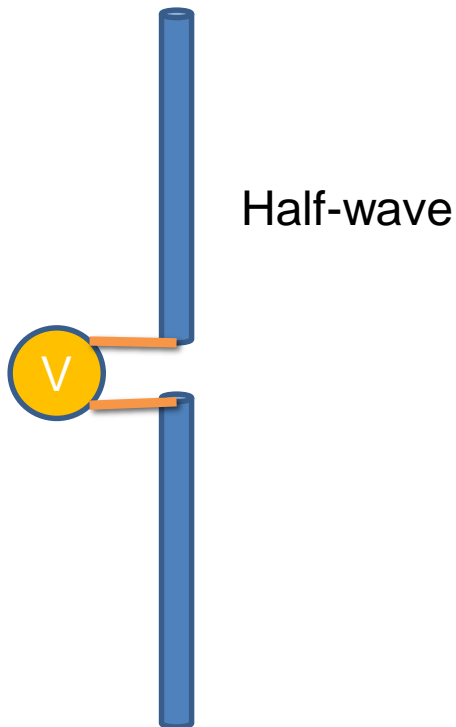
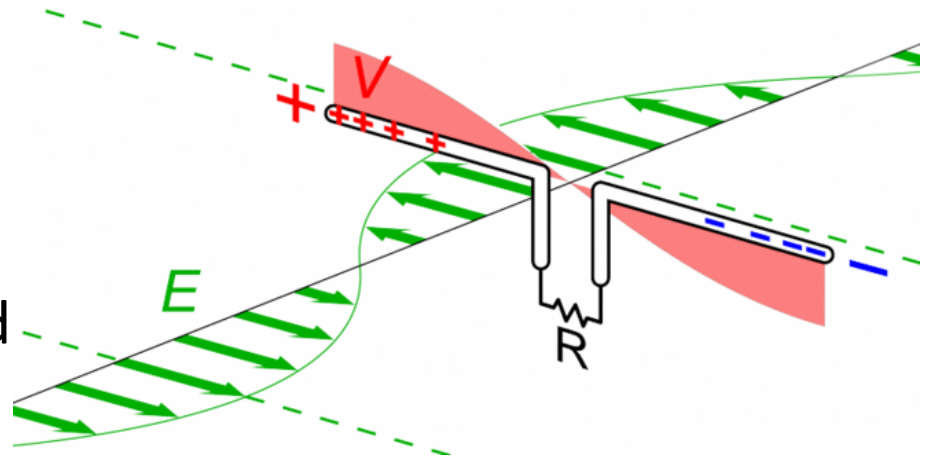
- Regulators defines the maximum radiated power in Equivalent Radiated Power (ERP) -> *In Europe : ERP @868MHz is **14 dBm***
 - **Effective Radiated Power** : amount of power applied to a half-wave dipole to give the same power density at a given point
 - **Effective Isotropic Radiated Power** : the reference is an isotropic radiator
$$\text{EIRP} = \text{ERP} + 2 \text{ dB}$$
- Tested during the certification process for all signal harmonics (CW test mode)
- Some operator ask for a minimal gain performance (or give classifications)
- Certification process is (very) expensive



Effect of terminal chassis

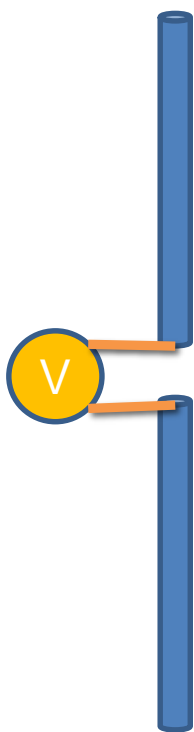
■ Two type of antenna

- Dual-pole : 2 parts contribute to the radiation (**cable effect**)
- Single-pole with a large ground plane (cable OK)

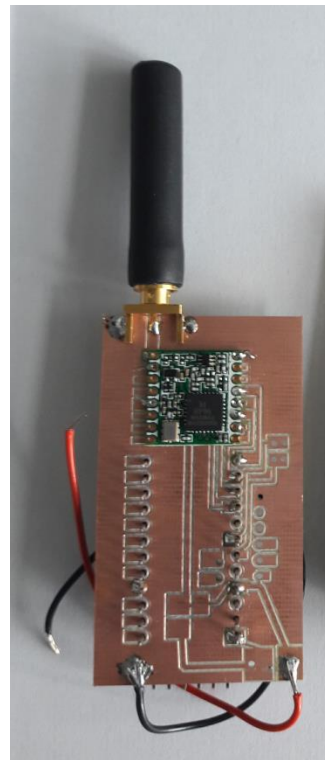


Effect of terminal chassis

- In most of the case, you will have a dual-pole antenna

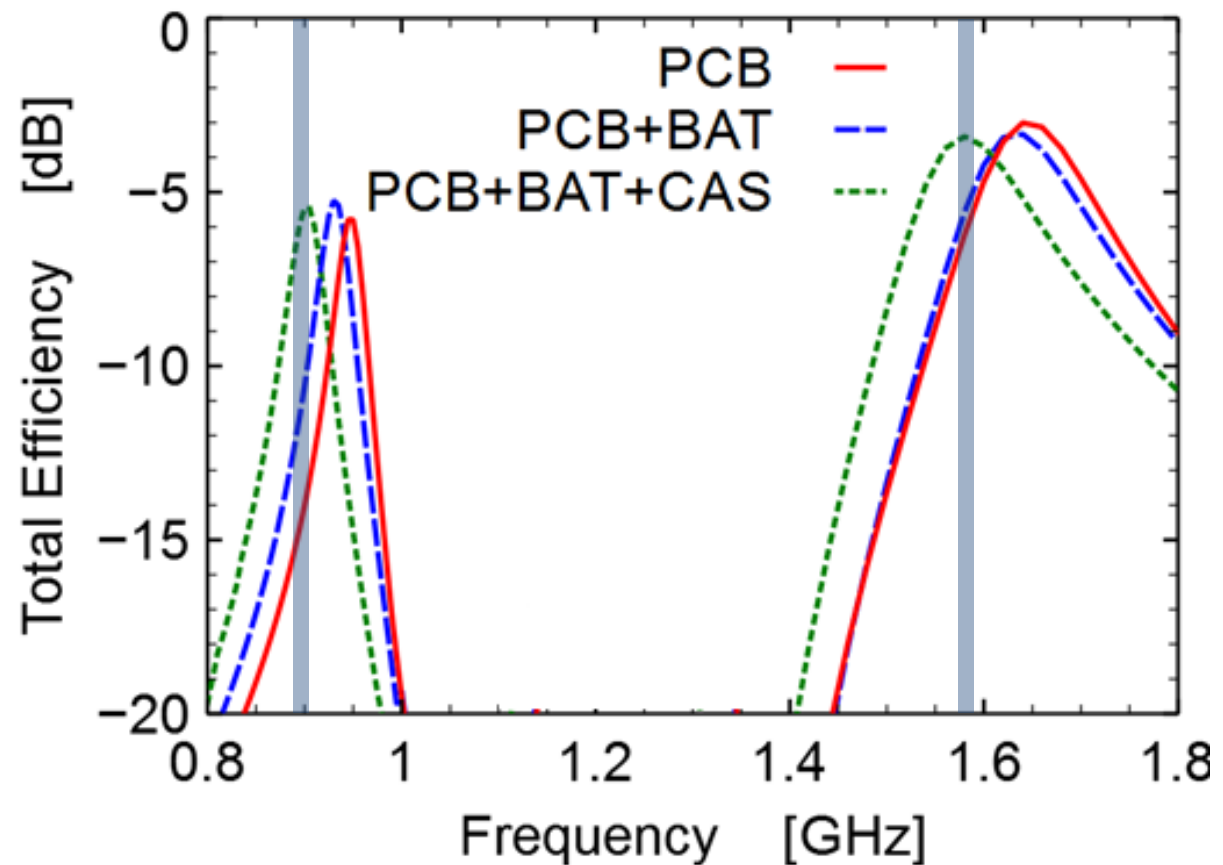
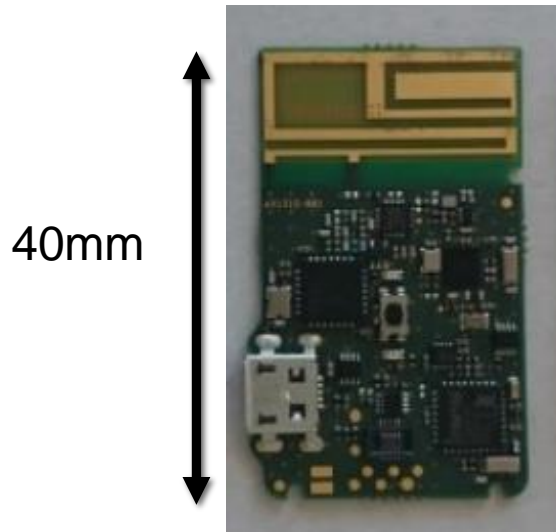


Half-wave



Effect of the environment

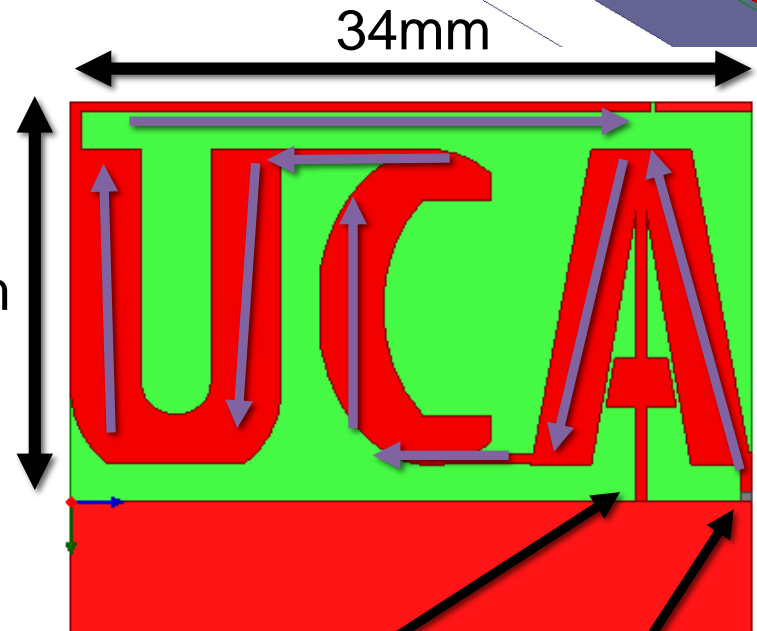
Antenna are strongly influenced by the close environment as the battery or the terminal casing



Small antenna have to be tuned

UCA

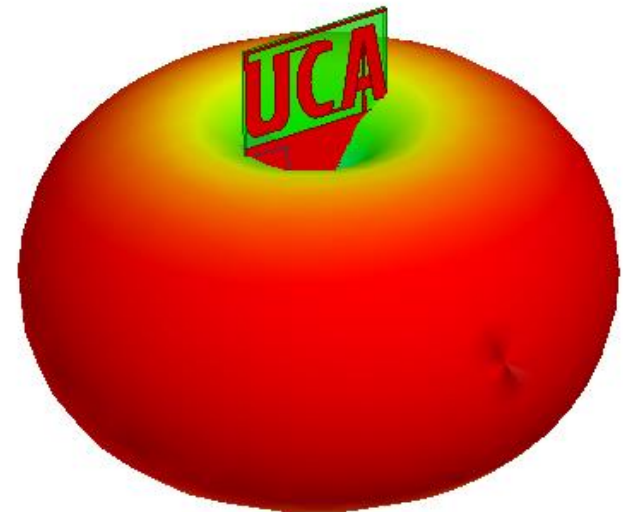
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Feeding
port

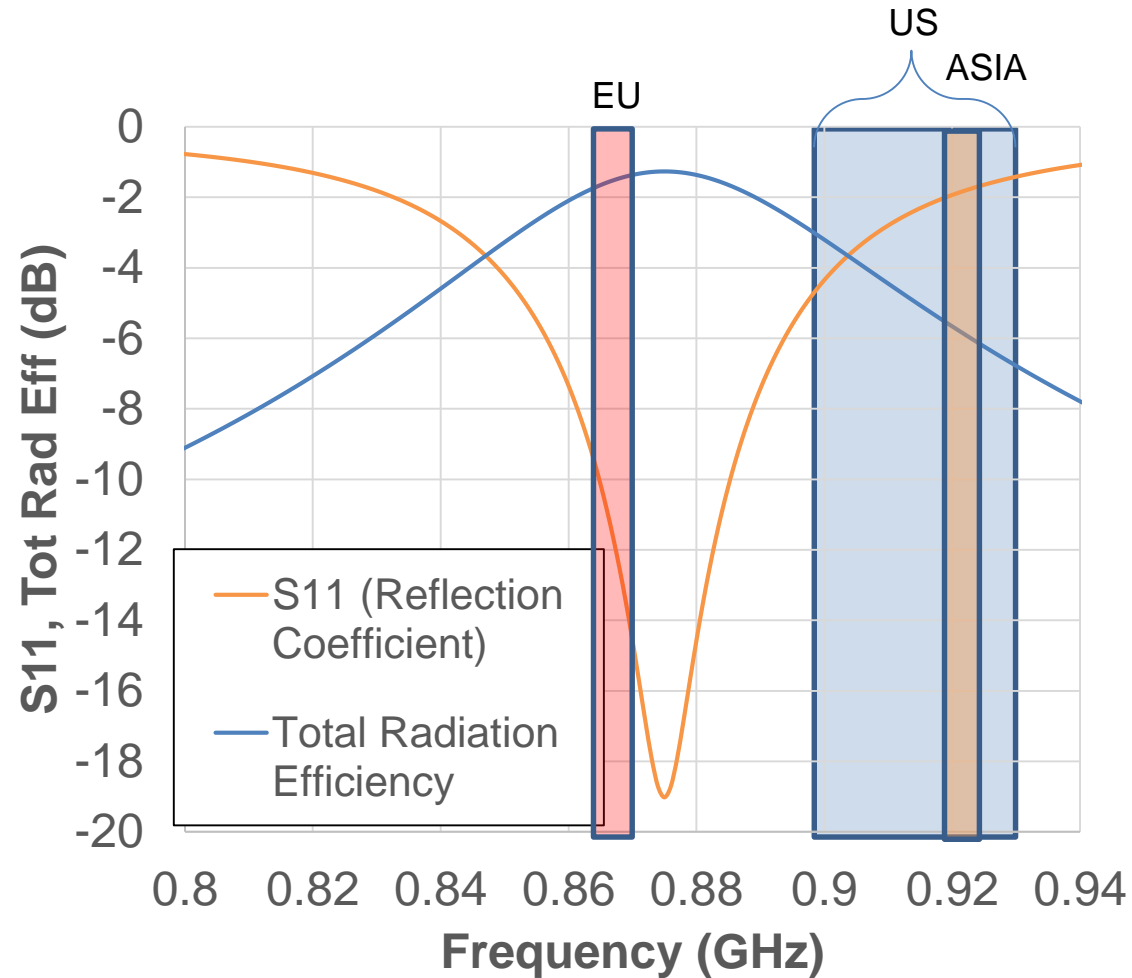
UCA Antenna tuned for EU band

- Antenna simulation
 - Matched to 50 ohm
 - Bw = 30MHz (@-6dB)
 - -1.2 dB radiation efficiency (75%)
 - Dipole radiation pattern
 - 2.1 dBi peak directivity
 - 0.9 dBi peak Gain



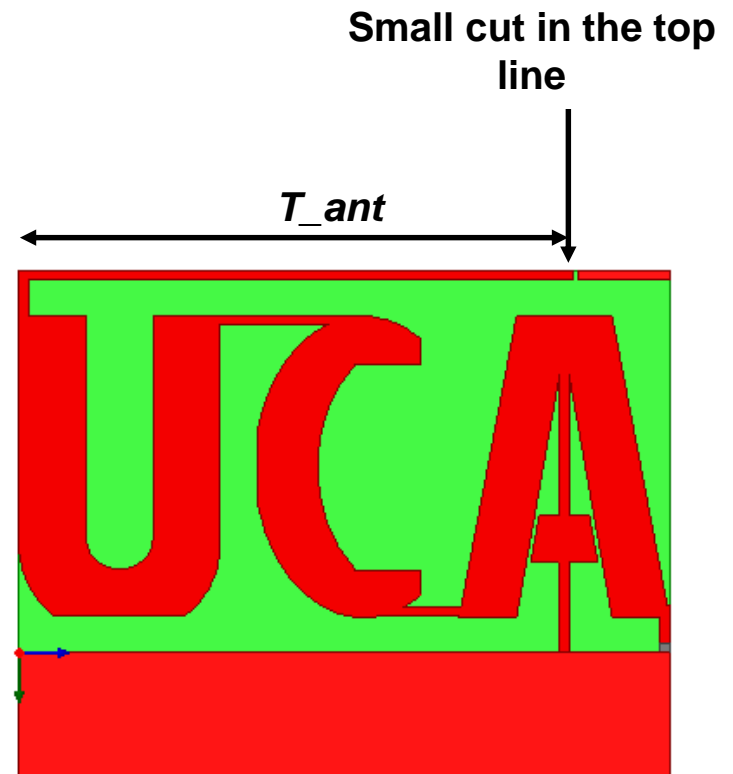
UCA Antenna tuned for EU band

- Miniature antenna
 - Limited frequency bandwidth
 - If the antenna is matched for European band, the antenna has poor radiation performance in US and ASIA bands

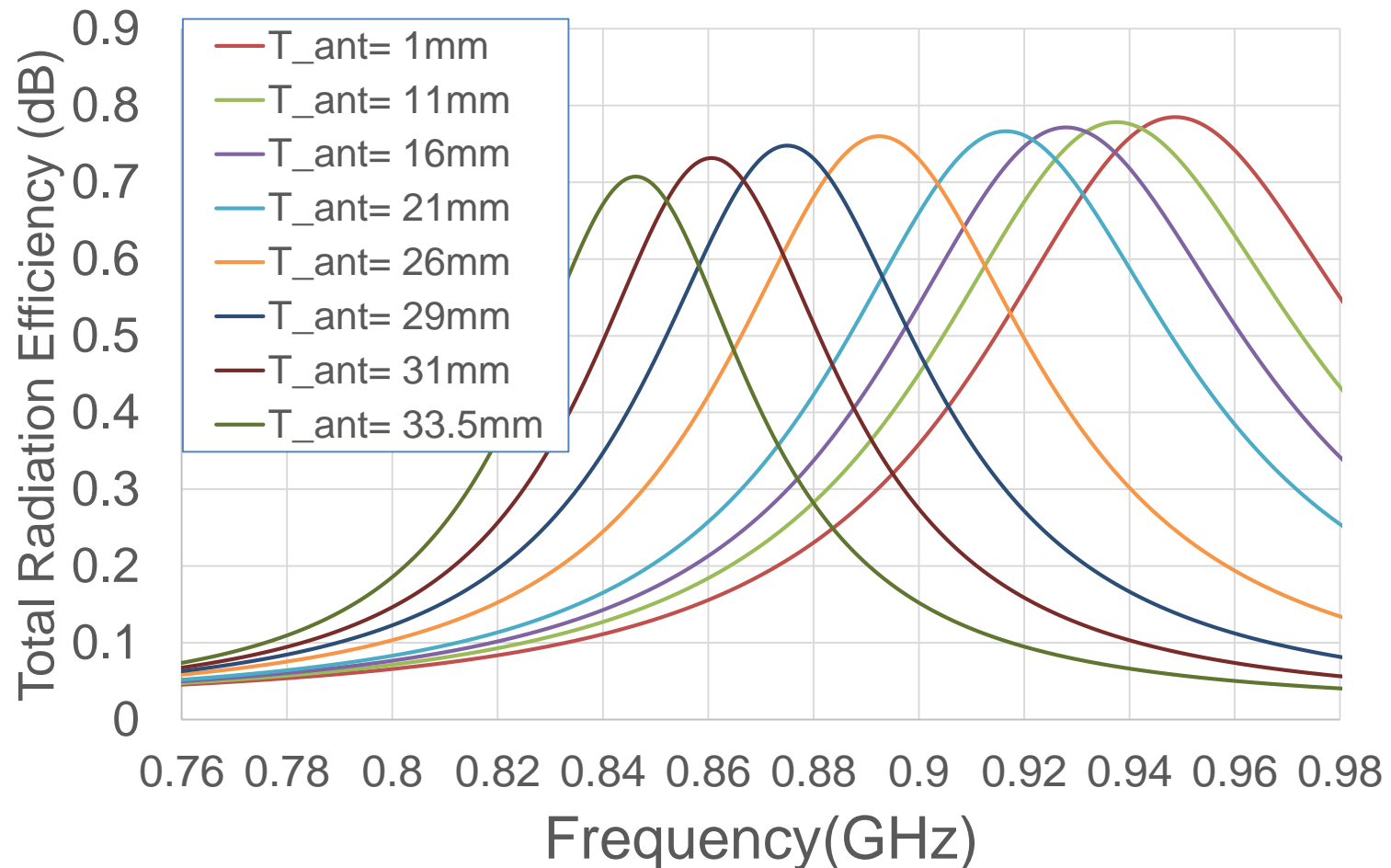


Antenna design

- The antenna shape can be easily tuned to different frequencies
 - The top line can be cut at different position to change the antenna trace length
 - T_{ant} parameter can be tuned from 0 to 34mm
 - Antenna resonance frequency can be tuned from 845 to 950MHz

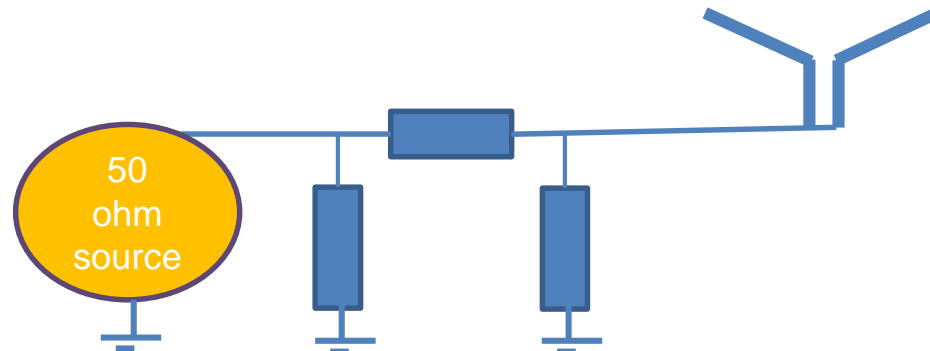


UCA Antenna : Linear Total Rad. Efficiency



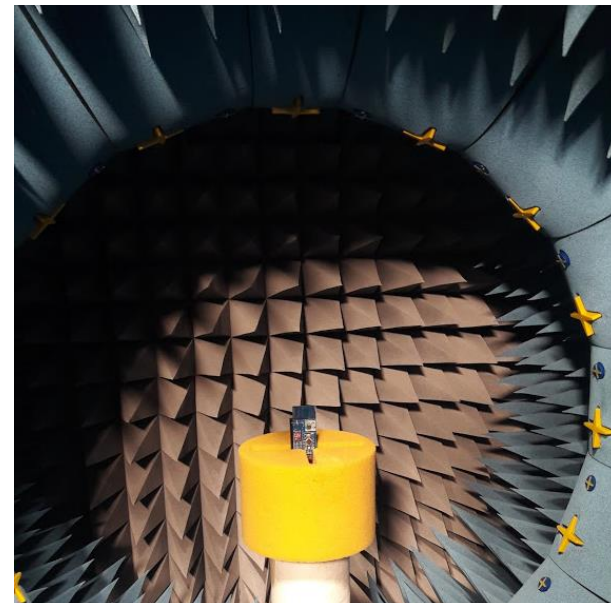
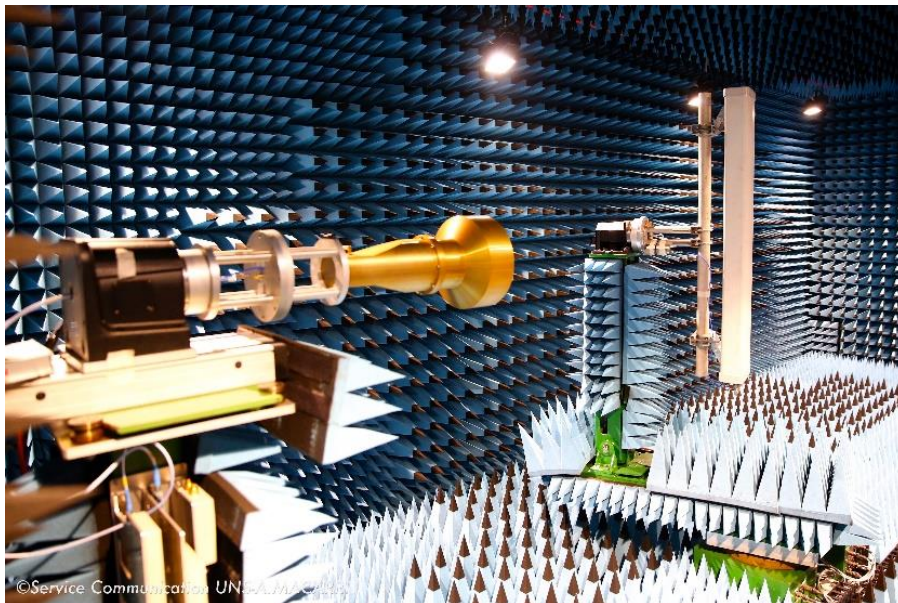
Classical issues with antenna and solutions

- Most of the time, your antenna won't be tuned at the wanted resonance frequency
 - Usually, tuning antenna frequency is quite simple by changing the antenna geometry (length) and by changing the matching network
- Sometimes, you may have issue with the level of matching
 - Measurement with VNA is helpful but effect of the cable has to be carefully considered
 - « **Test and Try** » with gain measurement and matching network modification is the most secure solution
- Always add a PI matching network in front of your antenna
 - Use 0402 or 0603 package
 - Pay attention to component resonance frequency !



How to perform antenna radiation measurement ?

- Accurate antenna measurement is difficult
- Cables have a large influence on the measurement
- Only consider Total Radiated Power (TRP) measurement (your device will be in Continuous Wave mode)



How to perform antenna radiation measurement ?

ETSI TS 103 052 V1.1.1 (2011-03)

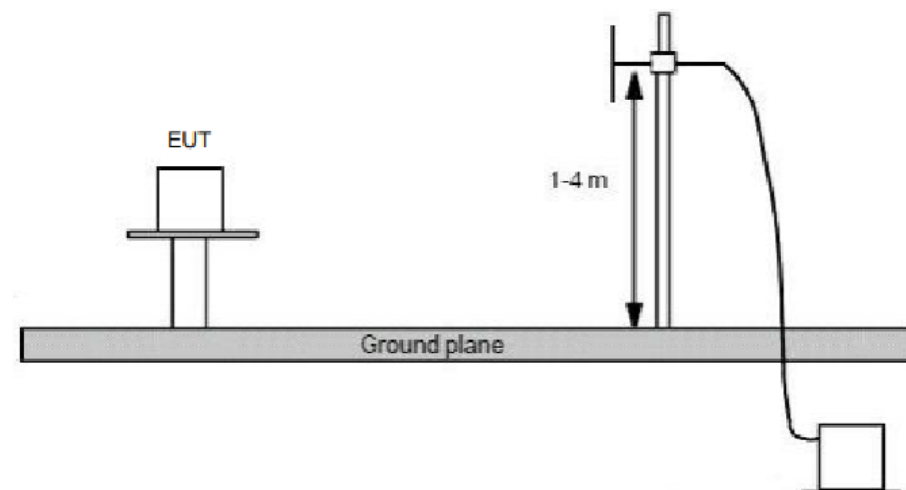
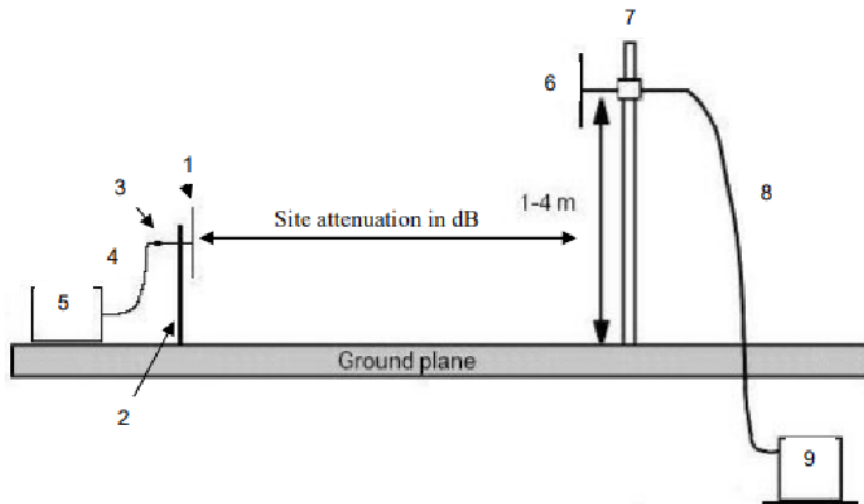
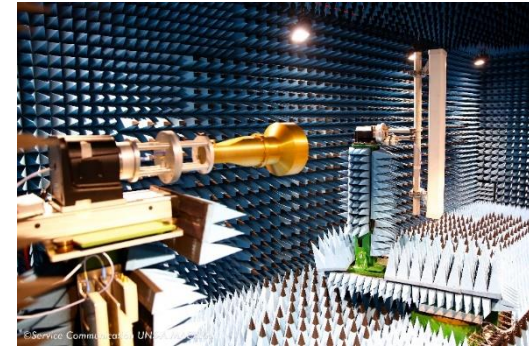
- Anechoic chamber
- 2 Reference antennas
- Power source
- Power measurement equipment (**Spectrum analyser** or power meter)



How to perform an antenna measurement ?

ETSI TS 103 052 V1.1.1 (2011-03)

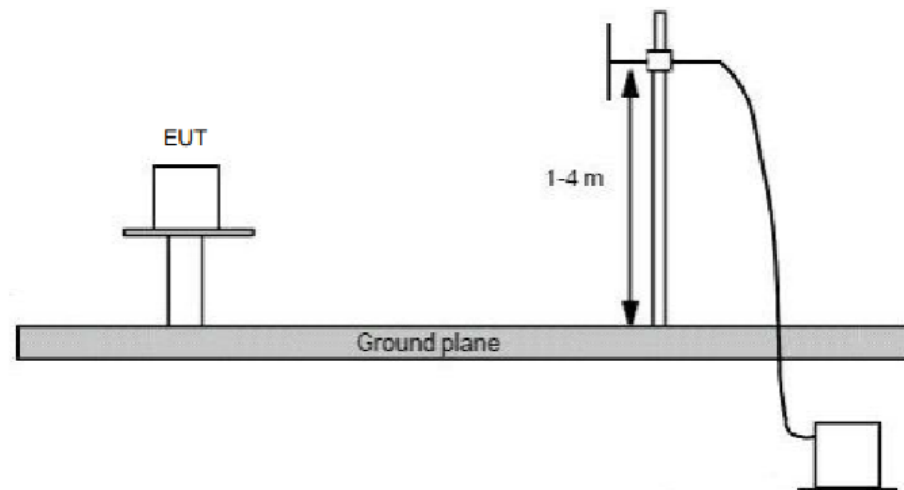
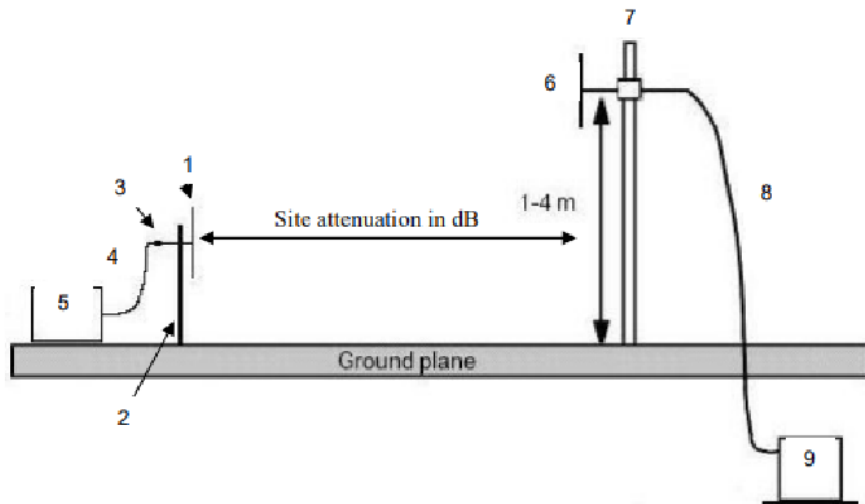
- Anechoic chamber or open site
- Reference antenna : 1 & 6
- Power source : 5
- Power measurement equipment : 9



How to perform an antenna measurement ?

- Substitution or pre-substitution method
 - Power source for the ref. ant. and AUT must be the same
 - First measurement Rx_{Cal} for calibration using a reference antenna
 - Second measurement Rx_{AUT} of the Antenna under Test (AUT)

$$(Gain_{AUT})_{dBi} = (Rx_{AUT})_{dBm} - (Rx_{Cal})_{dBm} + (Gain_{Ref\ Ant})_{dBi}$$

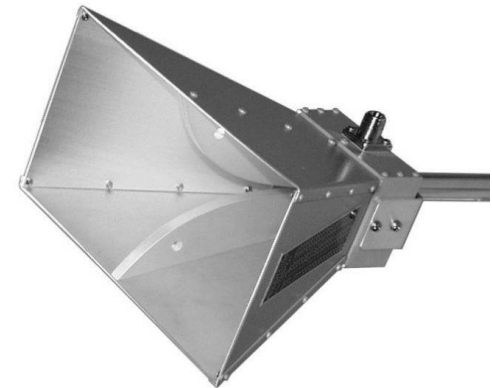


How to perform an antenna measurement ?

- Anechoic chamber – 500 000 €
- Reference antenna – 3000 €
- Power source -20 000 €
- Spectrum analyser - 20 000 €



Can we reduce the price ?



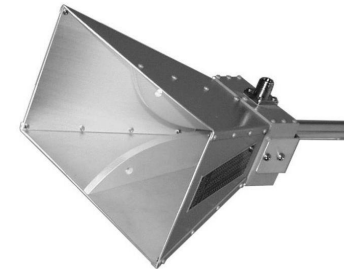
How to perform an antenna measurement ?

- Miniature chamber – 50 000 €
- Reference antenna – 3000 €
- Power source -20 000 €
- Spectrum analyser - 20 000 €



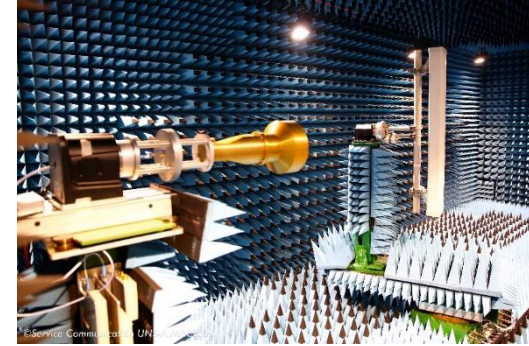
DST200 from R&S

Can we reduce the price ?



How to perform an antenna measurement ?

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- ~~■ Power source – 20 000 €~~
- Spectrum analyser - 20 000 €

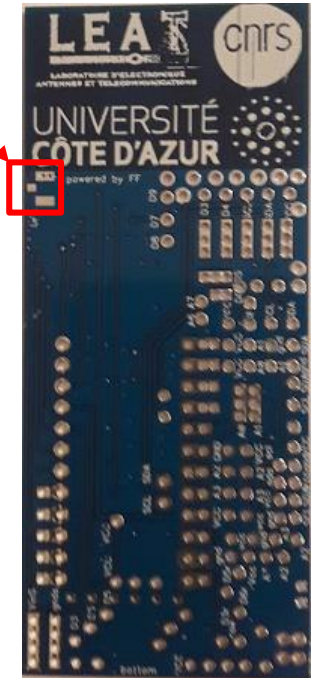


My LoRa chip can transmit a continuous wave !

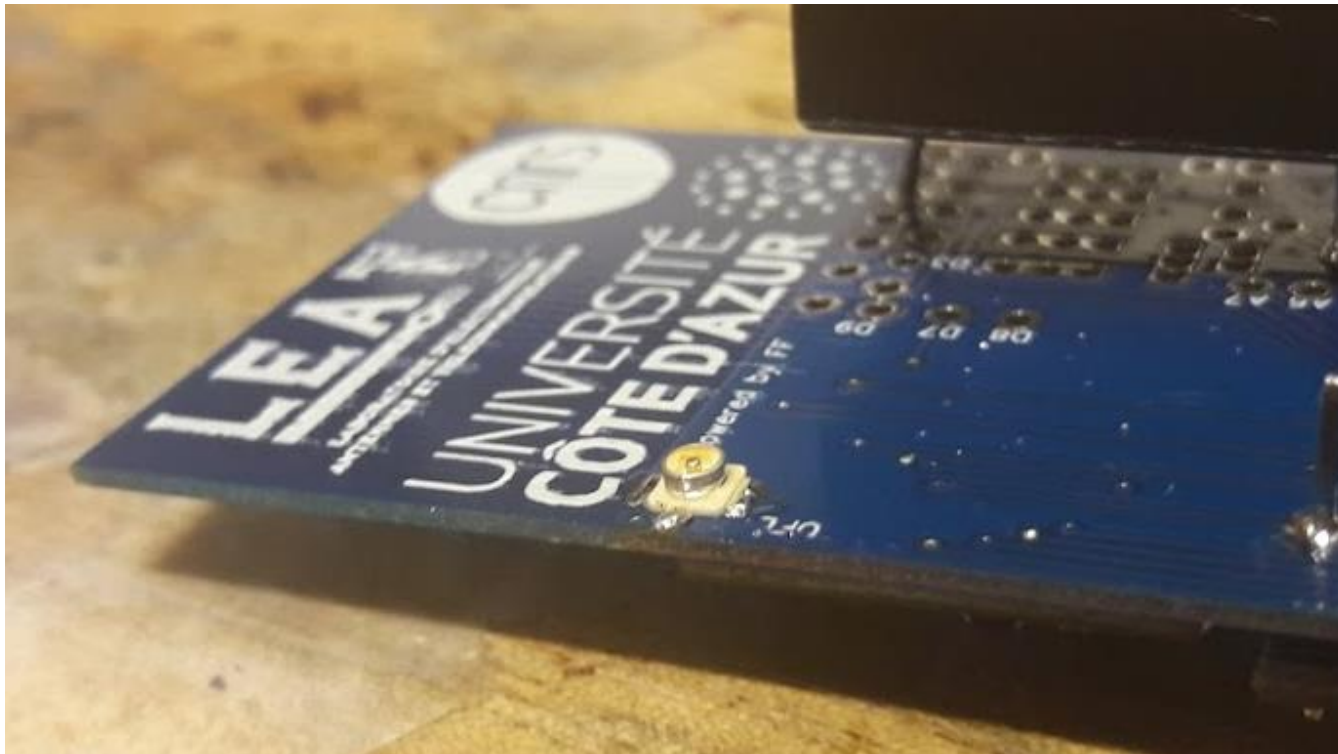
It is interesting to measure the exact output power of my module for a given configuration

Adding a RF connector

- Try to place a connector footprint
- UFL are very small and easy to find
- Very important for debug !
- A UFL connector can be soldered on the bottom part of the board
- If you just solder the connector, the UFL will be in shunt with the existing « UCA » antenna
 - If you leave the UFL unconnected, your board will work as usual (the UFL effect is negligible)
 - If you connect a load (antenna or spectrum) on the UFL, roughly half of the power will be captured by the UFL, and half part of the power will be radiated (and a part of the power will be reflected to the source)

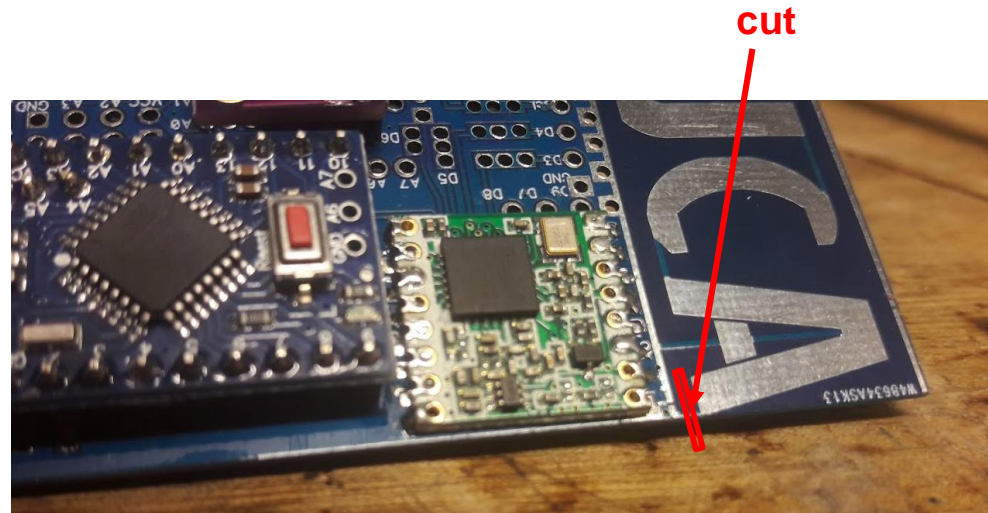


Adding a RF connector



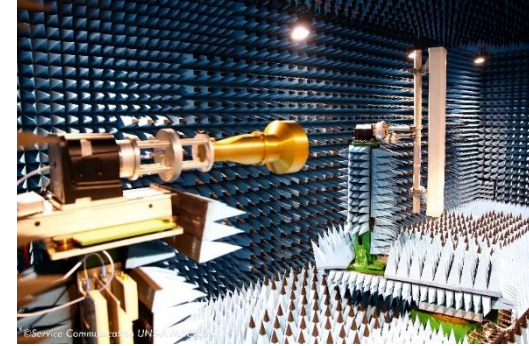
Adding a RF connector

- To have 100% of the power on the UFL connector
 - You need to cut the antenna feeding line
 - You will be able to solder it again



How to perform an antenna measurement ?

- Anechoic chamber – 500 000 €
- ~~Reference antenna – 3000 €~~
- ~~Power source – 20 000 €~~
- Spectrum analyser - 20 000 €

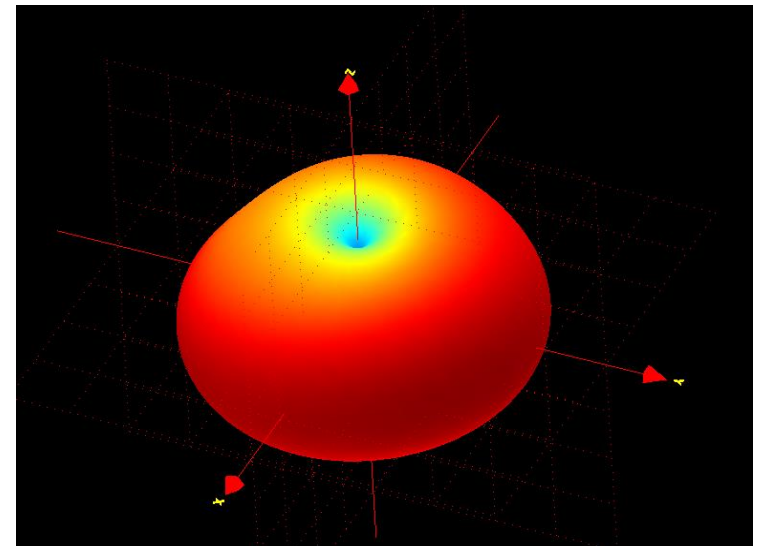


Can I use a low cost reference antenna ?

Can find some open source design or buy is cheap one

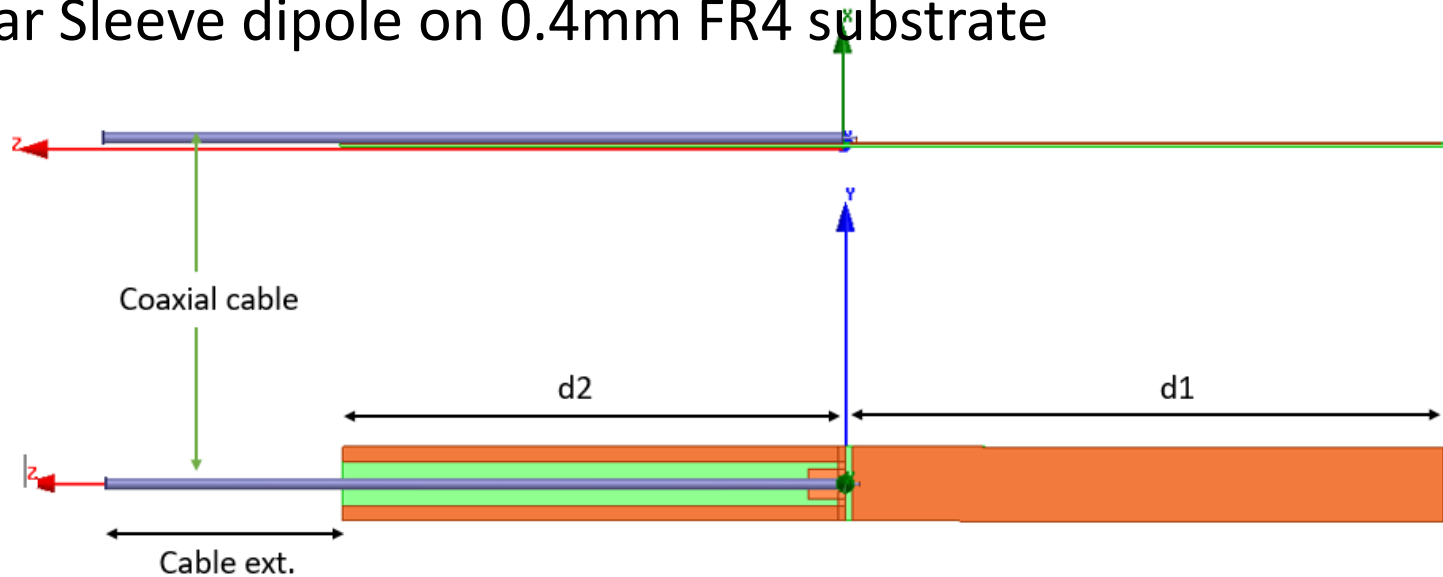
Printed Sleeve dipole with coaxial cable

- Low cost 0.4mm FR4 Epoxy 140x15mm
- Low cost Small coaxial cable
- Integrated Balun for environment robustness
- Omnidirectional pattern
- Gain 2.5dBi
- Measured Efficiency 83%

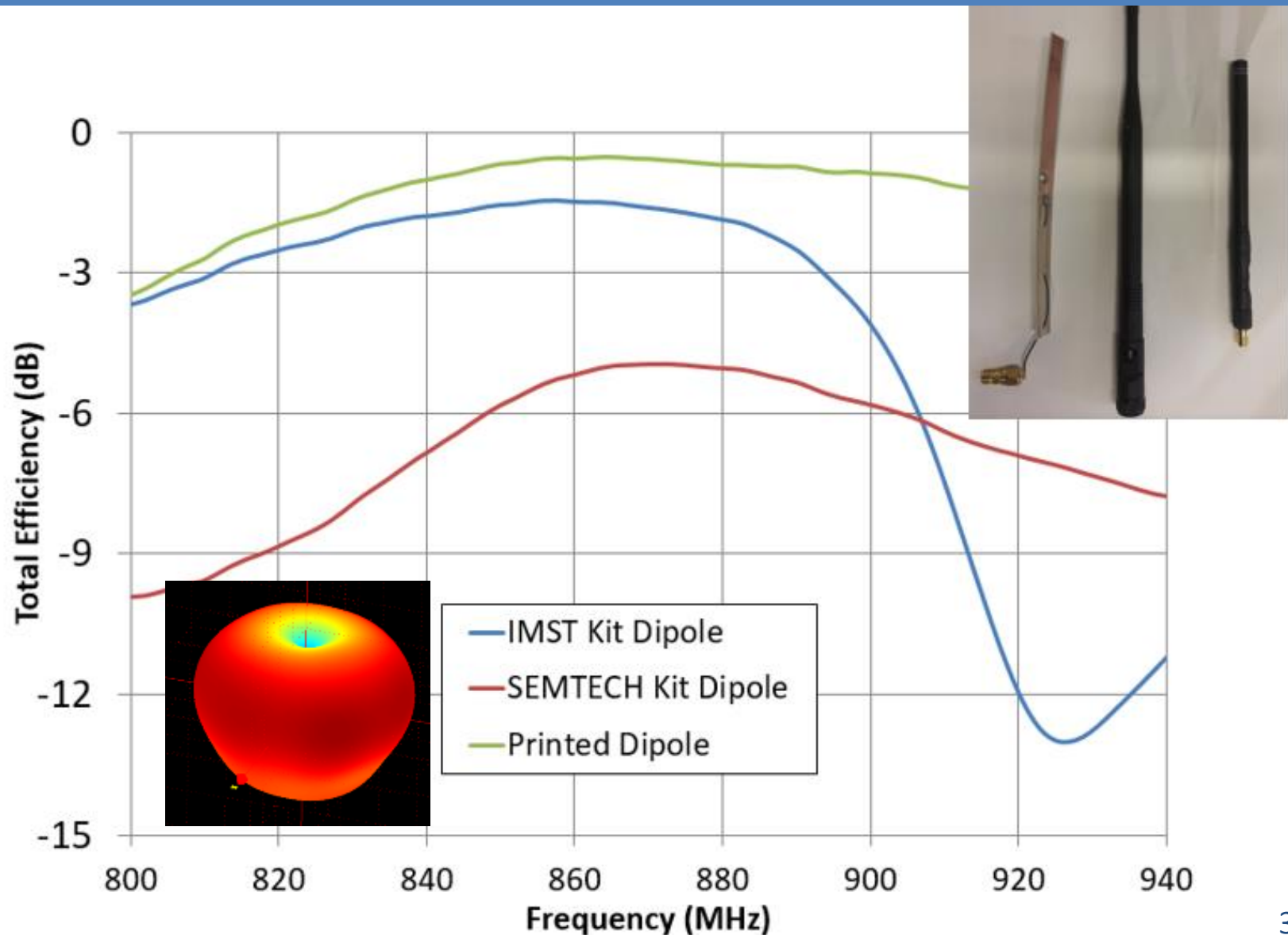


Half-wave dipole Antenna

- Planar Sleeve dipole on 0.4mm FR4 substrate

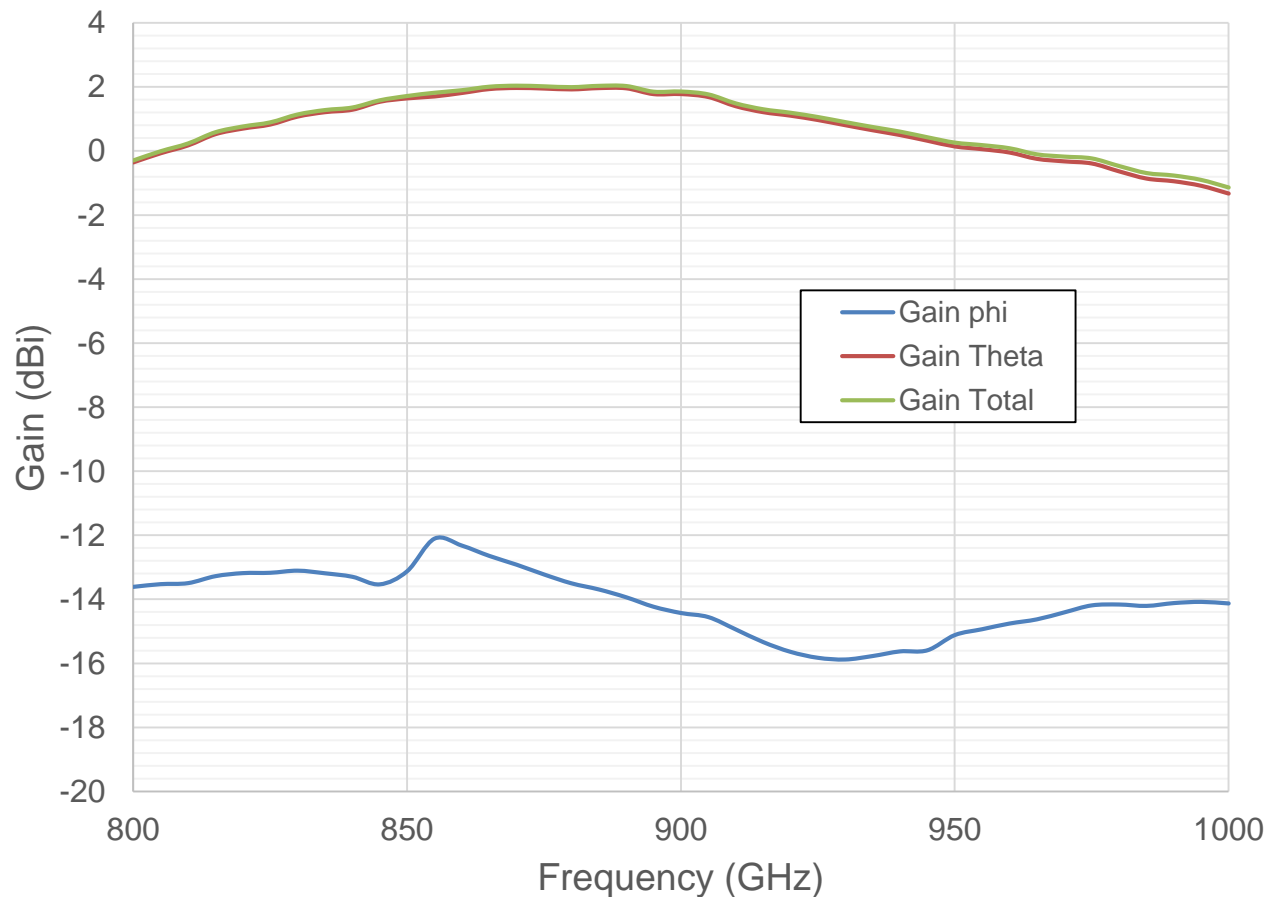


Comparison with on-the-shelf antenna



Printed Sleeve dipole with coaxial cable


- Low cost 0.4mm FR4 Epoxy 140x15mm



Printed Sleeve dipole with coaxial cable

- Don't want to fabricate it ? can just buy it !

https://furiousfpv.com/advanced_search_result.php?keywords=lora

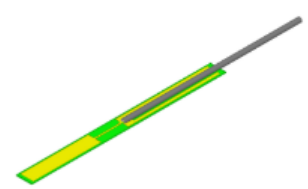


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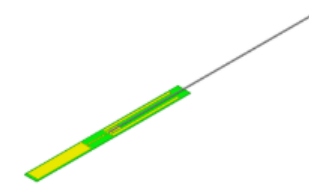


ETA 03/11/2019

\$10.00

FPV-LORA140-S

FuriousFPV - Reference LoRa Antenna 140mm



ETA 03/11/2019

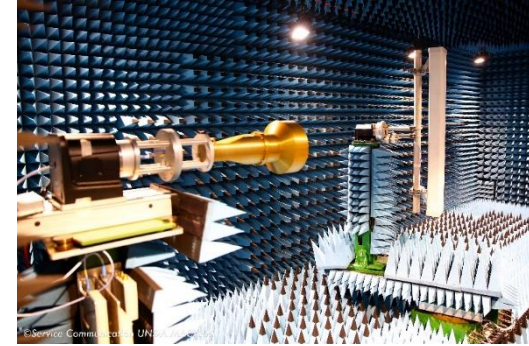
\$10.00

FPV-LORA300-S

FuriousFPV - Reference LoRa Antenna 300mm

How to perform an antenna measurement ?

- ~~Anechoic chamber – 500 000 €~~
- ~~Reference antenna – 3000 €~~
- ~~Power source – 20 000 €~~
- Spectrum analyser - 20 000 €



Can we do measurement without anechoic chamber ?

Yes and No

How to perform an antenna measurement ?

ETSI TS 103 052 V1.1.1 (2011-03)

- Distance between antenna
- It shall be ensured that radiated measurements are tested in the far field.
- There is no clearly defined transition from near field to far field. The distance should be equal to or exceed:

$$\frac{2(d_1 + d_2)^2}{\lambda}$$

where:

d_1 is the largest dimension of the EUT/dipole after substitution (m);

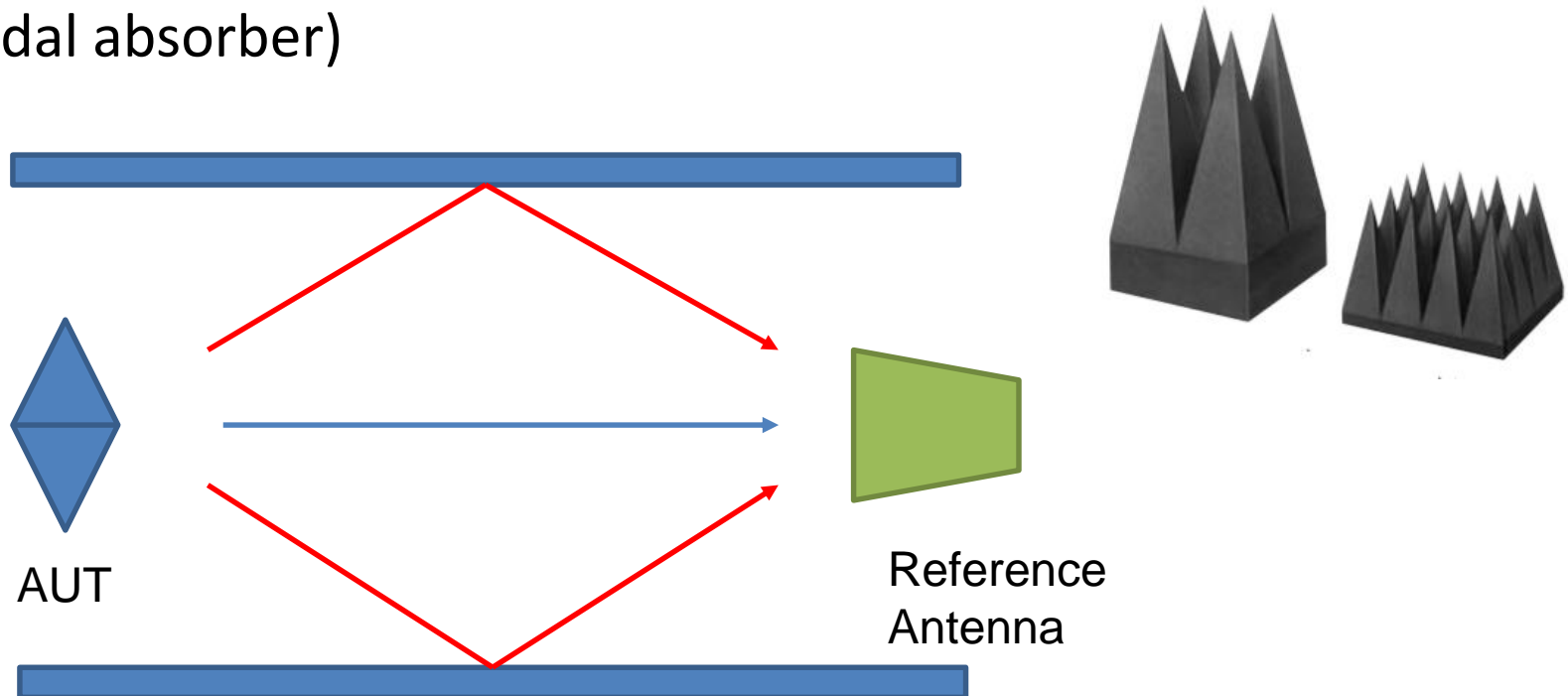
d_2 is the largest dimension of the test antenna (m);

λ is the test frequency wavelength (m).

No anechoic chamber ?

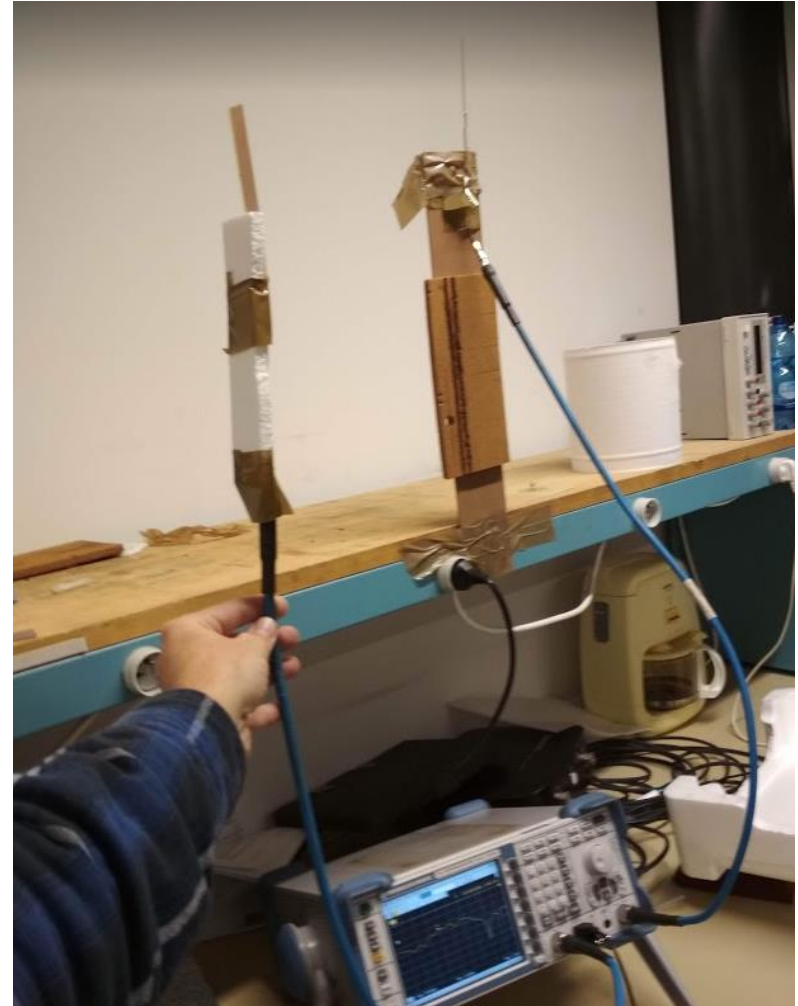
Why do we need anechoic chamber or open site ?

- We want Free Space : No reflection (because of interferences)
- Try to analyze the possible origin for reflection and to limits as much as you can
- You can also buy some absorber to improve your test-bed (EM sheet, Pyramidal absorber)



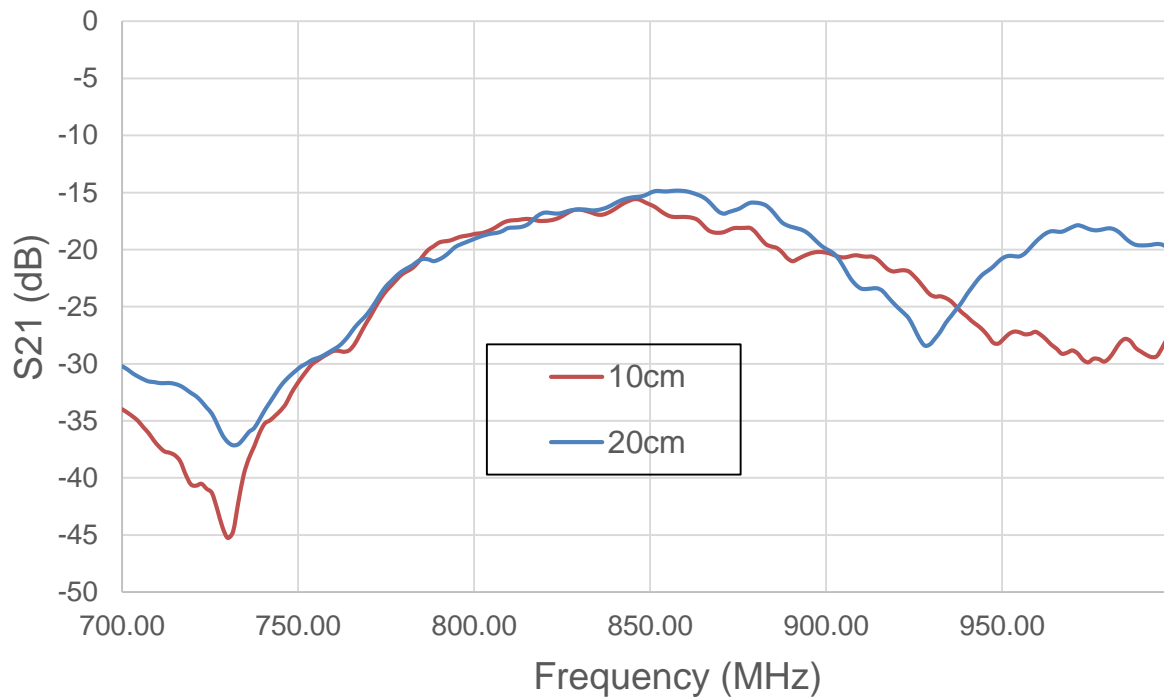
No anechoic chamber ?

- Transmission power versus frequency for different distances
- Measurement with VNA in a lab with walls, metal shelf, metal ceiling, etc



No anechoic chamber ?

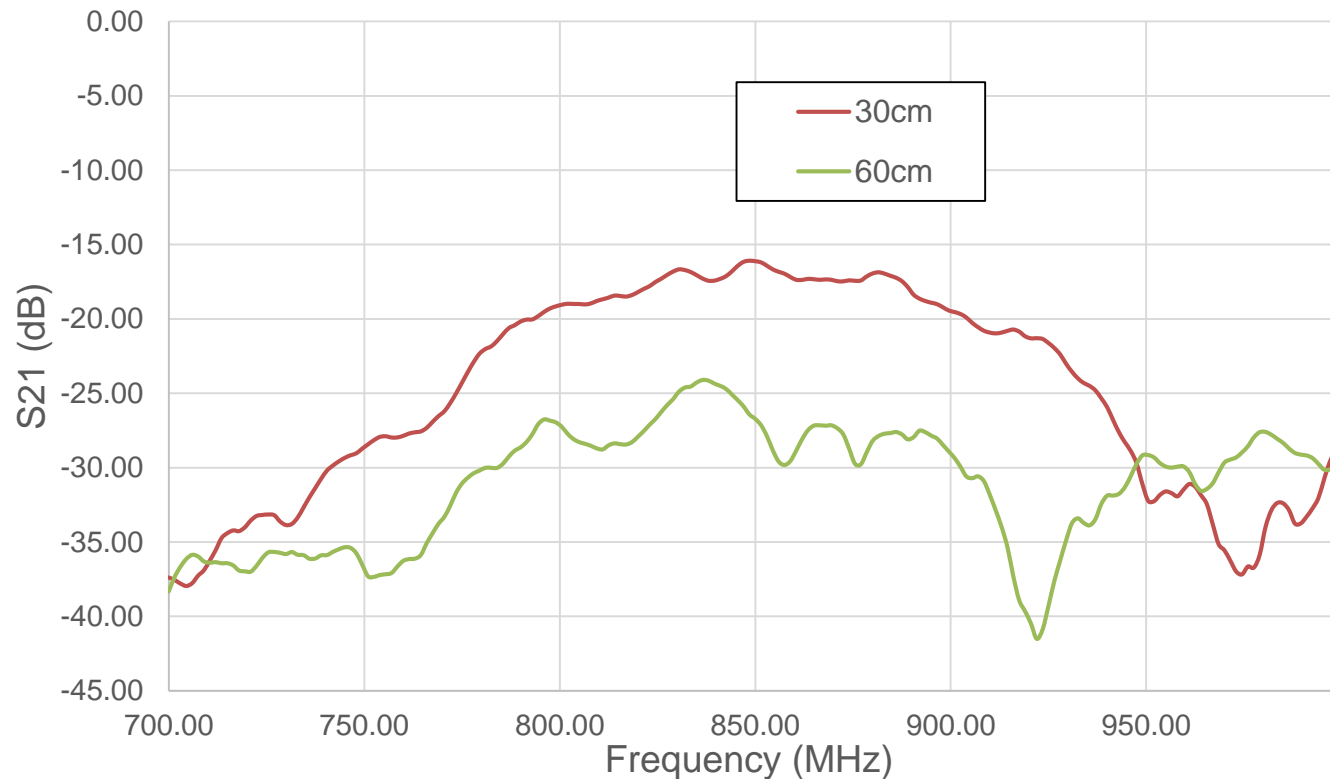
- Transmission power versus frequency for different distances



When antennas are too close, effect of near field

No anechoic chamber ?

- Transmission power versus frequency for different distances



When antennas are too far, multipath is too important

How to perform an antenna measurement ?

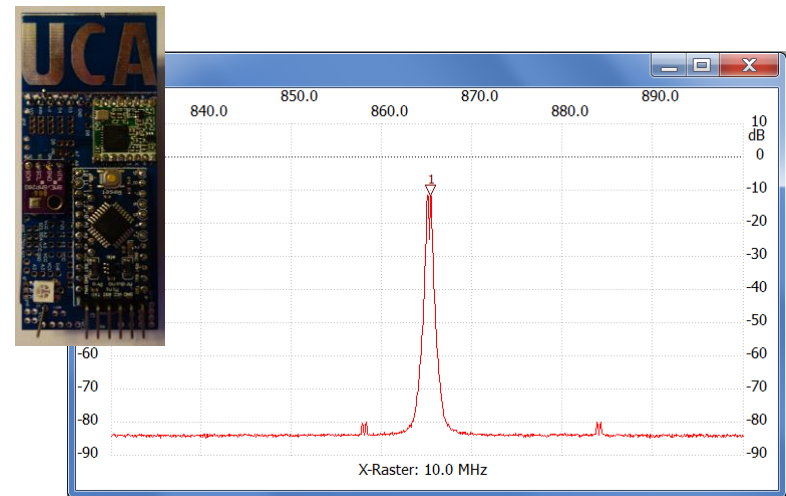
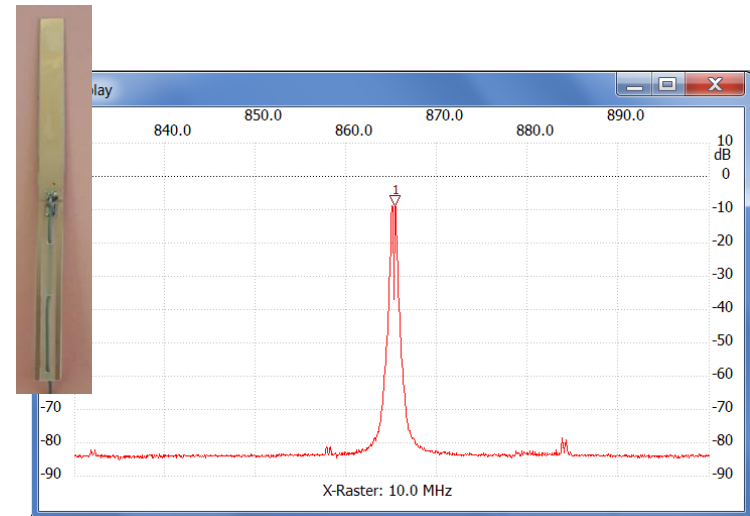
- ~~■ Anechoic chamber — 500 000 €~~
- ~~■ Reference antenna — 3000 €~~
- ~~■ Power source — 20 000 €~~
- Spectrum analyzer - 20 000 €

Can we reduce the price ?

*Some lower cost Spectrum (refurbish) or on Aliexpress can be found
for less than 100€*

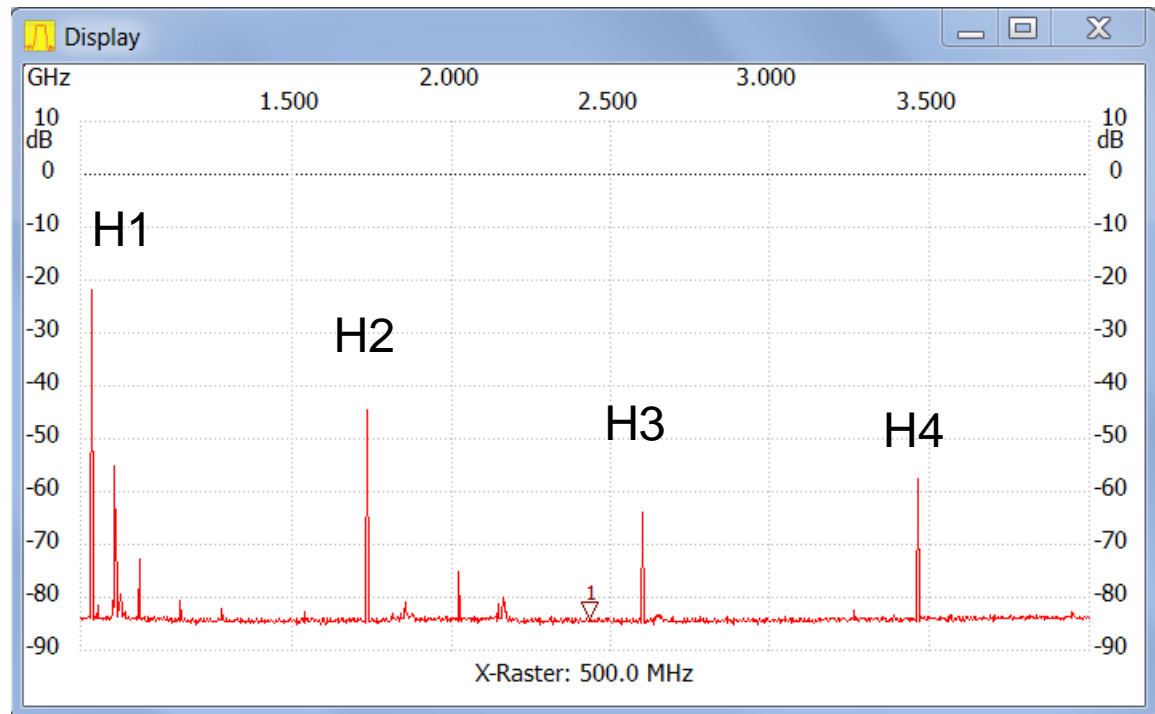
Summary of the method

- Use CW mode for AUT
- Measure for a given distance with ref antenna
 - Exemple: $(Rx_{Cal})_{dBm} = -9.4dBm$
- Measure for the same distance AUT
 - Exemple: $(Rx_{AUT})_{dBm} = -11.1dBm$
- At 865MHz, $(Gain_{Ref Ant})_{dBi} = 2 dBi$
- Then, $(Gain_{AUT})_{dBi} = -11.1 + 9.4 + 2 = 0.3dBi$
- Measured gain of this antenna at 865MHz is 1.1 dBi, so it is fair



How to perform an antenna measurement ?

- Harmonics can be also measured with this method
 - But you need a reference antenna for the harmonics frequencies
- frequencies



How to perform an antenna measurement ?

- ~~Anechoic chamber – 500 000 €~~
- ~~Reference antenna – 3000 €~~
- ~~Power source – 20 000 €~~
- ~~Spectrum analyser – 20 000 €~~

LoRa chip can provide RSSI

Can I use my LoRa chip as a receiver ?

Can be also sweep the frequency ?

How to perform an antenna measurement ?

A LoRa transmitter send a packet with the next frequency in the payload



TTGO or Heltec board with OLED Screen

A LoRa receiver get the packet, decode the payload and move to the next frequency

Setting-up Receiver device

Set-up the reference device and receiver device at a distance between 30 and 50 cm.

Push the button, the calibration start with the reference antenna.

Wait for the complete scan between 800 and 950MHz

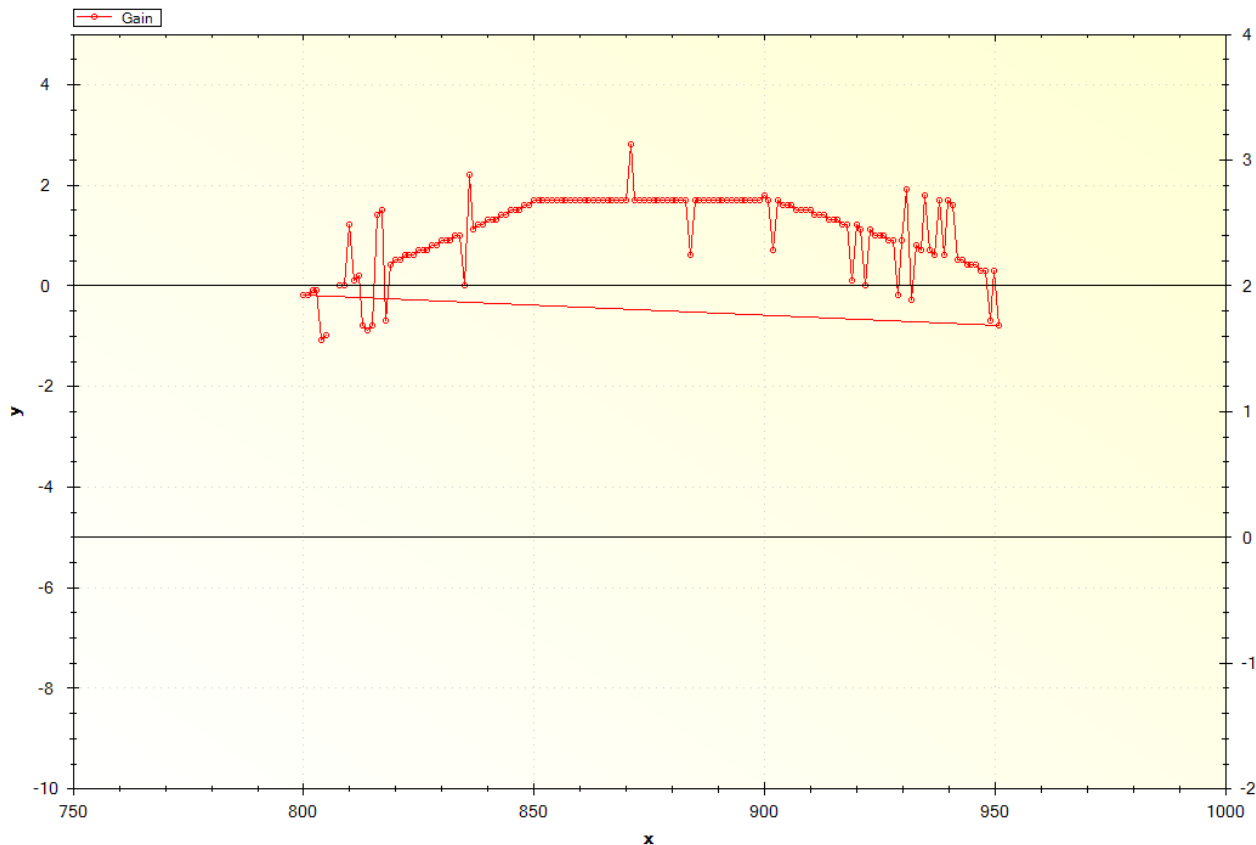


30 to 50 cm

How to perform an antenna measurement ?

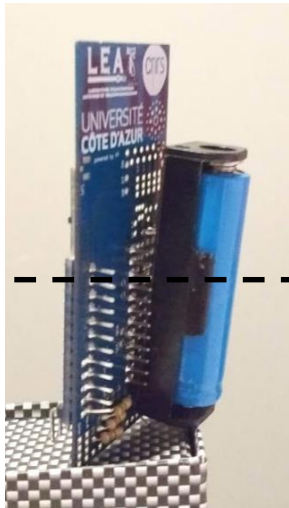
Once it's done, the system is calibrated.

The system will continue to scan but you should find the gain of the reference antenna



Setting-up Receiver device

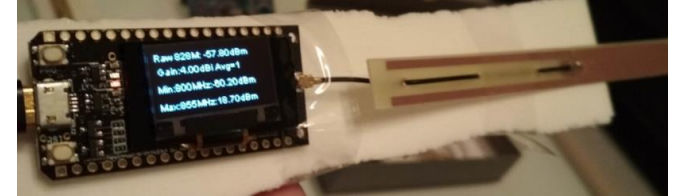
- Now you can replace the reference antenna by the Antenna Under Test.
- Try to place it exactly at the same position



30 to 50 cm

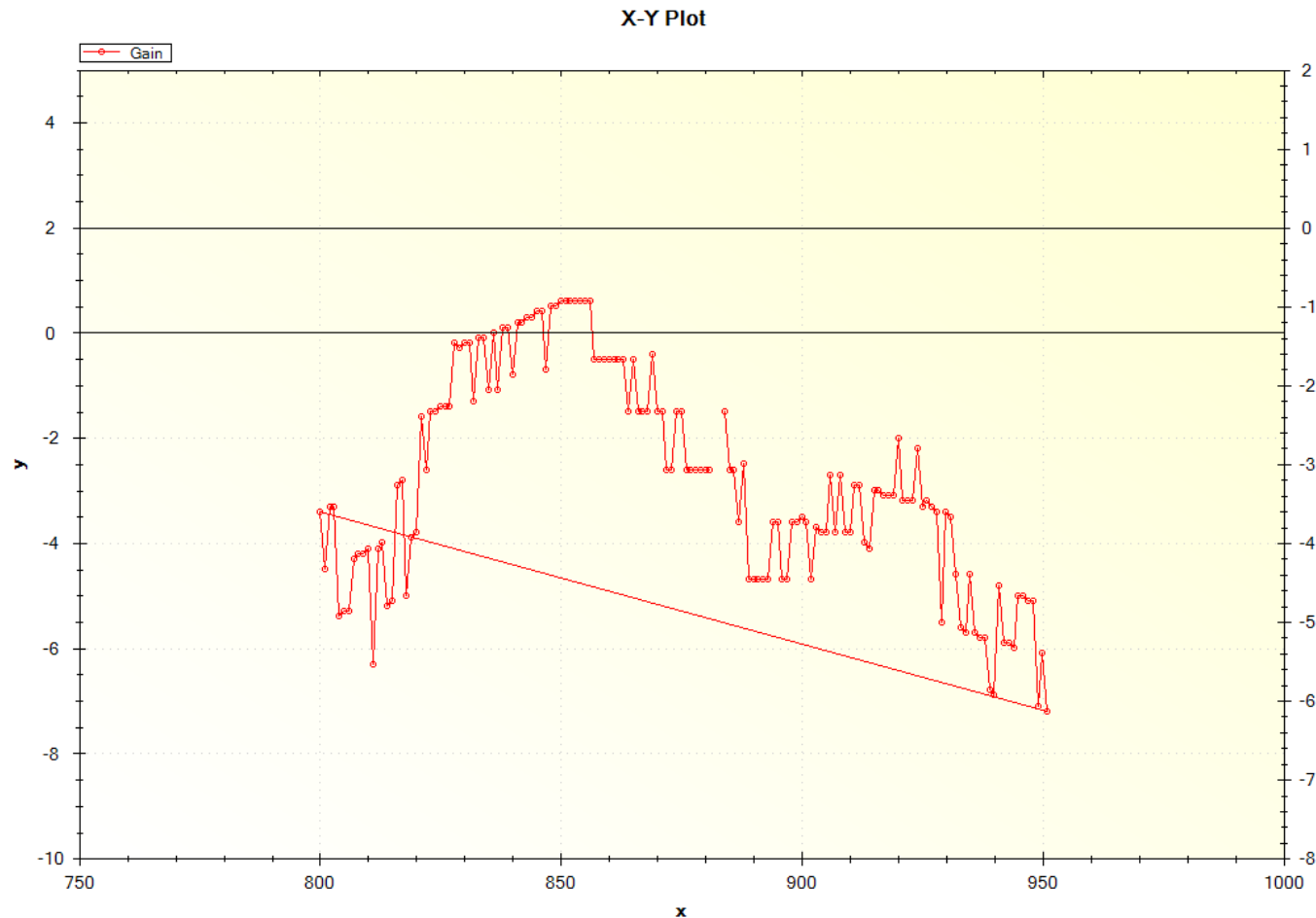
How to perform an antenna measurement ?

Can we reduce the price ?



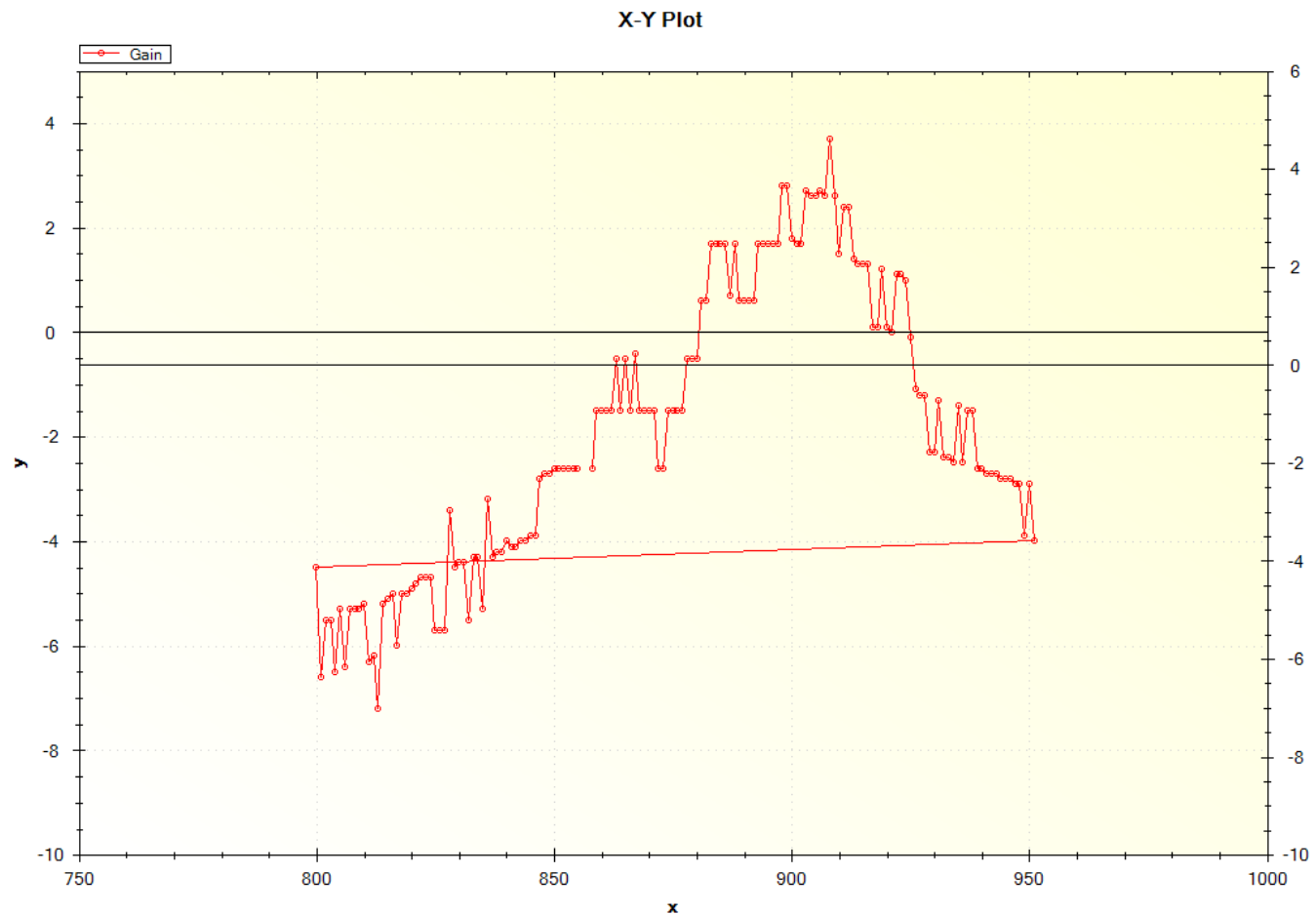
How to perform an antenna measurement ?

Measurement of 868MHz antenna
Sweep from 800 to 950 MHz



How to perform an antenna measurement ?

Measurement of 920 MHz antenna
Sweep from 800 to 950 MHz



Conclusion and perspective

- Can we do low-cost antenna radiation measurement ?
 - Yes and No, it depends on the accuracy you expect
 - Practice and know-how are essential
- Preliminary measurement can be realized to gain time
 - Some filtering can help
 - Repeat the same measurement for different distances
- Always consider uncertainty sources
- The more you invest, the more confident you will be in your measurement

REFERENCES

- Fabien Ferrero, CongDuc Pham, “Low Cost Antenna for IoT Deployment in Developing Country”, 12th European Conference on Antennas and Propagation (EuCAP 2018), 09/04/2018, London, Great Britain
- ETSI TS 103 052 V1.1.1 (2011-03)

Thanks to Christophe Danchesi and Stephane Boudaud from Abeeway for sharing the micro-tracker pictures

And thanks to Leonardo Lizzi from UCA for contributing in most on this work



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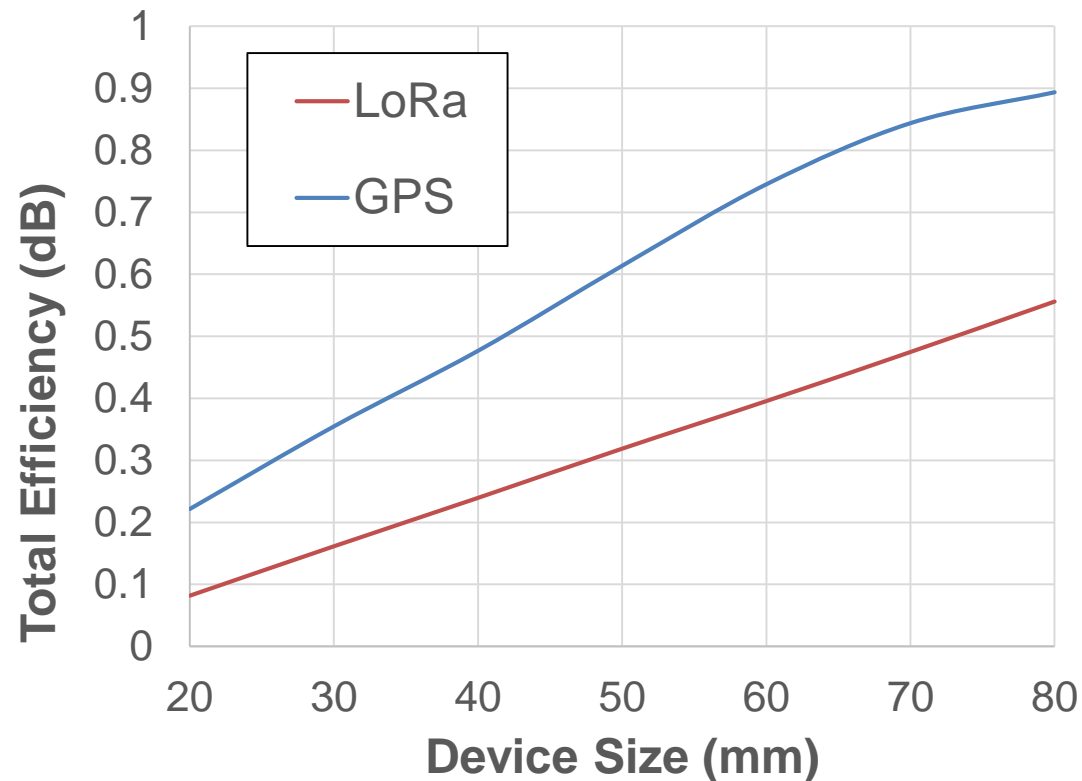
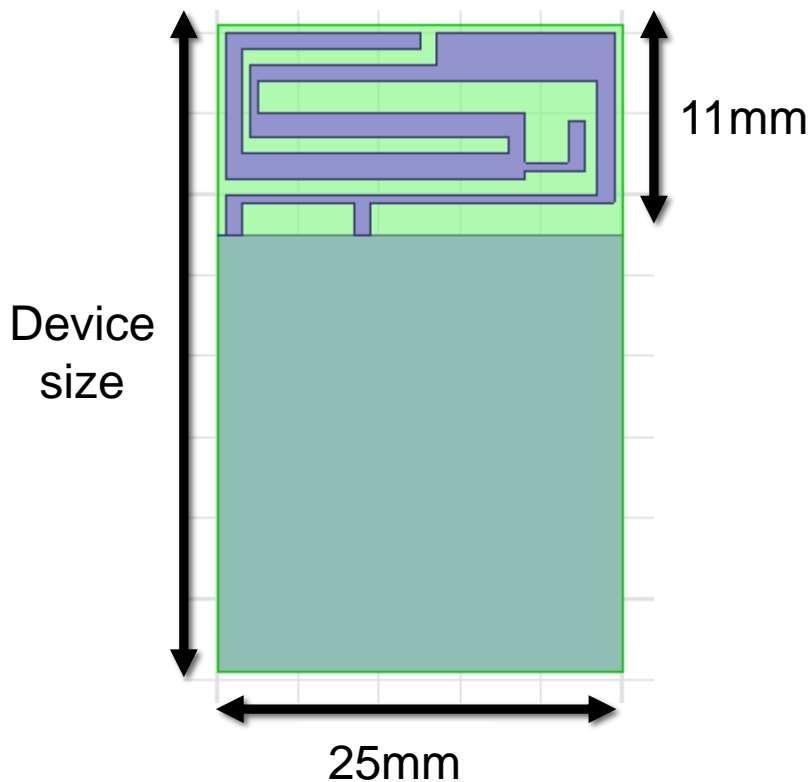
leat.unice.fr



Back-up Slides

Effect of terminal chassis

- LoRa (868MHz) and GPS (1575MHz) antenna on small terminal



UCA Antenna tuning : Reflection coefficient

