# PAU-SARA: a L1-GPS Band Radiometer and Reflectometer with Digital Beamforming and Polarization Synthesis

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# 0. Outline

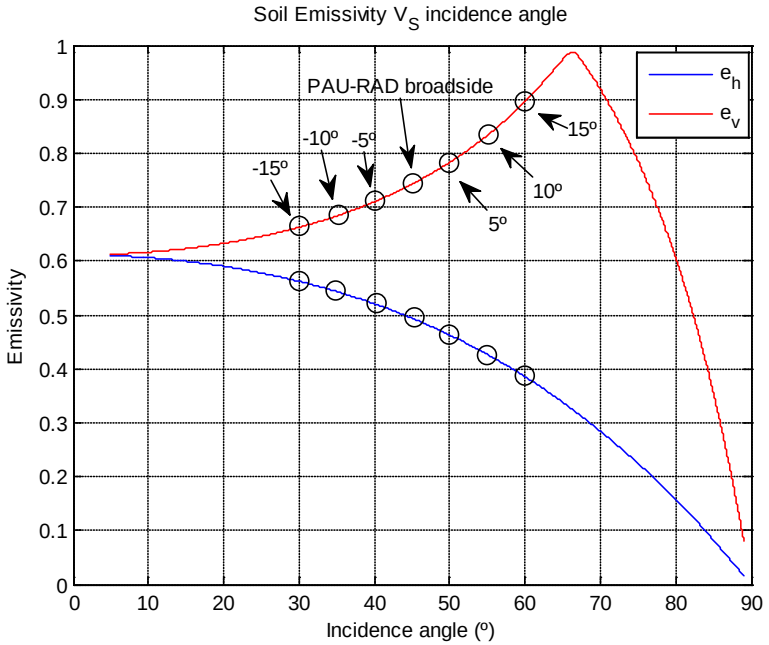
1. Introduction
2. PAU-SARA
3. SMIGOL Reflectometer
4. Conducted Field Experiment
   1. Pointing to the Horizon (IP-Reflectometer)
   2. Pointing to $\theta_i$=45º (Radiometer)
5. Conclusions

# 1. PAU-SARA instrument

1. **P**assive **A**dvanced **U**nit with **S**ynthetic **A**perture and **R**eal **A**perture

2. **REAL TIME Digital Beam Forming (DBF)** 4x4 elements: triangular-squared array at L1-GPS band

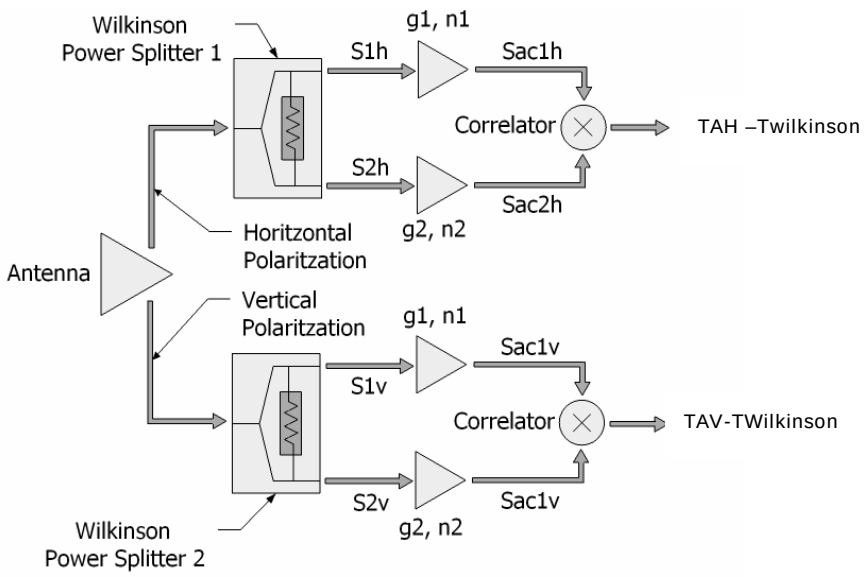
3. Steering: $\pm 20^o$ ($\Delta\theta = 5^o$) $\Rightarrow$ multi-angular observations




Boresight = 45º

# 1. PAU-SARA Main Characteristics

Architecture based on new kind of correlation radiometer.

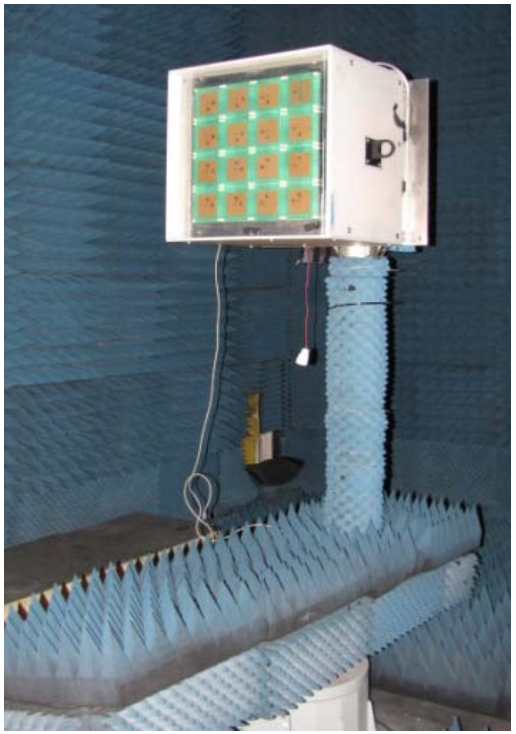


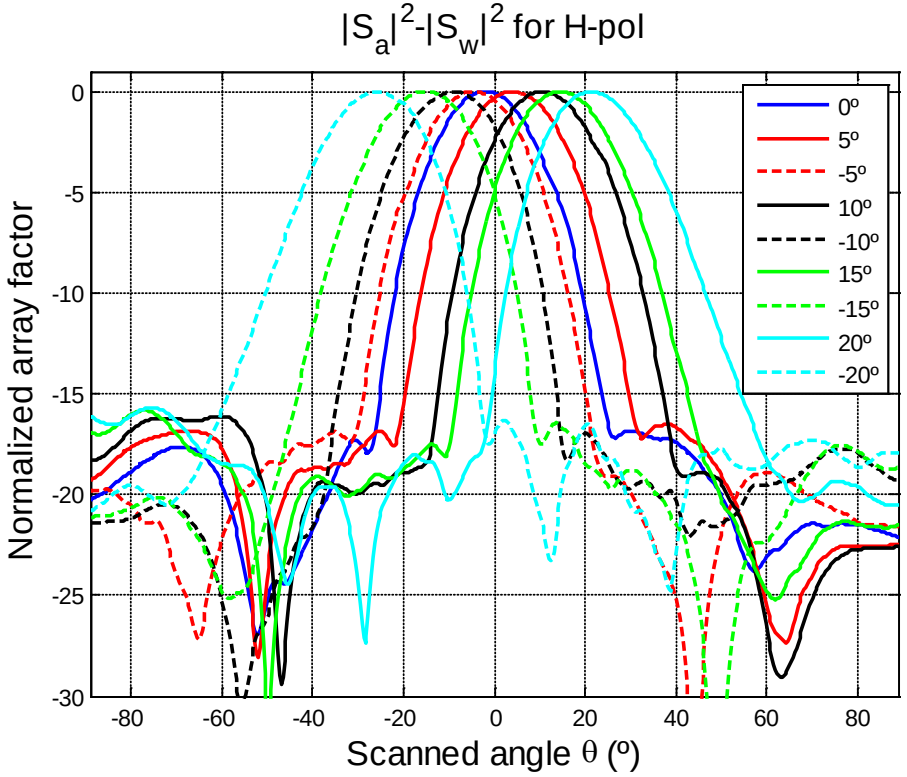

Topology suitable for :

1. Radiometric applications (output ~ Dicke radiometer)
2. Reflectometer applications (input signal not chopped ⟹ Tracking GPS)

# 2.PAU-SARA Performance

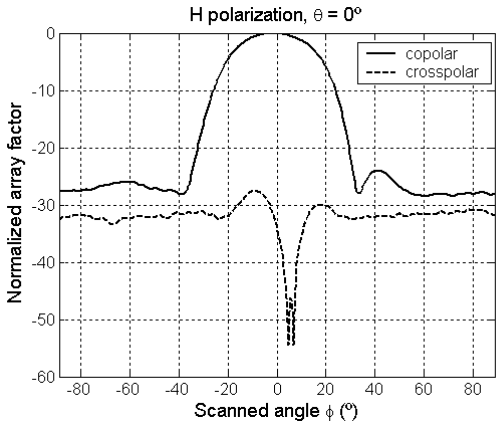
Synthesized beams as Real Aperture Radiometer measured at the UPC anechoic chamber.

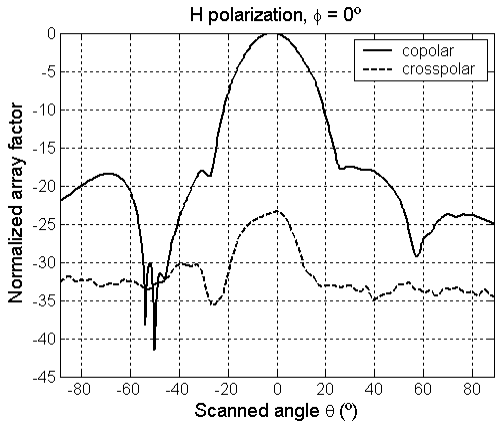




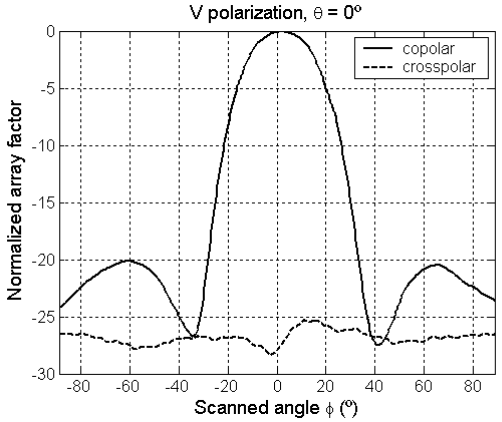
# 2. PAU-SARA performance for 0º steering beam (1/2)

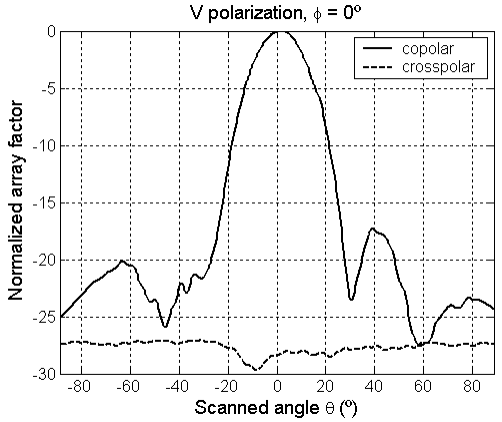
First Stokes parameter




Second Stokes parameter



# 2. PAU-SARA performance for all steering beams

Main Beam Efficiency Summary (Always >91%)

| Polarization<br>Beam steering | H | V |
|---|---|---|
| -20º | 92.5 % | 91.8 % |
| -15º | 93.2 % | 92.6 % |
| -10º | 93.2 % | 92.7 % |
| -5º | 93.3 % | 92.9 % |
| **0º** | **94.8 %** | **93.4 %** |
| 5º | 92.9 % | 92.5 % |
| 10º | 92.8 % | 91.9 % |
| 15º | 92.7 % | 91.7 % |
| 20º | 92.3 % | 91.2 % |

Beamwidth Summary (Always <24.6º)

| Polarization<br>Beam steering | H | V |
|---|---|---|
| -20º | 24.6 º | 24.2 º |
| -15º | 25.0 º | 24.8 º |
| -10º | 24.1 º | 24.0 º |
| -5º | 23.7 º | 23.1 º |
| **0º** | **22.8 º** | **22.4 º** |
| 5º | 23.7 º | 23.3 º |
| 10º | 24.6 º | 24.2 º |
| 15º | 23.8 º | 23.5 º |
| 20º | 24.2 º | 24.1 º |

# 3. SMIGOL Reflectometer

The **S**oil **M**oisture **I**nterference-pattern **G**NSS **O**bservations at **L**-band (SMIGOL) Reflectometer is the instrument implementing the IPT.

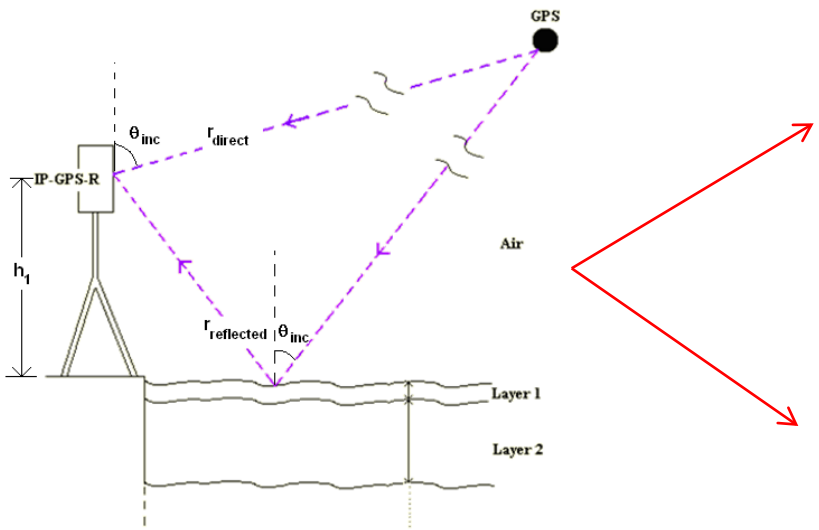
1. Working frequency = 1.57542 GHz (GPS L1)
2. Measures the interference between direct and reflected signals during all the satellite passages.
3. The IPT and the SMIGOL-Reflectometer can also be used to retrieve topography, soil moisture over vegetation-covered soils, and vegetation height as it has been tested in [1]

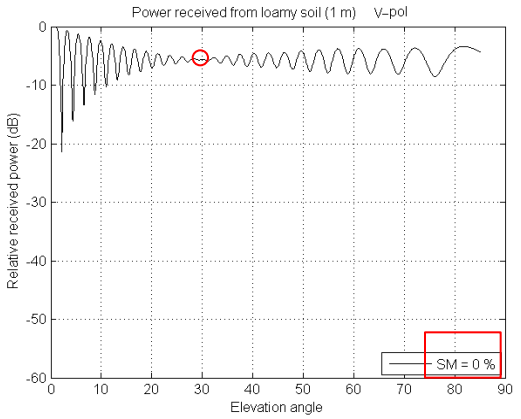
You can find more information about SMIGOL-Reflectometer and the IPT in the poster session, where a summary of their applications is shown.

LAND RETRIEVALS:–THE SMIGOL-REFLECTOMETER AND THE INTERFERENCE PATTERN TECHNIQUE

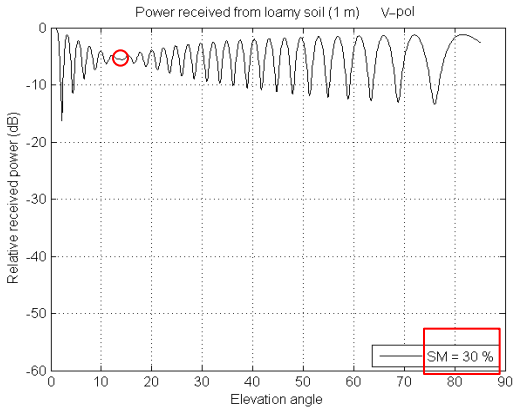
[1] Rodriguez-Alvarez, N., Camps, A., Vall-Llossera, M., Bosch-Lluis, X., Monerrris, A., Ramos-Perez, I., Valencia, E., Marchan-Hernandez, J.F., Martinez-Fernandez,J., Baroncini-Turricchia, G., Pérez-Gutiérrez C., Sánchez, N., "Land Geophysical Parameters Retrieval Using The Interference Pattern GNSS-R Technique" *IEEE Transactions on Geoscience and Remote Sensing*, DOI: 10.1109/TGRS.2010.2049023

# 3. Fundamentals of the Interference Pattern Technique




30 °

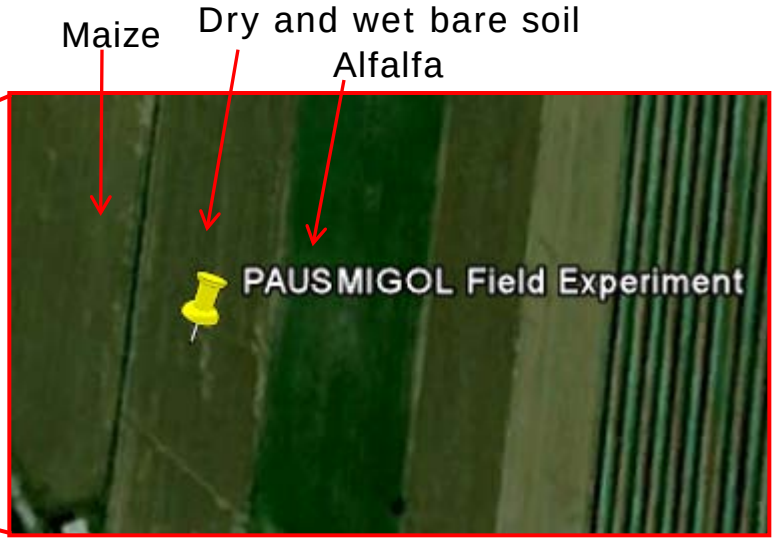



12 °

IPT for soil moisture retrieval over bare soils [1]

[1] Rodriguez-Alvarez, N., Bosch-Lluis, X., Camps, A., Vall-llossera, M., Valencia, E., Marchan-Hernandez, J.F., Ramos-Perez, I.; "Soil moisture retrieval using GNSS-R techniques: experimental results over a bare soil field," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 47 (11), pp. 245-248, November 2009.

# 4. Field experiment, Test Site

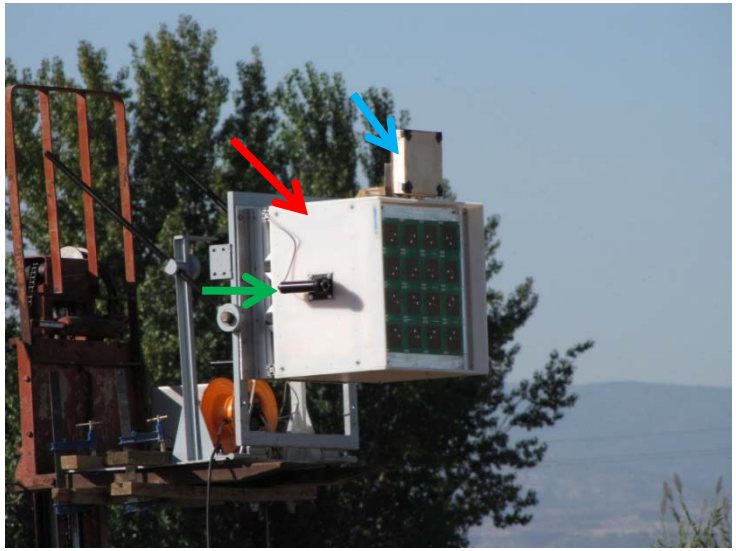

TEST Site:
Palau d'Anglesola, in an intensive agricultural environment

Lat. 41°39'57"N
Lon. 0°52'43"E

DATE: October the 5th 2010

# 4. Field experiment, Deployed Instruments

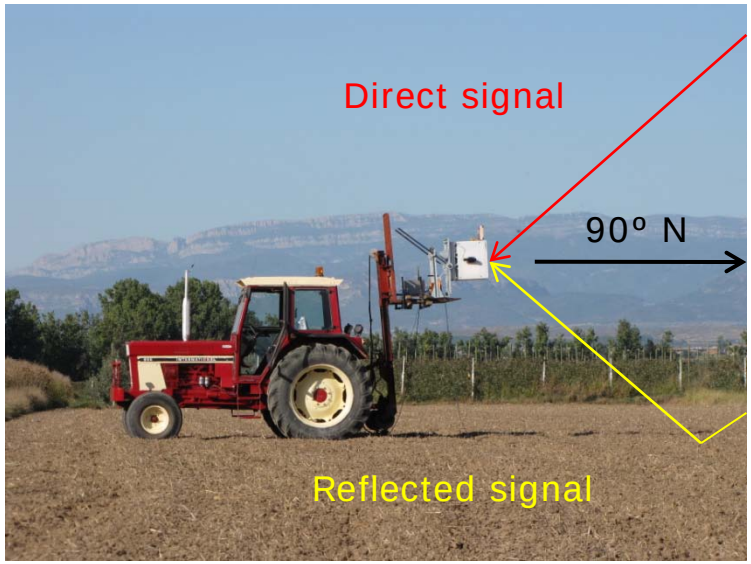
1. SMIGOL ,
2. PAU-SARA,
3. InfraRed termometer,



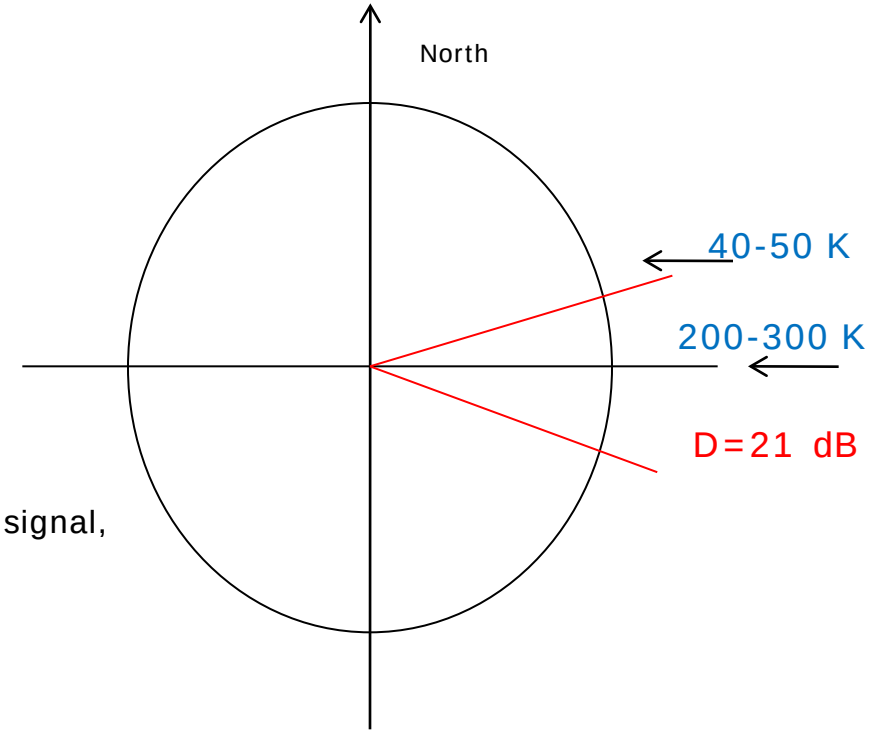
Ground truth measurement

4. Decagon ECH2O Soil Moisture probes , and
5. Thermometers

# 4.1. Field experiment, IP-REFLECTOMETER mode

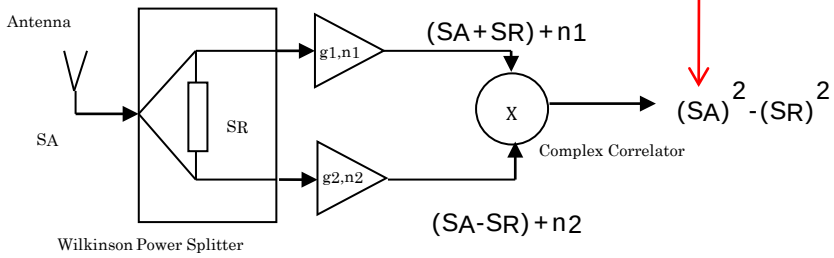



Beam shape spatial filter,
Azimuth : from 70º to 110º
Elevation: from 0º to 20º




IP-Reflectometer mode:

1. Does not use a PRN code replica to correlate the input signal,
2. Measures the fluctuation of the antenna input power,

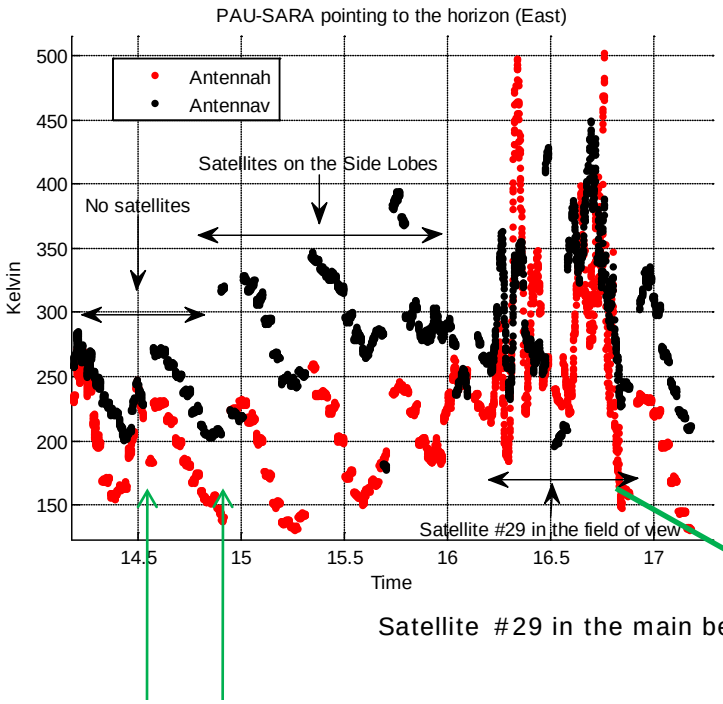



GPS no significant impact when signal attenuated >15 dB then Tb<0.3k

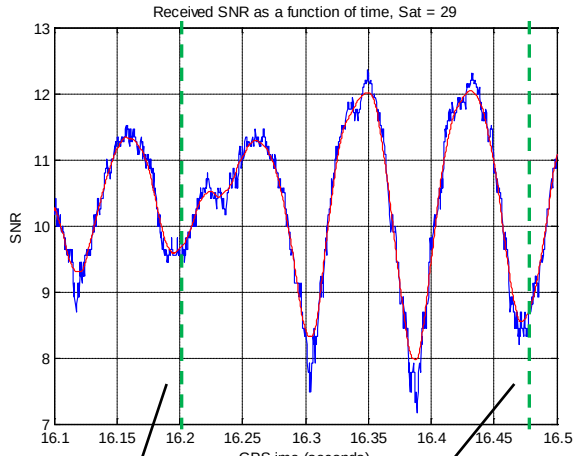
# 4.1. Field experiment, REFLECTOMETER mode

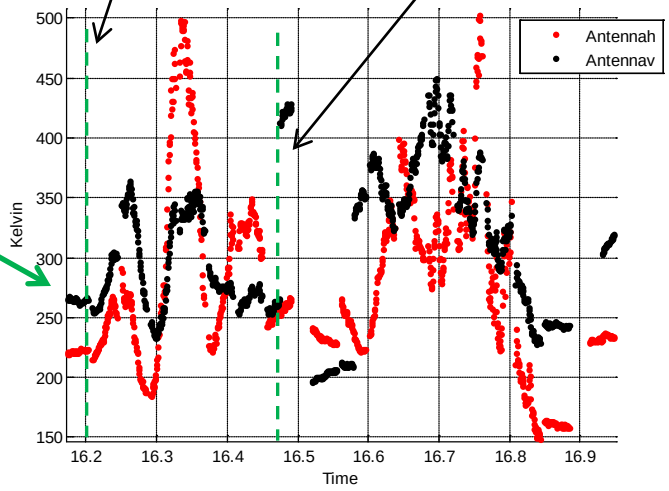
Azimuth considered: from 70º to 110º
Elevation considered: from 0º to 20º

As expected V polarization is the most sensitive



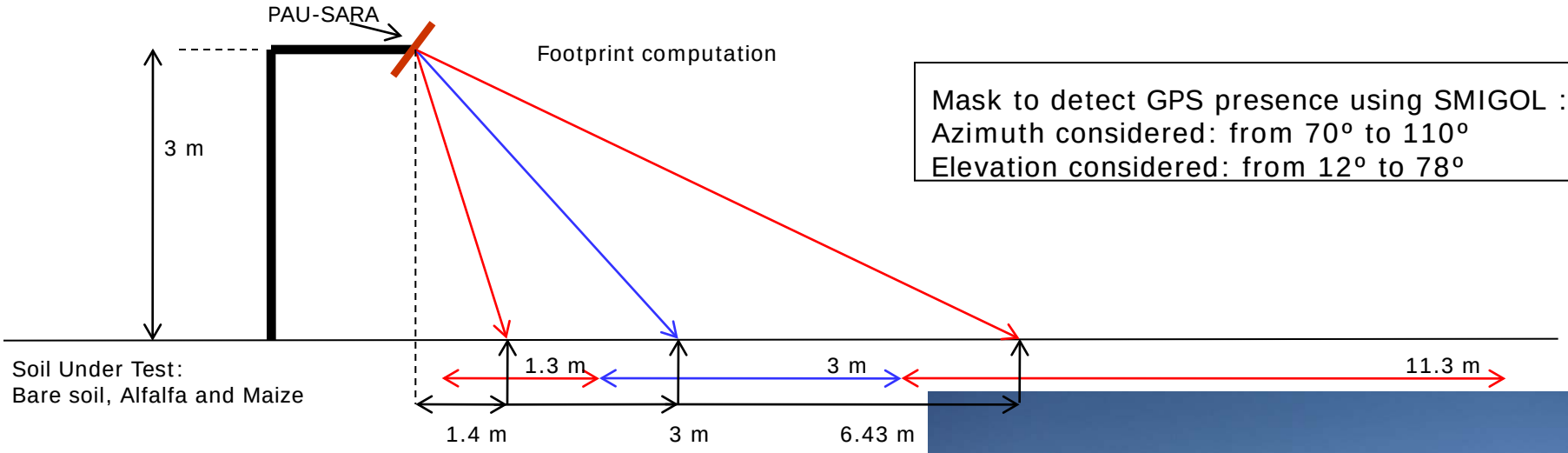

Satellite #29 in the main beam



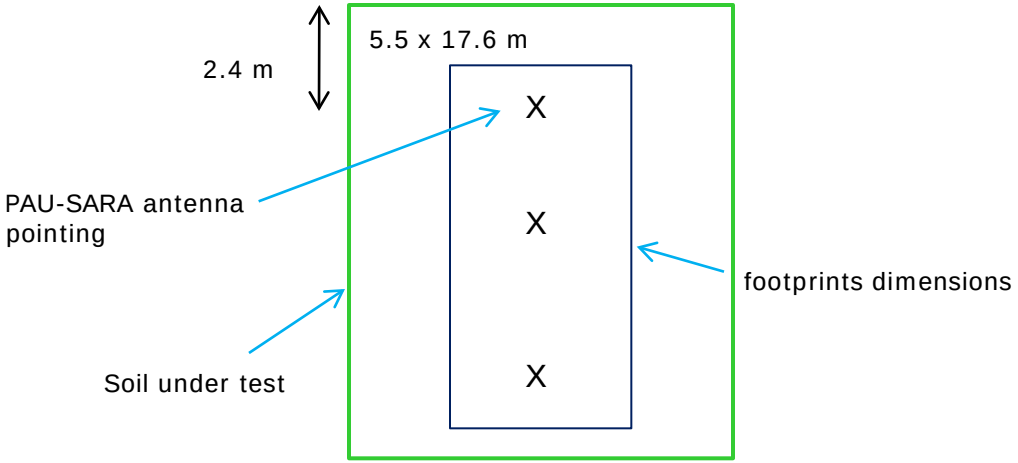



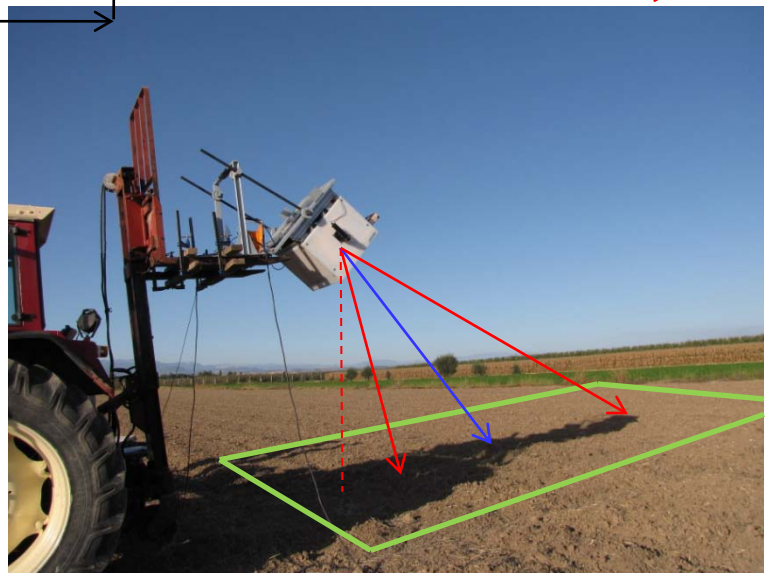

DBF scanning period from -20º (mainly Soil) to +20º (half Sky)

# 4.2. Field experiment, Set UP

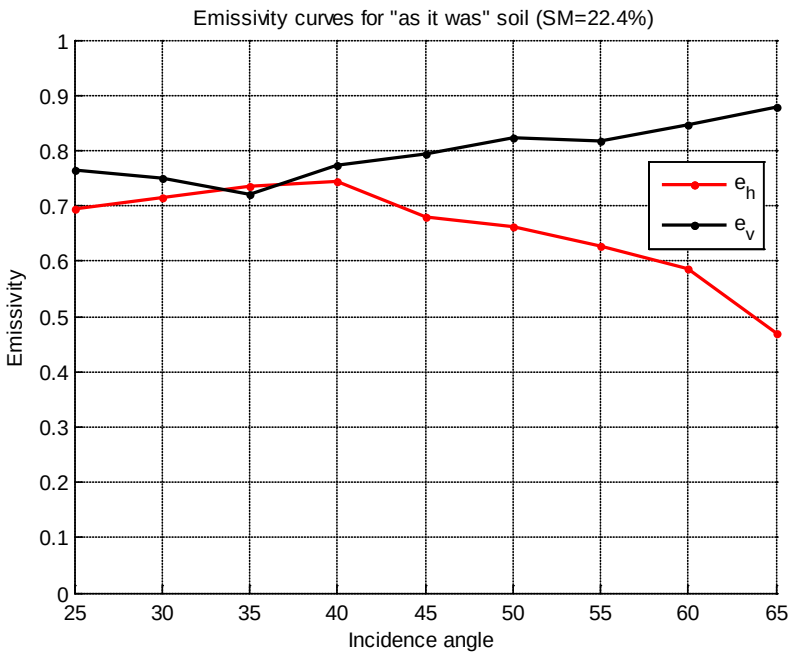


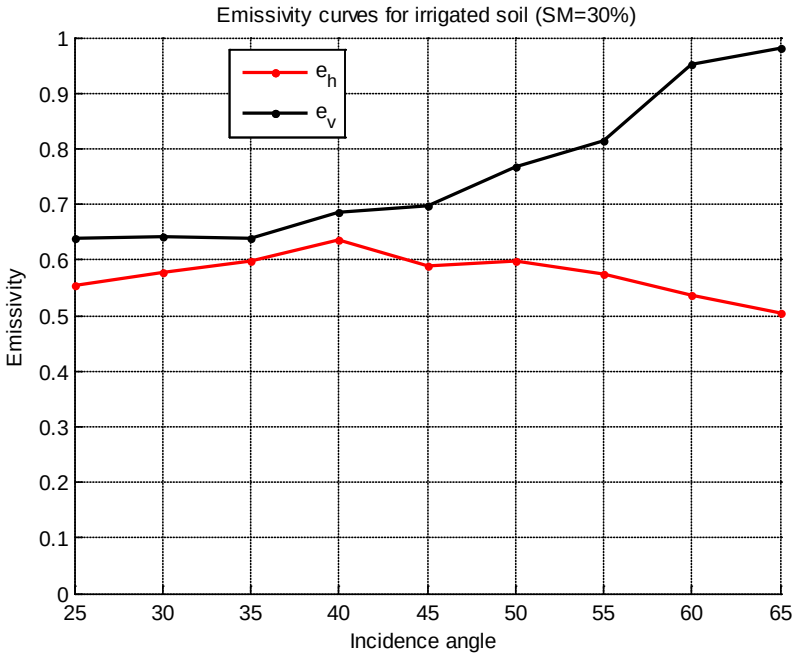

Mask to detect GPS presence using SMIGOL :
Azimuth considered: from 70º to 110º
Elevation considered: from 12º to 78º



# 4.2. Field experiment, Radiometer mode Results

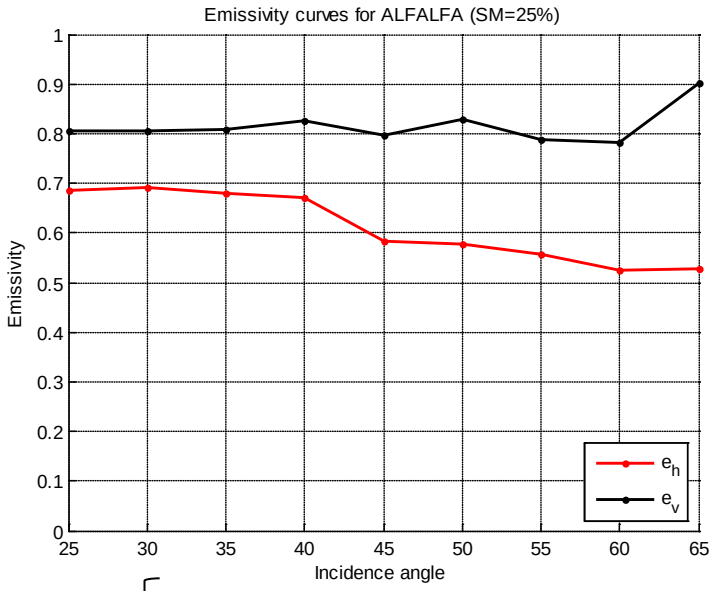


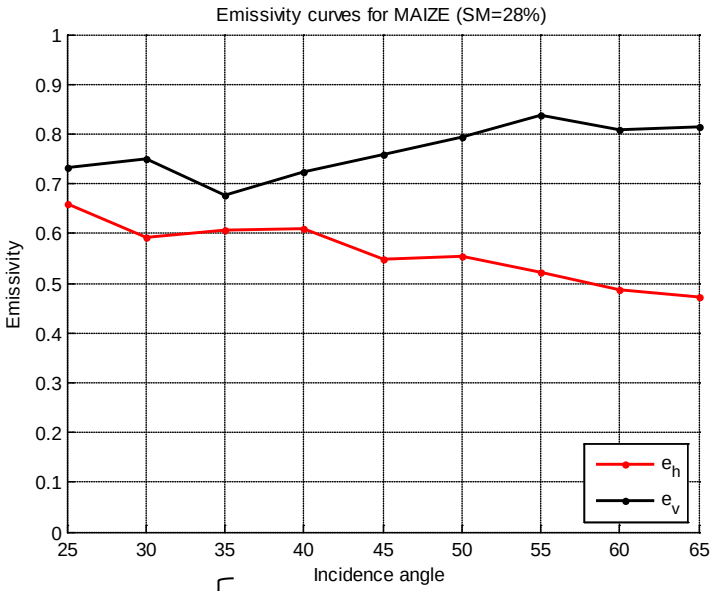




Data–Sets without presence of GPS in the main beam

# 4.2. Field experiment, Radiometer mode Results

Data Sets without presence of GPS in the main beam




hAlfalfa= 15 cm
SM= 25%
Tsoil= 287.1 K

hMaize=2.85 m
SM= 28%
Tsoil= 285.3 K
Maize plants were dry

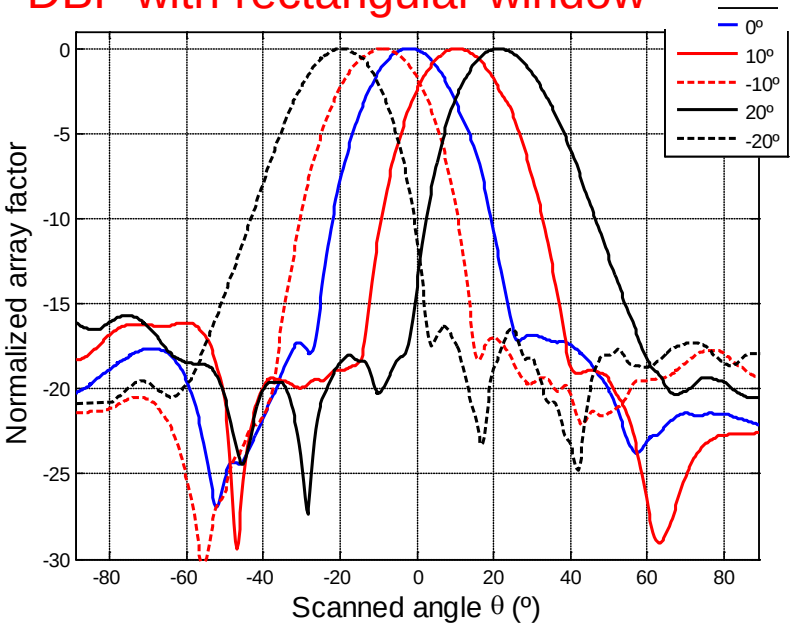
# 5. Conclusions

1. A radiometer with DBF at GPS-L1 band has successfully developed and tested for radiometric applications,( it is possible to neglect the GPS impact with $\theta_i$= 45 and a narrow beam, ~ 0.3 K of impact when entering from the side lobes),
2. it is recommended to have a GPS receiver to ensure that there is no GPS satellite presence corrupting the measurements. If possible, pointing the instrument to the North(no Satellites),
3. when the GPS signal is corrupting a measurement, RFI techniques can be applied to nitigate the GPS effect on the radiometric data,
4. with the PAU-SARA antenna, when looking to the horizon the GPS can increase the measured power 300 K, without correlating it with any PRN code,
5. PAU-SARA can also successfully work as a IP-Reflectometer despite it only measures power, really convenient to make SM maps (better using a high bandwitdh antenna), and
6. Keep on working on collected data sets to retrieve SM information from collected data sets.

# THANK YOU!

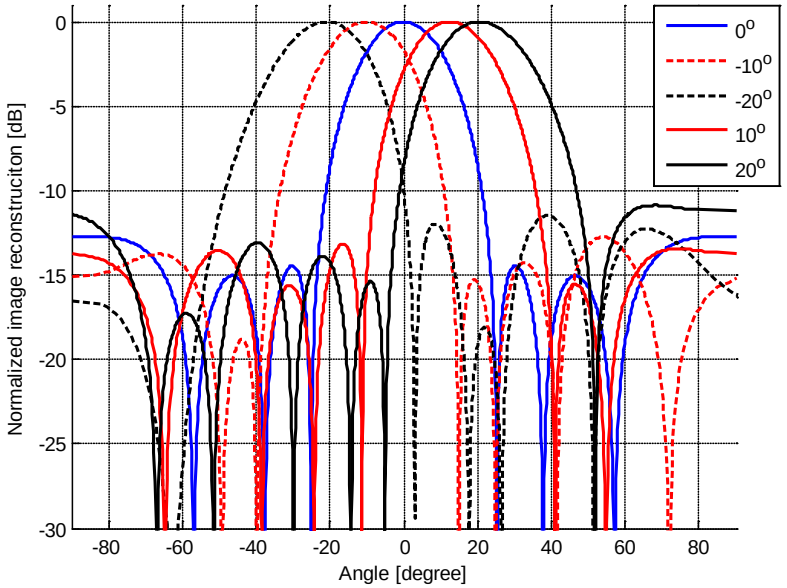
# B1. PAU-SARA real and synthetic imager equivalence

DBF with rectangular window




(a)

Synthetic aperture with triangular window




(b)

Sample of PAU-SARA measurements at the UPC anechoic chamber.

(a) PAU-RAD DBF measured results, normalized array factor for multiple measured beams in the H polarization scanning the zenith range,
(b) reconstructed synthetic images for different point sources at different zenith angles, using a triangular window.