Consiglio Nazionale delle Ricerche

Istituto di Elettronica e di Ingegneria dell'Informazione e delle Telecomunicazioni

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Recent Results with the UAV-based Array Verification and Calibration System

Giuseppe Virone

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POLITECNICO DI TORINO
DIATI

UNIVERSITY OF CAMBRIDGE

ASTRON

Framework

Research contract between INAF and CNR-IEIIT

- Title: Power Pattern Measurements on the Modern Low-Frequency Arrays for Radioastronomy (AAVSx, LOFAR, SAD) and Feasibility of Phase Pattern Measurements
- INAF PI: Jader Monari and Pietro Bolli
- CNR PI: Giuseppe Virone
- Partner : Politecnico di Torino- DIATI, Resp. Prof. Andrea M. Lingua
- Official initial date: September 2015

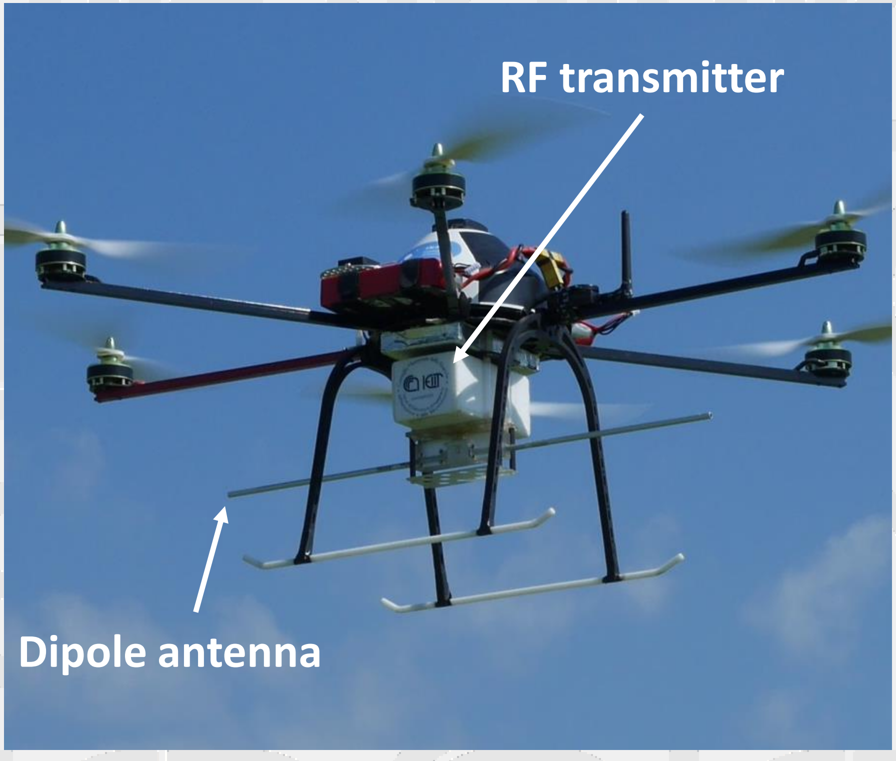
TECNO INAF 2014

- Title: Advanced calibration techniques for next generation low-frequency radio astronomical arrays
- PI: Pietro Bolli (OAA) – co-PI: Giuseppe Pupillo (IRA-MED) and Tonino Pisanu (OAC)
- Official initial date: April 2015
- Research grant (18 months) to Salvo Pluchino (IRA-Noto)
- External collaborators: Stefan Wijnholds, Andrea Lingua and Giuseppe Virone

Flying Far-field Test Source

A micro hexacopter is used as far-field RF source

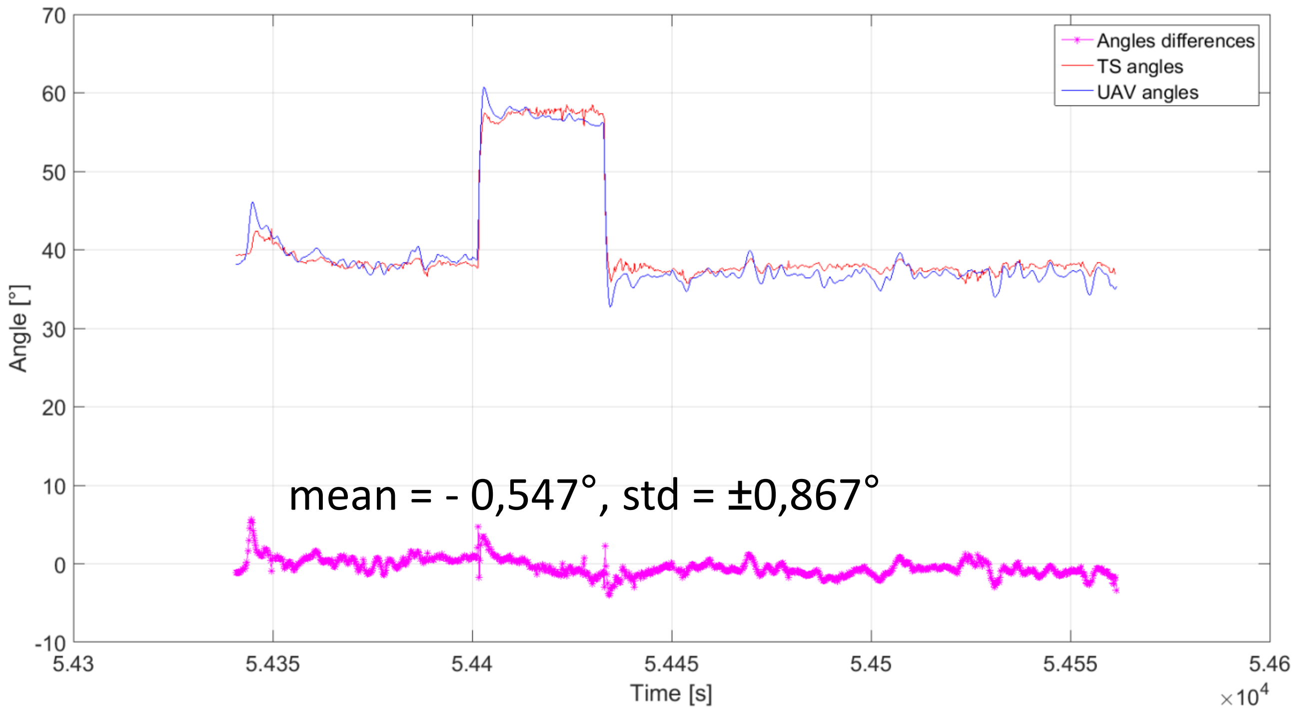
flying over the AUT



- UAV equipped with a continuous-wave RF transmitter and a dipole antenna
- The UAV autonomously performs quasi-rectilinear, constant height paths (GPS navigation) e.g. E-plane or H-plane cuts
- Automatic take-off and landing
- Differental GNSS system to track the position (accuracy few cm)
- On-board IMU to measured attitude (pitch, roll, yaw)

Compass Verification

DIATI

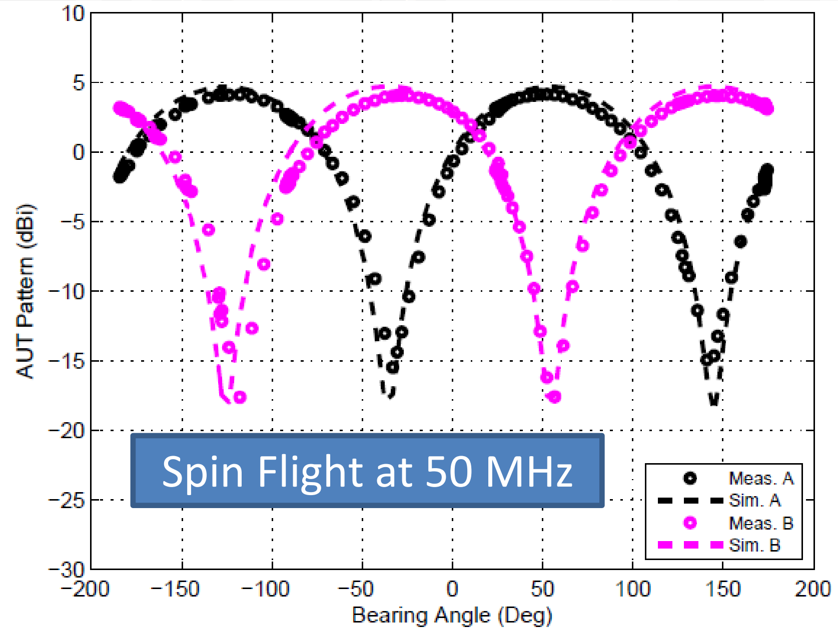


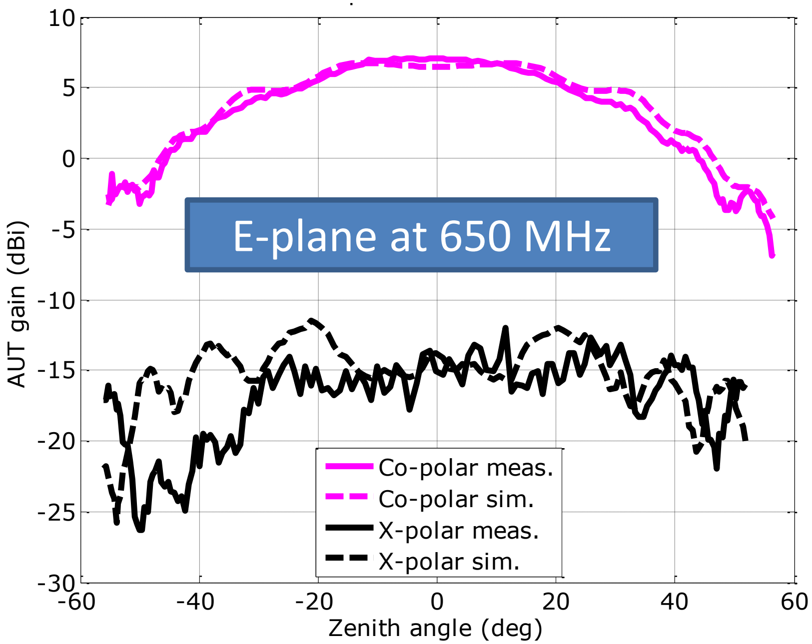
- Two scatterers on the UAV
- Two total station pointing the UAV (accuracy 1 cm)
- The other angles could be verified as well

SKALA 2.0 Pattern from 50 to 650 MHz

Courtesy of

SKALA dual log-periodic antenna working from 50 to 650 MHz. Height is about 1.8 m

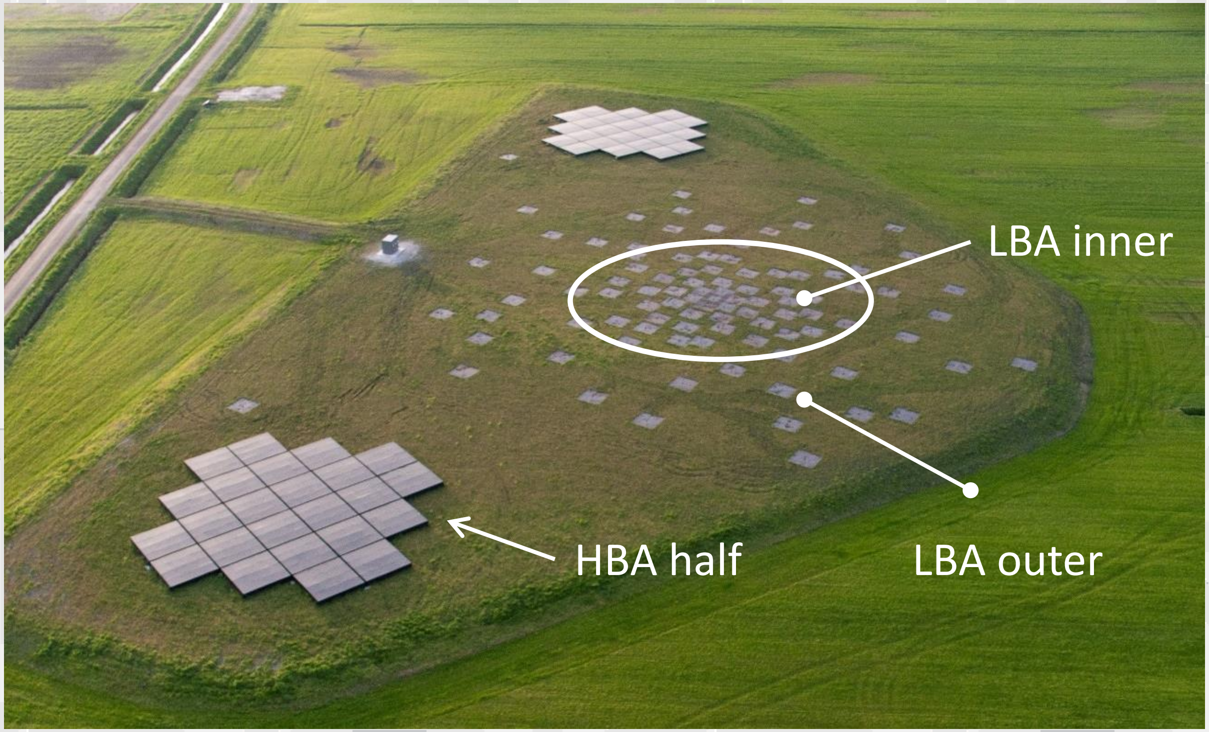




LOFAR campaign April 2016

in collaboration with Stefan Wijnholds and Menno Norden

Aerial View of a LOFAR station (The Netherlands)



UAV to perform an end-to-end system verification

Three Arrays in Three Days with Multi-frequency TX (almost 300 Patterns/Flight)

Embedded Element Patterns

Array Calibration and Pattern

Antenna positions (SW's talk)

Courtesy of ASTRON

LBAinner: 48 dual-pol elements (random quasi-dense) 10-80 MHz

LBAouter: 48 dual-pol elements (random sparse) 10-80 MHz

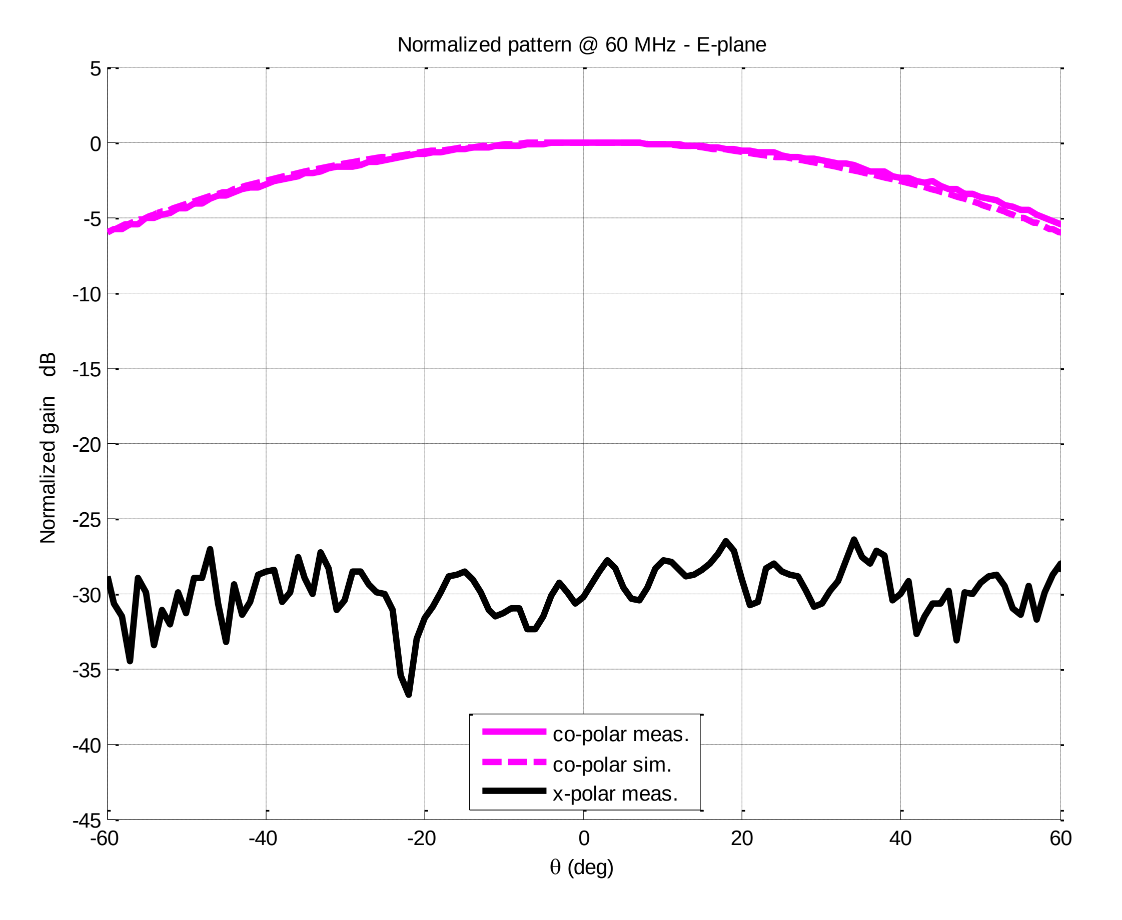
HBA: 48 tiles having 16 dual-pol bow-ties (dense) 120-240 MHz

LOFAR LBA antenna in Turin

LOFAR Low-Band Antenna in Turin

Courtesy of: ASTRON

LBA simulation by Michel Arts using WIPL-D



LBA antenna consists of a pair of crossed inverted-V dipoles operating from 10 to 80 MHz. Antenna height is 1.7 m, width is about 3 m

Gain Measurement

	60 MHz pol. A (1st)	60 MHz pol. A (2nd)	60 MHz pol. B
P_{rec} (dBm)	-24.272±0.1	-24.101±0.1	-24.775±0.1
P_{TX} (dBm)	5.050±0.1	5.050±0.1	5.050±0.1
$InsLos$ (balun) (dB)	0.298±0.1	0.298±0.1	0.298±0.1
$MisLos$ (UAV dipole) (dB)	4.181±0.159	4.181±0.159	4.181±0.159
g_{UAV} (dB)	2.562±0.1	2.576±0.1	2.603±0.1
$PatLos$ (dB)	45.437±0.012	45.514±0.012	45.237±0.012
A_{cables} (dB)	9.252±0.1	9.252±0.1	9.942±0.1
g_{AUT} (dB)	+27.284±0.276	+27.519±0.276	+27.231±0.276

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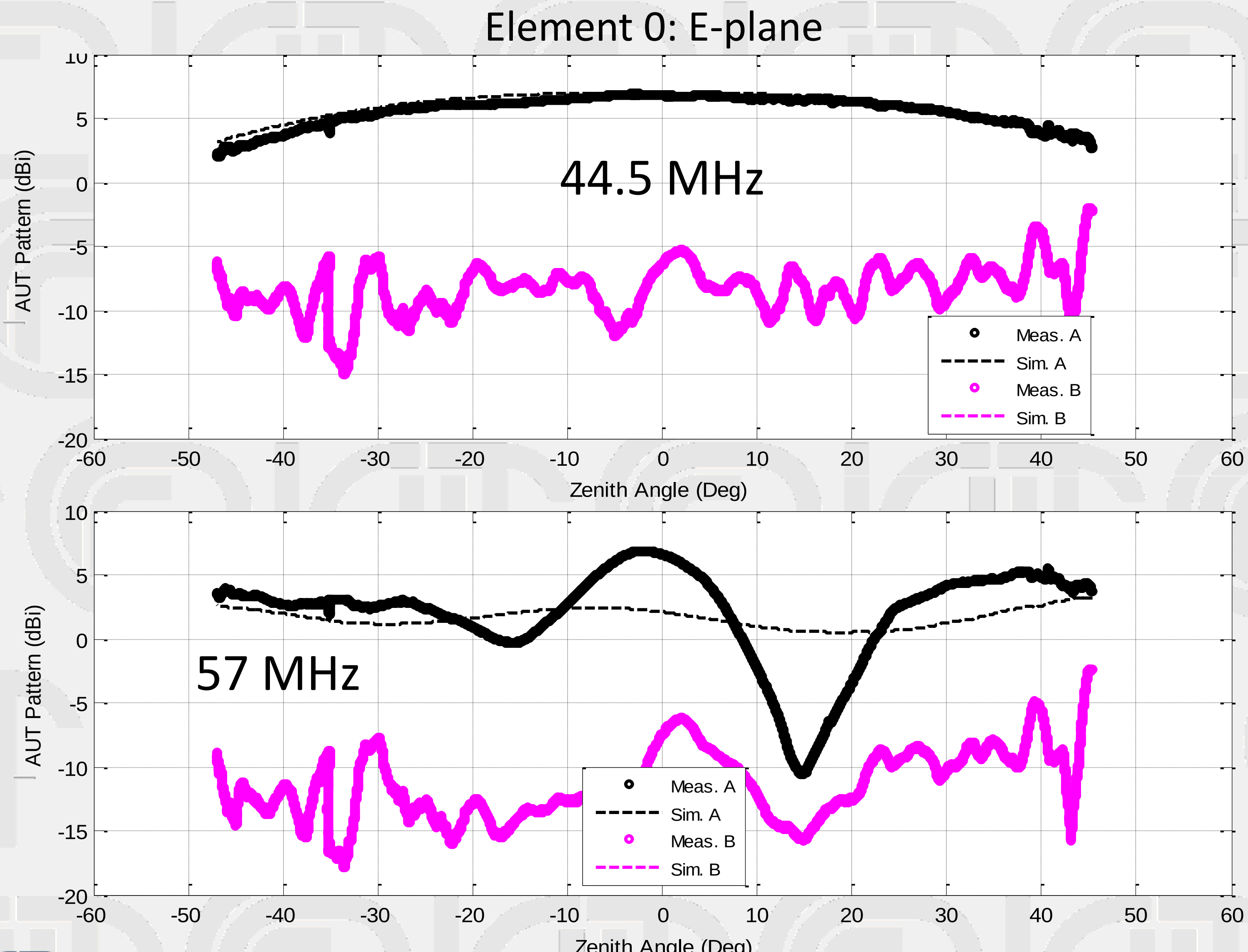
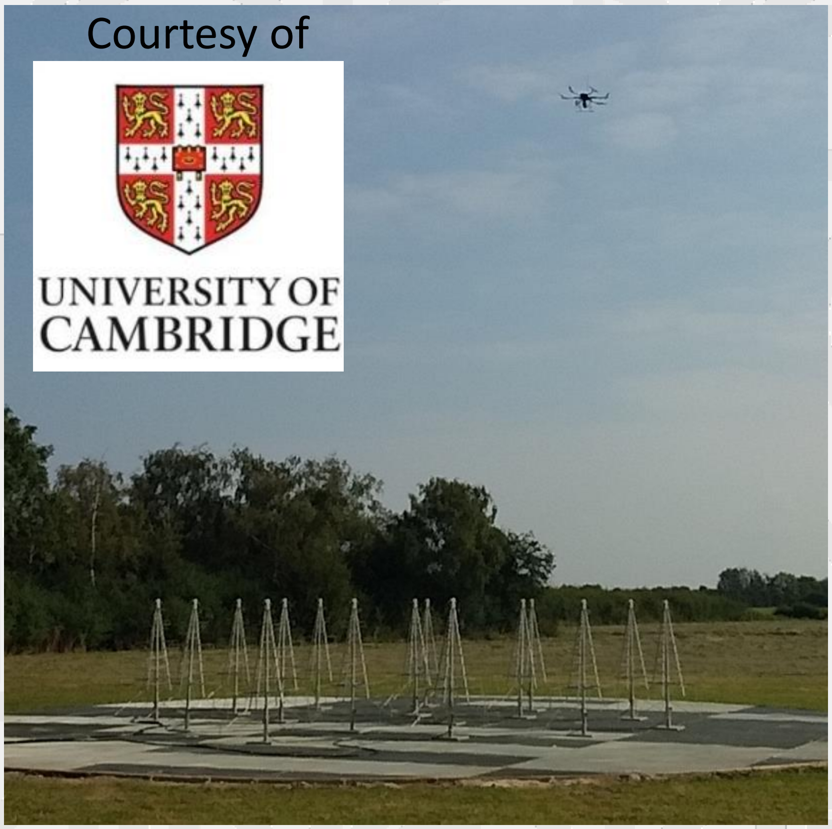
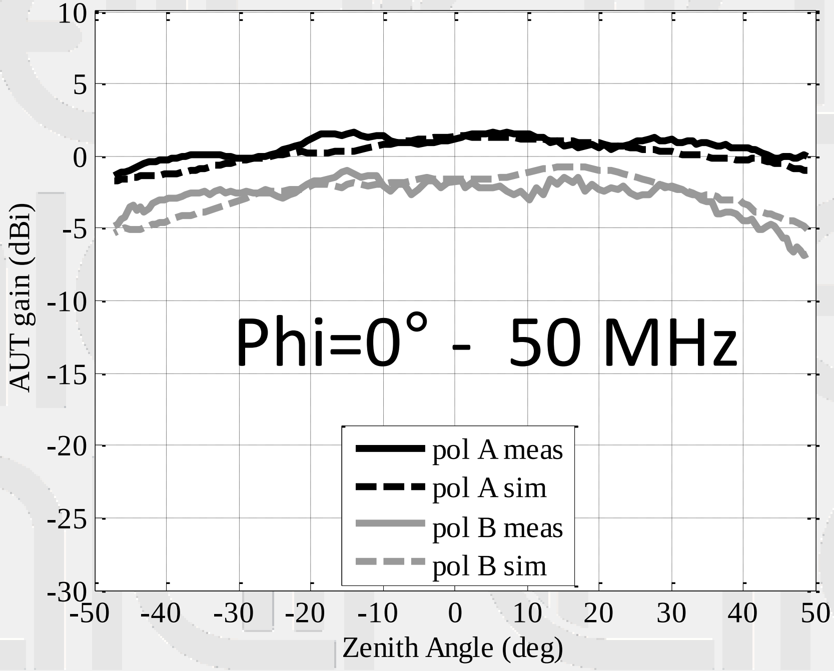
Embedded Element Pattern LBA inner

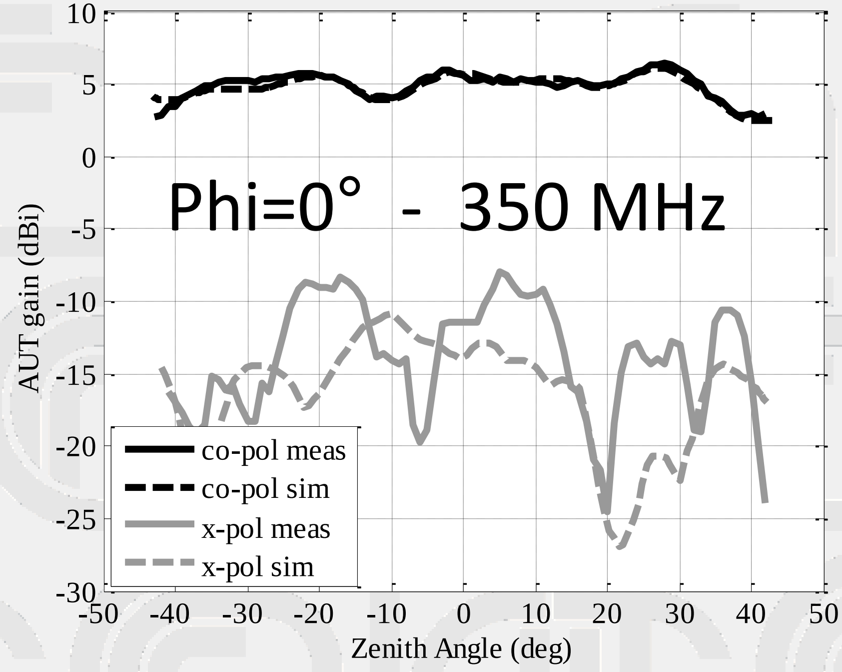


AAVS0.5 Embedded Element Patterns at 50 and 350 MHz

Mullard Radio Astronomy Observatory (UK)

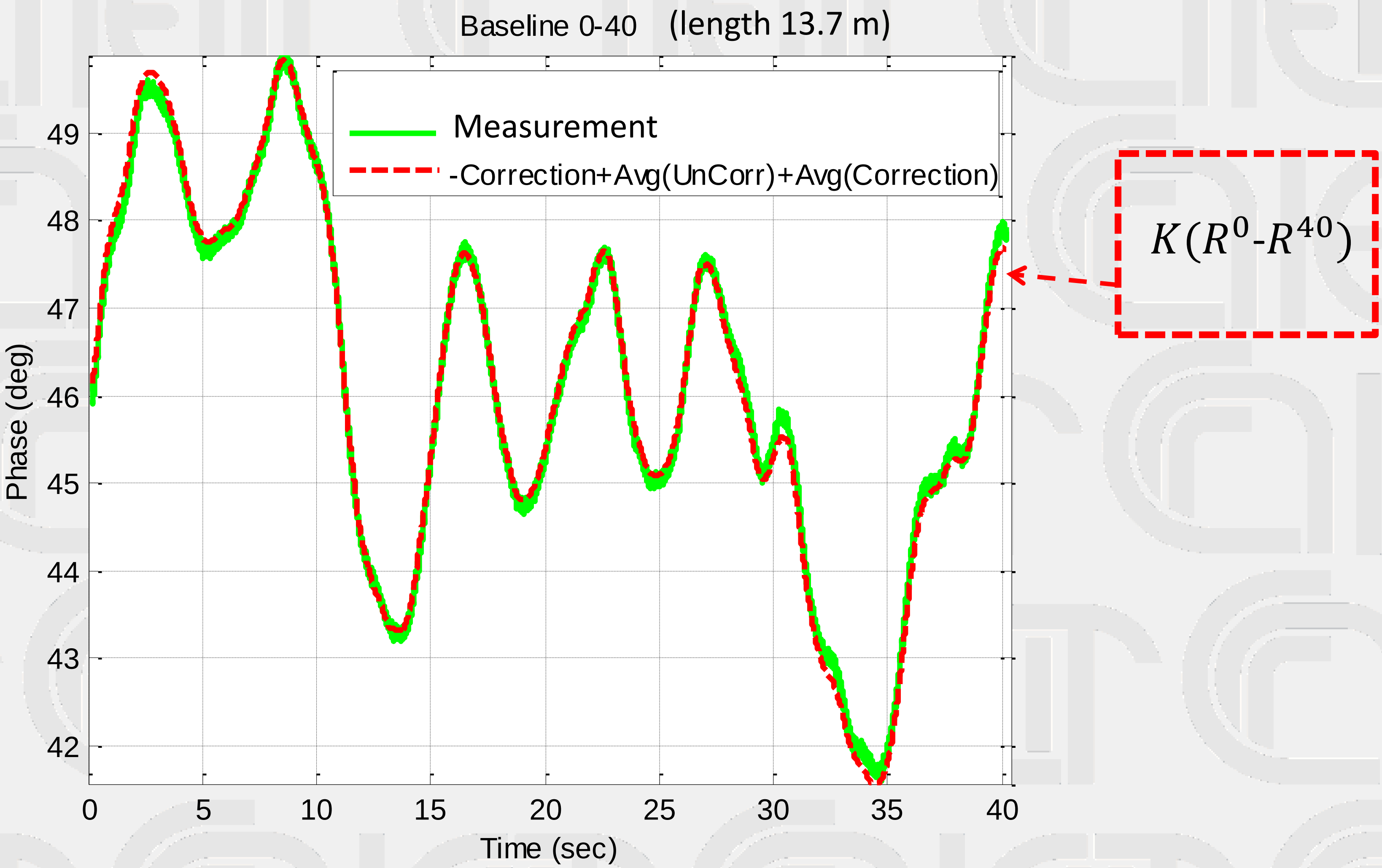




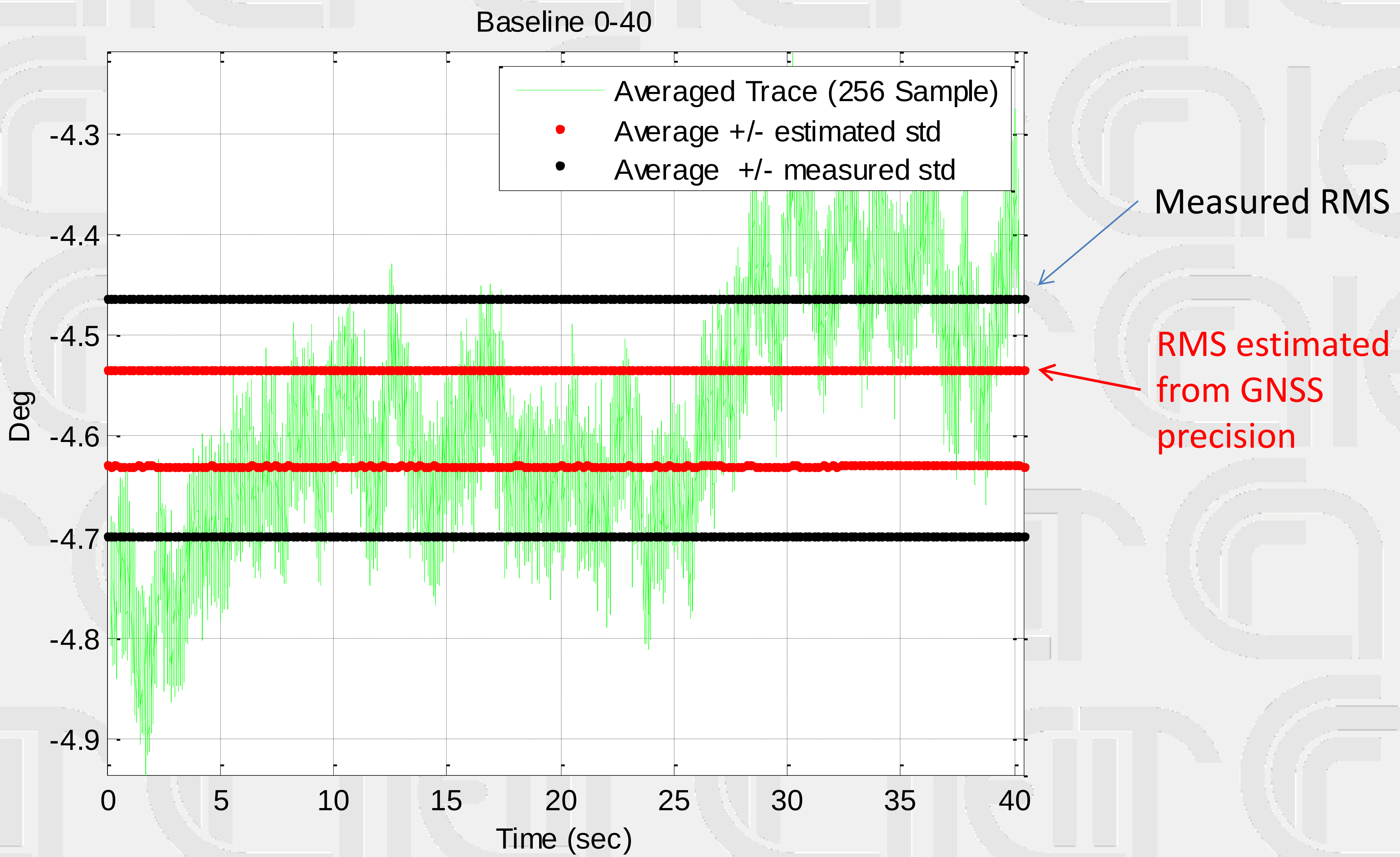


Phase of Cross Correlation Coefficient at 44.5 MHz

UAV at zenith above central element of the LBA inner



Residual Phase Value



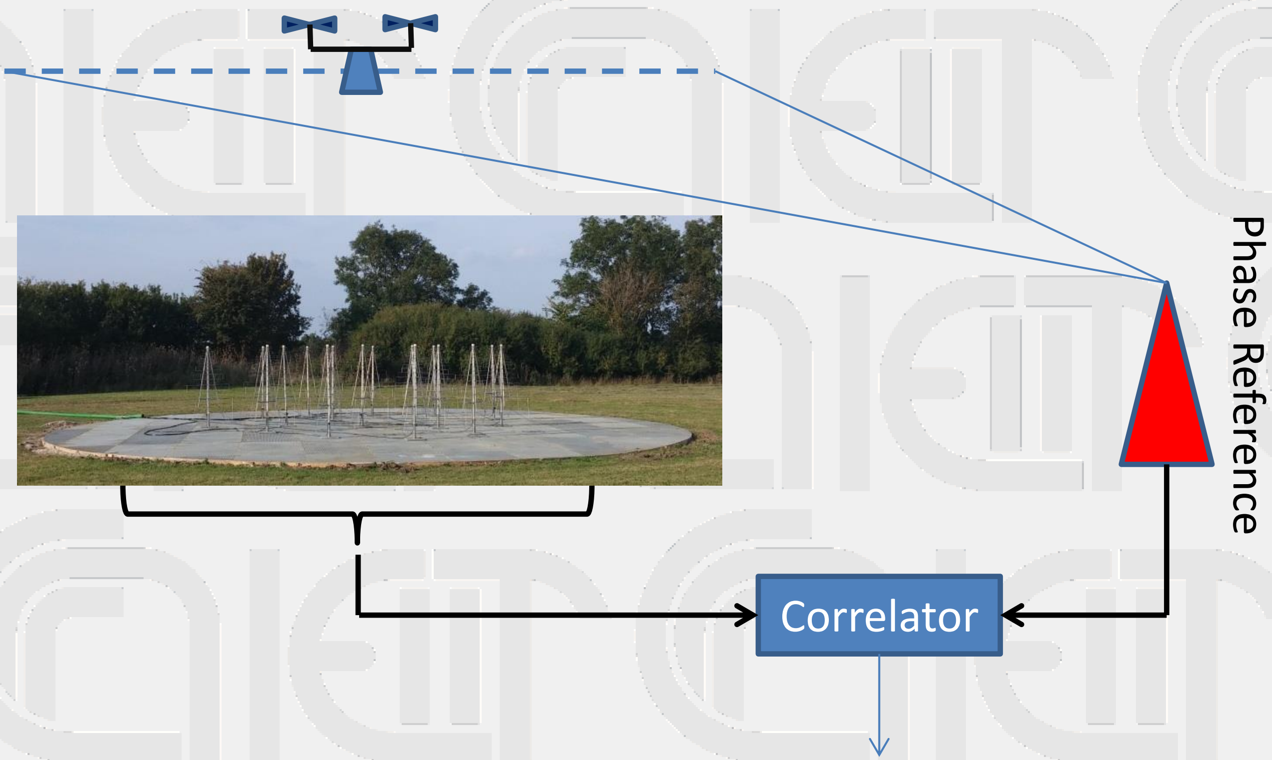
For shorter baselines where the elements see the UAV at the same observation angle, this residual correspond to the **calibration coefficient**

Second Day: Wind Speed 35 km/h

- Cause not yet fully understood
- The day before the wind was even faster. The UAV was not able to follow the preset path but was still able to land automatically
- The values of attitude angles (pitch about 20 Deg) are less accurate
- All the attitude traces are more noisy

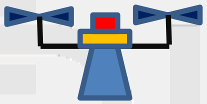
Ideas for the Upcoming Cambridge pre-AAVS1 Campaign

Near-field scan and Relative Phase Measurements



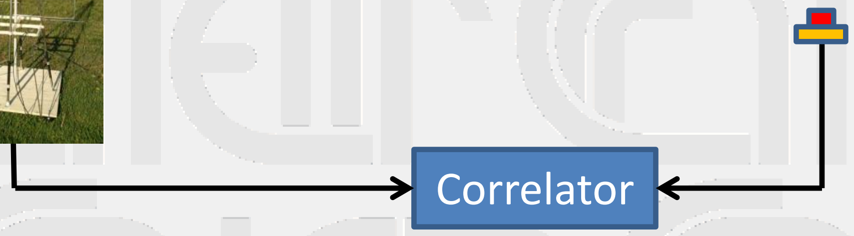
Measured Phase $\varphi^{out} = \varphi^{array} - \varphi^{ref} - K(R^{array}\text{-}R^{ref})$

Ongoing: Phase-Locked UAV Transmitter

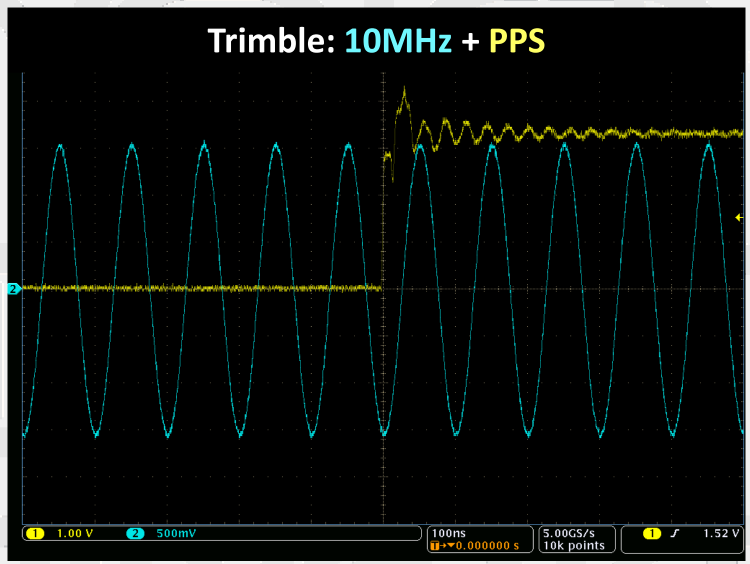


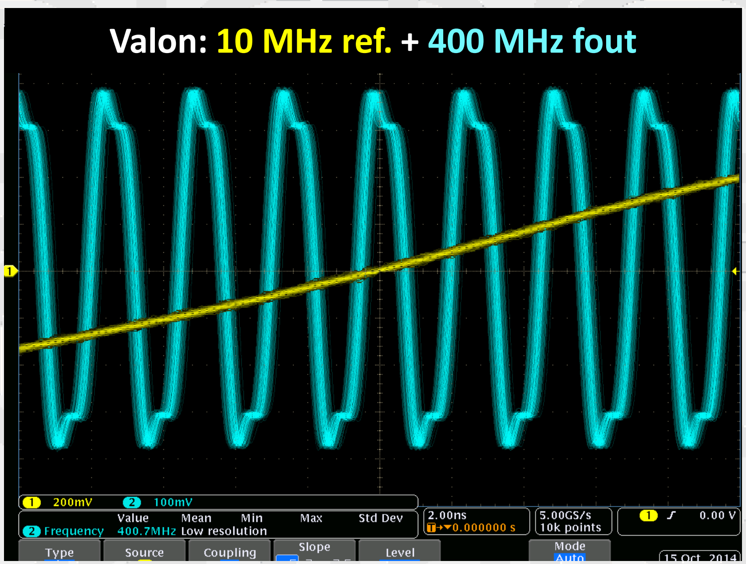
RF oscillator locked with the GNSS PPS signal

Independent of Reference Antennas



Copy of the transmitted signal

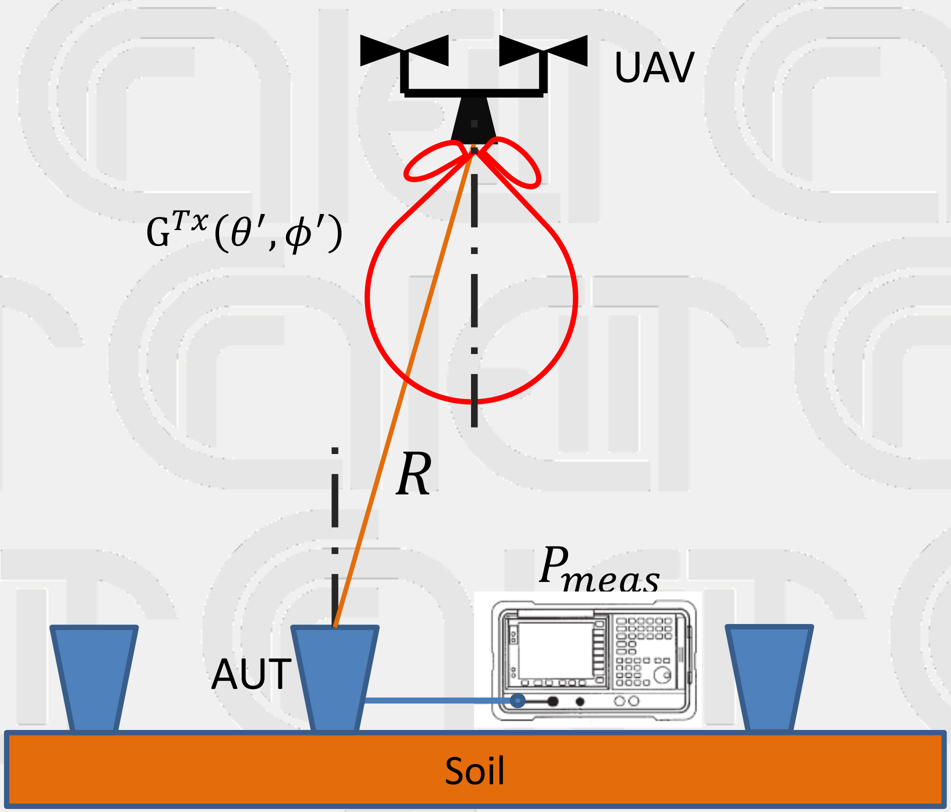




Ongoing: UAV-based Sensitivity Measurements

by G. Pupillo and S. Pluchino

The proposed method allows to measure the Sensitivity (A_{eff} / T_{sys}) of the system, including all its parts, in the operating environment.



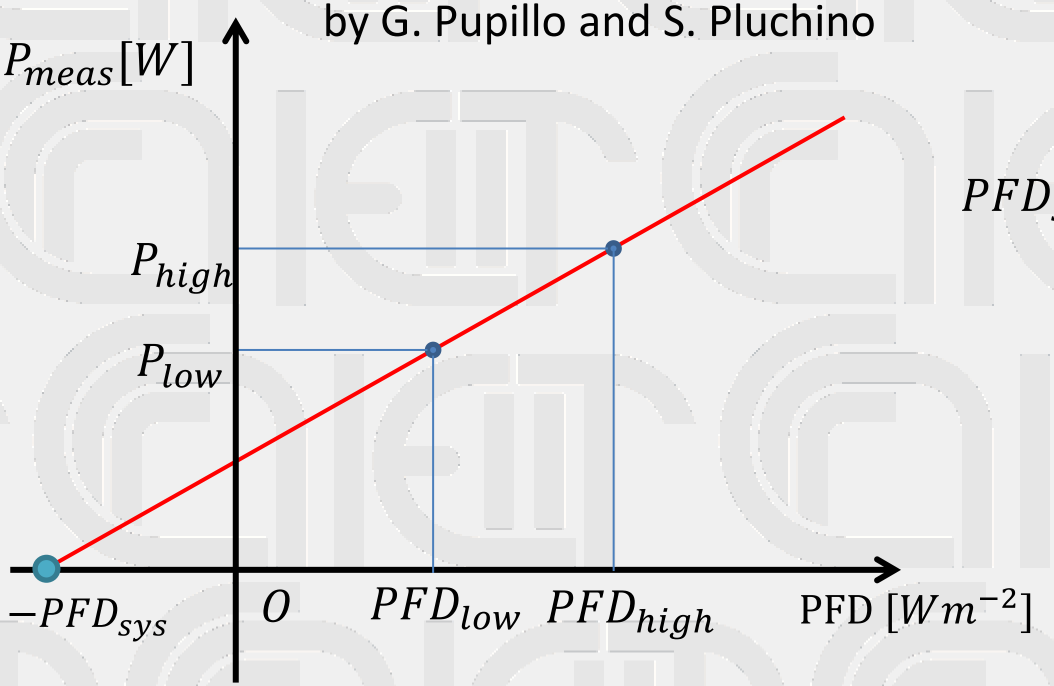
The method estimates the Power Flux Density at AUT

$$PFD = \frac{P_{Tx}\, G_{Tx}(\theta', \phi')}{4\pi R^2} \quad [W m^{-2}]$$

PFD is defined as the transmitted UAV energy, impinging upon the AUT per unit area

UAV-based Sensitivity measurements

by G. Pupillo and S. Pluchino



$$PFD_{sys} = \frac{PFD_{high}P_{low} - PFD_{low}P_{high}}{P_{high} - P_{low}}$$

The sensitivity can be estimated by mean of PFD_{sys} as follow:

$$\boxed{\frac{A_{eff}}{T_{sys}} = \frac{kB}{PFD_{sys}} \quad \left[\frac{m^2}{K}\right]}$$

Where:

- P_{meas} = measured received power $[W]$
- PFD_{low}, PFD_{high}= Surface Power Density $[Wm^{-2}]$ corresponding to two different power level trasmissions by UAV

Assumptions:

- Rx chain linearity
- Negligible T_{sys} and gain variations

Tasks to be done:

- Error budget investigation
- Simulations
- Test on the field

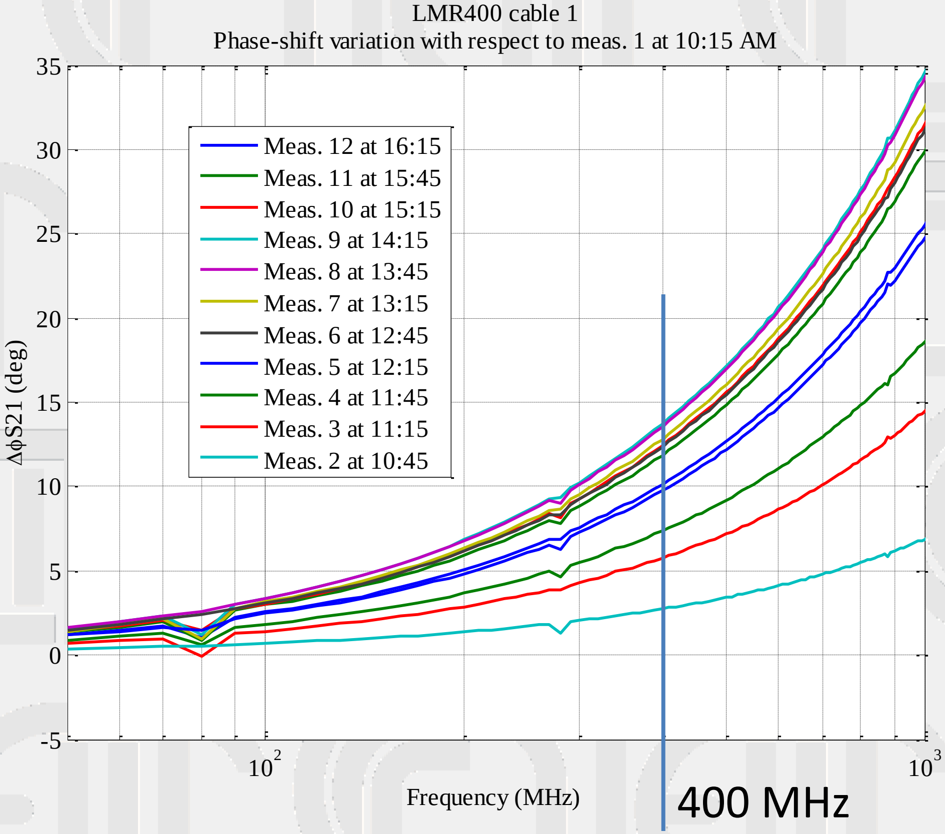
Conclusion

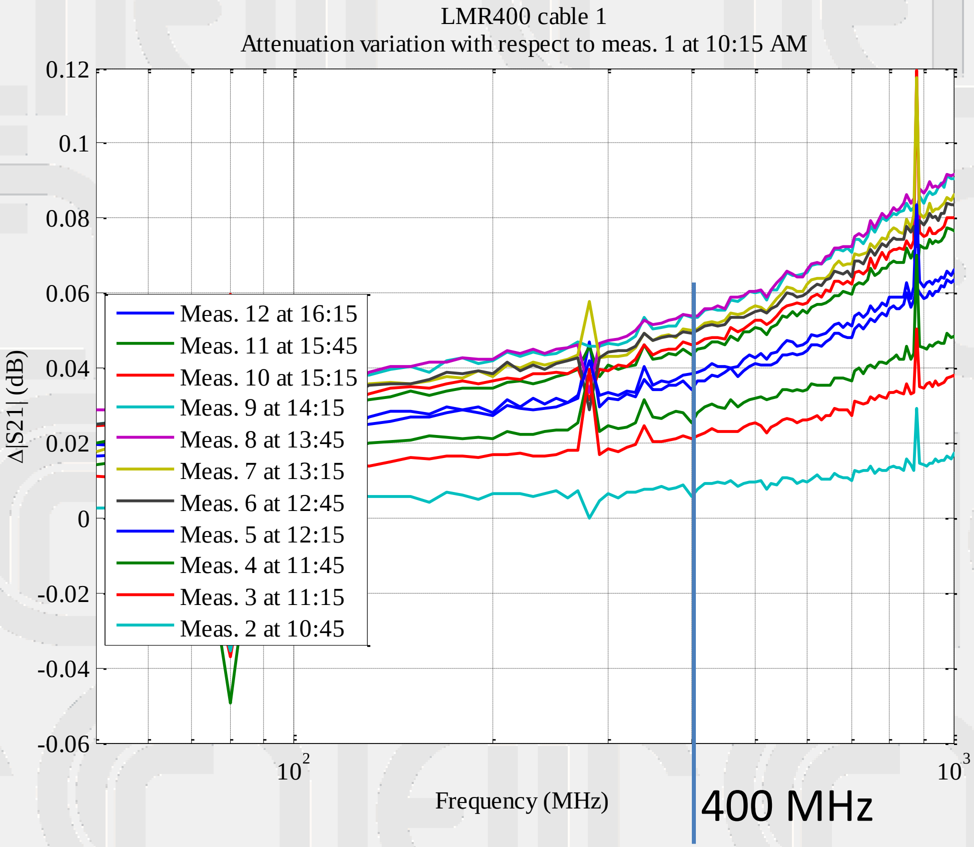
- Good results obtained on single element, embedded-element patterns from 50 to 650 MHz
- UAV flying test source as an

end-to-end verification and calibration system

- Advantages of UAV-based antenna measurements:
  - Measurements in the real installation conditions
  - Beam pattern measurements on arrays and instrument calibration are possible (see G. Pupillo, et al. “Medicina Array Demonstrator: calibration and radiation pattern characterization using a UAV-mounted radio-frequency source,” Experimental Astronomy, pp. 1-17, Apr. 2015
  - Low cost, portability, no infrastructures

Phase measurements - CABLES

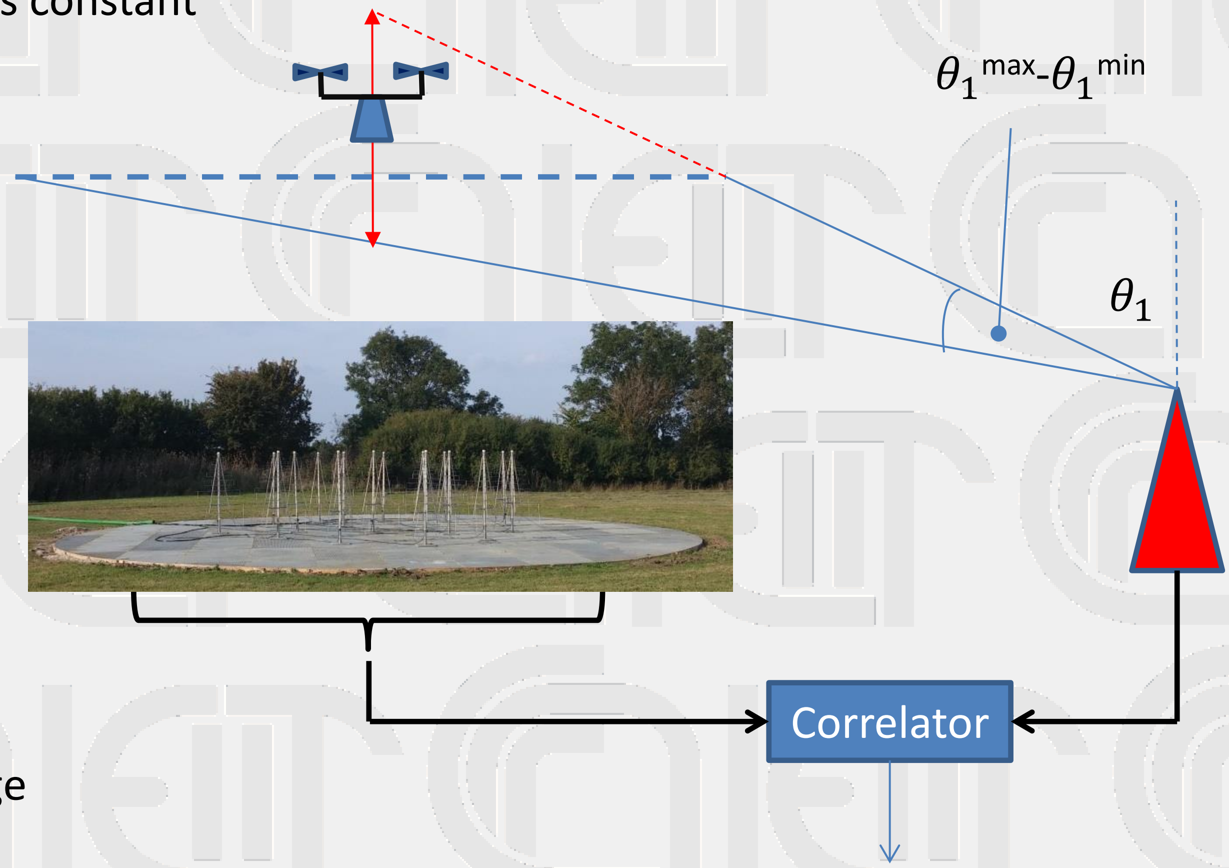




Relative Phase Measurements

Reference characterization

In a vertical Flight φ^{array} is constant



Reference will be characterized in the range from θ_1^{min} *to* θ_1^{max}

$$\varphi^{out} = \varphi^{array} - \varphi^{ref} - K(R^{array}\text{-}R^{ref})$$