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

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CNR IEIIT – Applied Electromagnetics Group

AADC workshop, Bologna, May. 9-13, 2016
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
- Differential GNSS system to track the position (accuracy few cm)
- On-board IMU to measured attitude (pitch, roll, yaw)
Compass Verification

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

mean = -0.547°, std = ±0.867°
SKALA 2.0 Pattern from 50 to 650 MHz

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

Spin Flight at 50 MHz

E-plane at 650 MHz
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)

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

Courtesy of

LBAinner: 48 dual-pol elements (random quasi-dense) 10-80 MHz
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LOFAR LBA antenna in Turin

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>60 MHz pol. A (1st)</th>
<th>60 MHz pol. A (2nd)</th>
<th>60 MHz pol. B</th>
</tr>
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<tbody>
<tr>
<td>$P_{rec}$ (dBm)</td>
<td>-24.272±0.1</td>
<td>-24.101±0.1</td>
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<td>$P_{TX}$ (dBm)</td>
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<td>$A_{cables}$ (dB)</td>
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<td>9.942±0.1</td>
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Embedded Element Pattern LBA inner

Element 0: E-plane

44.5 MHz

57 MHz

Extracted AUT pattern @4.450950e+01 MHz, volo2_autocorr_44p5MHz
TW1, x scan, average bearing: 88°, RMS dev. from ideal plane: 0.4°
CH A: H-plane cross-polar; CH B: E-plane co-polar

Meas. A
Sim. A
Meas. B
Sim. B
AAVS0.5 Embedded Element Patterns at 50 and 350 MHz

Mullard Radio Astronomy Observatory (UK)

Courtesy of

UNIVERSITY OF CAMBRIDGE
Phase of Cross Correlation Coefficient at 44.5 MHz

UAV at zenith above central element of the LBA inner

Baseline 0-40 (length 13.7 m)

\[ K(R_0 - R_{40}) \]

Measurement
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

\[ \varphi_{out} = \varphi_{array} - \varphi_{ref} - K(R_{array} - R_{ref}) \]
Ongoing: Phase-Locked UAV Transmitter

RF oscillator locked with the GNSS PPS signal

Independent of Reference Antennas

Copy of the transmitted signal

Trimble: 10MHz + PPS

Valon: 10 MHz ref. + 400 MHz fout
The proposed method allows to measure the Sensitivity \( (A_{eff} / T_{sys}) \) of the system, including all its parts, in the operating environment.

\[
P_{FD} = P_{Tx} G_{Tx}(\theta', \phi') \frac{4\pi R^2}{Wm^{-2}}
\]

\( P_{FD} \) is defined as the transmitted UAV energy, impinging upon the AUT per unit area.

Ongoing: UAV-based Sensitivity Measurements
by G. Pupillo and S. Pluchino
UAV-based Sensitivity measurements
by G. Pupillo and S. Pluchino

\[ P_{FD_{sys}} = \frac{PFD_{high} P_{low} - PFD_{low} P_{high}}{P_{high} - P_{low}} \]

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

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

Where:
• \( P_{meas} \) = measured received power \([W]\)
• \( PFD_{low}, PFD_{high} \) = Surface Power Density \([Wm^{-2}]\) corresponding to two different power level transmissions 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

Phase-shift variation with respect to meas. 1 at 10:15 AM

Attenuation variation with respect to meas. 1 at 10:15 AM
Relative Phase Measurements
Reference characterization

In a vertical Flight, $\varphi^{array}$ is constant.

$\theta_1^{max} - \theta_1^{min}$

Reference will be characterized in the range from $\theta_1^{min}$ to $\theta_1^{max}$.

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