Recent Results on the Characterization of the LOFAR radio telescope by means of a micro UAV

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Abstract **– The main aim of the UAV-based measurement campaign conducted at a station of the LOw Frequency ARray (LOFAR) in 2016 was to validate the beam models for the LOFAR stations including mutual coupling, i.e., without assuming identical array elements. Such a validation can be performed as a verification of all the embedded-element patterns over the field-of view and the operative bandwidth. In this paper, the most significant measured results on the low-band elements are reported and discussed.**

1 INTRODUCTION

The LOw Frequency ARray (LOFAR) [1] is an important technological pathfinder towards the development of the low-frequency instrument of the Square Kilometre Array (SKA) [2].
The LOFAR consists of approximately 50 aperture array stations distributed over The Netherlands, Germany, Sweden, the UK, France and Poland. Each station is composed of two subarrays operating in two different frequency bands 10-90 MHz and 120-240 MHz.
The low-band array is a random distribution of dual-polarized inverted-V-shaped thin-wire dipole antennas. The high-band is instead covered with dual-polarized bow-tie dipoles arranged in a regular fashion. The 96 Low-Band Antennas (LBAs) are distributed over an area of about 5000 m^2, whereas the High-Band ones (HBAs) are arranged in two separated areas of about 600 m^2 each.
The overall signal chain includes both RF (antenna, Low Noise Amplifier, analogue signal transportation and conditioning) and digital (sampling, beam-forming and correlator) parts.
The validation and calibration of a LOFAR station has been already addressed exploiting astronomical calibration sources [3] and artificial sources [4]. However, the scientific community is nowadays demanding for a complete characterization of all the embedded-element radiation patterns in-situ across the overall field-of-view and the whole frequency band. As a reaction, an Italian collaboration involving the National Institute for Astrophysics (INAF), the National Research Council (CNR) and the Politecnico di Torino have recently developed a measurement system exploiting a radio frequency (RF) transmitter mounted on an Unmanned Aerial Vehicle (UAV) [5] (see Fig. 1). This system has been successfully used during measurements campaigns on the Medicina Array Demonstrator [6], the Square Kilometre Array Log-periodic Antenna (SKALA) [7] and a single LOFAR LBA [8].
Besides providing valuable data for the validation of the EM models of the aforementioned antenna systems, these campaigns have also been instrumental to further develop the UAV-based measurement system and associated procedures to the level of maturity required for validation of larger systems.

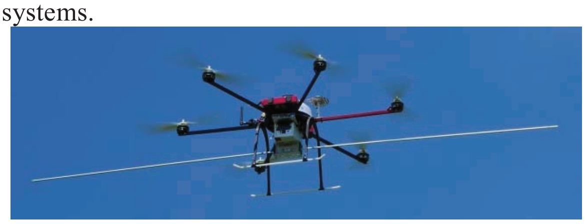

Figure 1: UAV-based flying test source. The payload consists of a GNSS receiver, an RF generator and a dipole antenna.

A UAV-based campaign was hence carried out on the LOFAR station CS302, located near Exloo (NL), in April 2016. During this campaign, various measurements on both LBA and HBA arrays were performed. In this paper, we present the most significant embedded-element patterns of the inner part of the LBA array, where the elements are closer to each other and the mutual coupling has stronger effects.

2 LBA EMBEDDED-ELEMENT PATTERNS

All embedded-element patterns of the LBA inner array have been measured in a single UAV flight for a finite set of frequencies. This task has been accomplished thanks to both the comb-like signal generated by the onboard RF source and the huge capabilities of the LOFAR back-end. The latter has been basically used as a multichannel and multi-frequency data recording system, since neither data correlation nor beam forming were required.
The flight consisted of a sequence of rectilinear paths over the array at a constant height of about 100 m. Even if this distance is not sufficient to satisfy the far-field condition for the overall array, it can be reasonably adopted to characterize the embedded elements. It should be noted that the radius of

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influence for random sparse non-connected arrays is generally smaller that the full array size.

The flight described above has been performed three times to assess repeatability. A significant subset of the obtained results is reported in Fig 2 for two operative frequencies: 44.5 MHz (top) and 57 MHz (bottom). This particular cut corresponds to the H-plane co-polar gain pattern of the dipoles oriented towards the North-East direction. It should be mentioned that the gain of the Low-Noise Amplifier (LNA) is also included in the present curves. The four colors refer to elements 0 (blue, array center), 3 (green), 15 (red) and 16 (cyan, close to the array boundary).

The three repeated measurements are reported with solid, dashed and dash-dotted lines. The agreement between different flights is remarkable. It is consistent with the error budget analysis reported in [8]. It can be observed that at 57 MHz (close to the dipole resonance), the third measured results (dash-dotted curves) are further from the first two. In particular, a constant offset with respect to zenith angle is present. According to the verification activity carried out on both the RF source and the positioning system (Differential Global Navigation Satellite System), this discrepancy cannot be associated to a time drift of the measurement setup. The third measurement was actually performed a few days after the first two with quite different environmental conditions (less wind, higher temperature). A possible explanation can hence be based on a slight variation of the LNA S-parameters owing to the higher physical temperature.

From Fig. 2, it is apparent that the embedded element pattern of the central elements (blue and green curves) are very different from the isolated dipole performance, especially at 57 MHz. A detailed simulation activity has been performed to explain such a behavior in terms of a combined effect of both mutual coupling between elements and high mismatch at the LNA input. Further details and additional measurements will be discussed at the conference.

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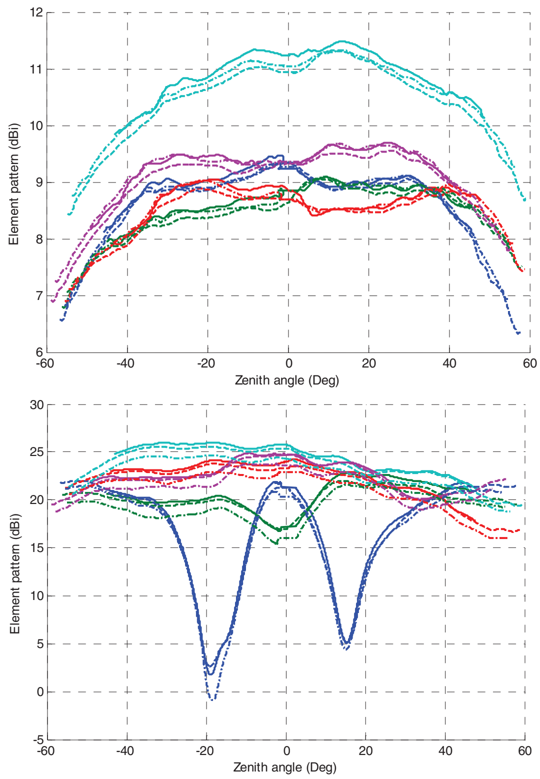

Figure 2: Measured LBA embedded patterns (H-plane of NE-oriented dipoles) at 44.5 (top) and 57 MHz (bottom): Element 0 (blue), Element 3 (green), Element 15 (red), Element 16 (cyan), Element 38 (magenta). Elements with higher label number are further from the center.