The SKA Aperture Array Verification System: Measured Digitally-Beam-Formed Radiation Patterns

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***Abstract*—The Aperture Array Verification System stimulated extensive test activities towards the development of the low-frequency instrument (50-350 MHz) of the Square Kilometer Array. This paper discusses radiation patterns measurements carried out on a 16-element array prototype with full digital beam-forming. A micro Unmanned Aerial Vehicle was adopted as the automatic positioner for the test source.**

Keywords—Square Kilometer Array; Radio Astronomy; Arrays; Digital Beam Forming; Radiation Pattern Measurements; Unmanned Aerial Vehicle

I. INTRODUCTION

The Square Kilometer Array (SKA) is one of the most promising radio telescopes for the next decades. Its low-frequency instrument will consists of a sparse random array of dual-polarized log-periodic antennas operating from 50 to 350 MHz. In the framework of the Aperture Array Verification System (AAVS) project, two extensive experimental campaigns have been carried out on the AAVS0 and preAAVS1 array prototypes in September 2014 and 2016, respectively, in order to validate the computed radiation patterns (embedded-element and array). These prototypes were located at the Mullard Radio Astronomy Observatory (MRAO), south west of Cambridge (UK). Both prototypes were composed of 16 antennas log-periodic antennas (**Error! Reference source not found.**) arranged in a random configuration (see **Error! Reference source not found.**2). AAVS0 was built with SKALA-1 [1] antennas whereas SKALA-2 [2] were featured in preAAVS1. The aperture array prototypes were fully equipped with LNAs, receivers and beam-forming hardware. In particular, the AAVS0 exploited an analog combiner whereas a complete digital back-end has been used in preAAVS1.

Fig. 1. UAV flying over the preAAVS1 array (SKALA-2 antennas), deployed at the Mullard Radio Astronomy Observatory, Lords Bridge, Cambridge

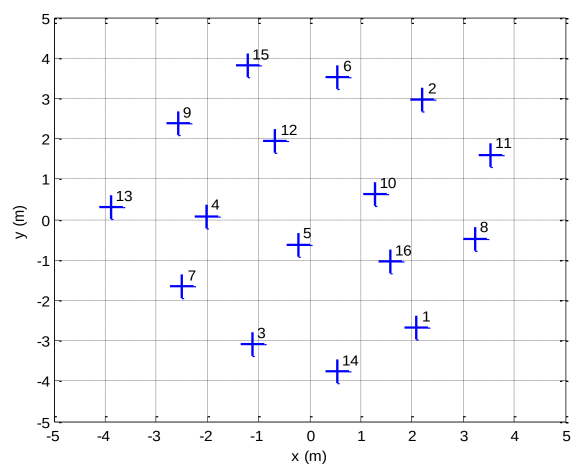

Fig. 2. Array geometry of both AAVS0 and preAAVS1

Radiation pattern measurement at both element and array level have been performed on both the array prototypes using a micro Unmanned Aerial Vehicle (UAV) carrying a test source. The results obtained with the analog combiner (AAVS0) are reported in [3]. This contribution presents the relevant results obtained on the digitally-beam-formed preAAVS1, with particular reference to the array calibration and the better agreement between simulations and measurements.

II. EXPERIMENTAL SETUP

A UAV-mounted test source (**Error! Reference source not found.**) has been exploited to perform end-to-end tests on aperture array prototypes. It is based on a micro hexacopter equipped with a synthesizer, a balun and a dipole antenna. The UAV can perform autonomous GPS-guided navigation according to a pre-programmed flight path. Its position is measured using a differential GNSS system which provides an accuracy of 2-3 centimeters. The UAV orientation is measured by the onboard Inertial Measurement Unit with an accuracy of about 2 Degrees.

It should be noted that this UAV-based test methodology has some advantages with respect to astronomical tests. First of all, the transmitted RF power is sufficient to measure the embedded-element pattern of each array element with a very high signal-to-noise ratio. Moreover, arbitrary scan strategies can be performed in order to completely map the radiation patterns in the overall hemispherical region. Both co- and cross-polar data can be collected (the source is linearly-polarized).

III. MEASURED RESULTS

Two interesting array patterns of the preAAVS1 campaign are reported in Figure 3 and 4. These results have been obtained from constant-height linear scans along the x-axis (see Figure 2), which corresponds to the *H*-plane of the dipoles oriented along the y-axis. The flying height was set to 100 m and 150 m in order to satisfy the far-field condition at 50 and 350 MHz, respectively. The time series acquired with the digital back-end (for each element) have been equalized at zenith in both magnitude and phase (see array calibration [5]). The effects of path loss and test source radiation pattern have been removed according to [6]. The extracted embedded-element patterns are normalized to 0 dB at zenith in order to compare the simulated (blue) and measured (red) beam patterns to the array factor (dashed green). The agreement between measurements and simulations is very good. It represents an improvement with respect to the AAVS0 data reported in [3], where the analog beam forming network was calibrated offline with VNA measurements. In the main beam region, the discrepancy is lower than 0.3 dB. The only significant discrepancy is observable on the second sidelobes at 350 MHz (right) around ±20° from zenith. This can be due to element positioning errors that are not taken into account in the simulations. Measured element positions acquired by means of aerial photogrammetry could be adopted to further improve the models.

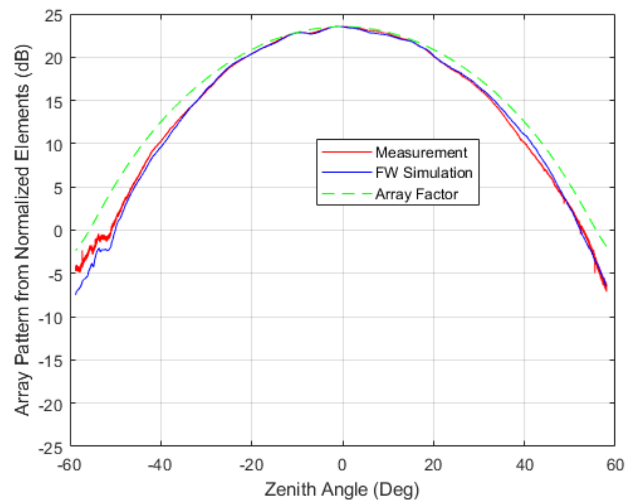

Fig. 3. preAAVS1 array (beam) patterns at 50 MHz.

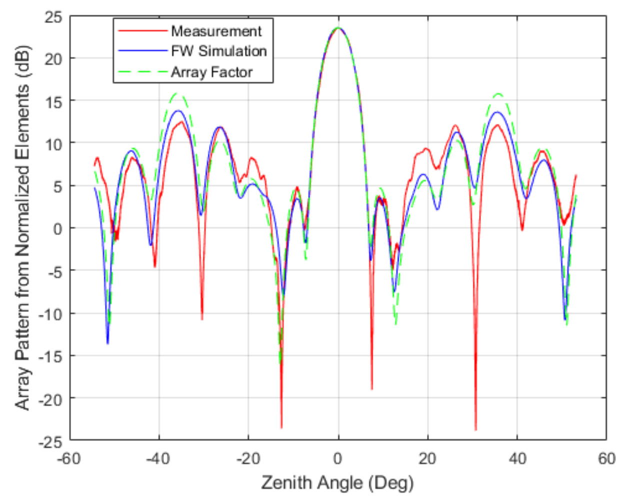

Fig. 4. preAAVS1 array (beam) patterns at 350 MHz.

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