Low-Cost Near Field Pattern Measurement Technique for Aperture Array Characterization

Application to the SKA telescope

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***Abstract*—This paper describes a low-cost innovative technique to characterize aperture arrays based on a near field pattern measurement. This measurement is as well used to validate a numerical method code, based on the method of moments, capable of realizing accurate electromagnetic simulations of very large non-regular arrays containing up to thousands of elements which are tens of wavelengths in diameter. A practical application of the technique and the code can be found in the low frequency aperture arrays for radio astronomy applications, such as the SKA telescope.**

***Index Terms*—Antenna arrays; Near-field radiation pattern; Antenna measurements; Computational electromagnetics; Radio astronomy**

I. Introduction

The authors describe here an innovative technique to characterize aperture arrays when the size of these is an impediment for a more traditional method such as a pattern measurement in an anechoic chamber. The low frequency radio astronomy community, working at cm wavelengths or more, is developing aperture arrays in order to improve the survey speed and sensitivity of the next generation radio telescopes [1]. Forming a large collecting aperture by using hundreds, thousands or up to millions of smaller antenna elements, has a number of advantages including a much easier mechanical realization of the instrument. In order to characterize this type of arrays, such as the ones being developed for the Square Kilometer Array telescope [2, 3], measurements in the field are necessary in order to characterize mutual coupling effects, effects of the soil, mechanical inaccuracies of the structures, misalignments, tolerances etc. Unfortunately, these types of arrays working at meter wavelengths rapidly grow to sizes that make almost impossible any measurement in a laboratory, test chamber, etc. Astronomical observations are typically the solution to test the front-end technologies of these instruments, but they require expensive infrastructure such as a processing back-end (beamformer, correlator, etc.) which results not only in delays but in a troublesome analysis of the complex measurement set-up. In here we present a cheap, easily deployable measurement technique especially designed for aperture arrays for radio astronomy applications.

These measurements are also used to validate a numerical code [4], based on the Methods of Moments, which is being developed to perform full wave electromagnetic simulations of arrays of hundreds of wavelengths in diameter. The code can now be used to simulate a specific antenna design [5], currently proposed as the element to cover the low frequency band of the SKAtelescope, SKA-AAlow from 70 to 450 MHz.

Section II presents the technique, while Sections III and IV are dedicated to explain the simulations and to compare simulations and measurements respectively. Finally, some conclusions are drawn and the future lines of work are highlighted.

II. Technique Description

The characterization technique is based on validating a numerical method code, based on the method of moments [4], by means of measuring the near field pattern of an embedded element in an aperture array. By using a telescopic fiber glass mast and a test antenna hanging from it we can map a 2D plane near field pattern above the array. In this experiment this plane is located 2 meters from the tip of the antenna under test in the set-up shown in Fig. 1 but this distance can be easily regulated. The same 2D plane pattern can then be simulated using the code confirming that the response of the embedded element (in the presence of mutual coupling) is as predicted by the simulations. One can then use the code to design a better element and array [5, 6] or to model the array beam for calibration proposes [7]. The telescopic mast is easily portable and can be moved across an array of antennas such as AAVS0 [8], a 16 element array of antennas at Lords Bridge, Cambridge UK, used for the verification of front-end technologies developed for the SKA. It can also be used for similar aperture arrays dedicated to radio astronomy applications (LOFAR [9], MWA [10], LWA [11], etc.). Despite the far field pattern is not measured here (at the top end of the frequency band of AAVS0 -450MHz- this will mean a measurement at ~300 m over the array), the accuracy of the simulations can be validated by measuring points in the near field.

For these measurements the following equipment was used:

- R&S ZVL3 VNA [12].
- 2 long coaxial cables to connect to the test antenna and the antenna under test.
- Tripod for telescopic mast.

- Fiber glass telescopic mast. A small modification was needed to connect the test antenna.
- Bicolog test antenna AARONIA BicLOG 30100 [13].

Figure 1: AAVS0 array at Lords Bridge Cambridge and telescopic mount holding the source antenna for the near field pattern test.

Assuming one always would needs a VNA or a spectrum analyzer plus a signal source and a test antenna for a pattern measurement, the equipment for this measurement cost only 400£ (150£ for the tripod and 250£ for the telescopic mast). The alignment was done using a thread hanging from the antenna taking as a reference the position of the elements under test. It took ~4 hours for 2 persons to perform the measurements presented in Section IV.

III. SIMULATIONS

The simulation model of the AAVS0 array (Fig. 1), including 16 SKALA elements (see Fig. 2 for a view of the antenna element) [5] on top of a ground plane 15 m in diameter is realized with both a commercial software (CST [14]) and a code based on the method of moments previously used for characterization of large irregular arrays dedicated to radio astronomy [6, 15]. The antenna is fed with a delta gap for each polarization at the top trying to recreate the differential LNA that will be used for the SKA [8].

Figure 2: SKALA element.

The antenna meshing for the MoM simulations (see Fig. 3) was created with the help of rectangular and triangular basis functions. Given its width, the antenna spine is subdivided into 3 columns, the middle one being connected to the feeding geometry at the top. The antenna is modeled with a flat mesh. In order to take into account the 3D aspects, the width of the flat wires and the flat spines have been set to about twice the diameters of the corresponding cylinder (for equal inductance per unit length). An infinite ground plane has been used for the MoM simulations.

For the near field experiment a model of a dipole was included in the simulations to represent the effect of the bicolog antenna. By repeating the simulation with CST using a model of the bicolog it was observed that a simple flat dipole 500 mm in length and 40 mm in width produced as good as results as the simulation using the bicolog model. This is true as far as we normalize all the results with respect to the measurement at zenith. Rectangular basis functions were used in the MoM code to model the dipole.

This experimental validation of the software allows one to verify its accuracy for the type of antennas envisaged for the low-frequency end of the SKA telescope, i.e. non-regular arrays of log-periodic antennas. In view of the complexity of the elements, methods based on Macro Basis Functions, as described in [16], are exploited. Fast versions of this method have been described in [4] and a first extension to arrays placed above layered media is described in [17]. This should allow the fast and accurate modeling of all effects of mutual coupling for complete SKA stations, which in turn can be exploited in calibration studies.

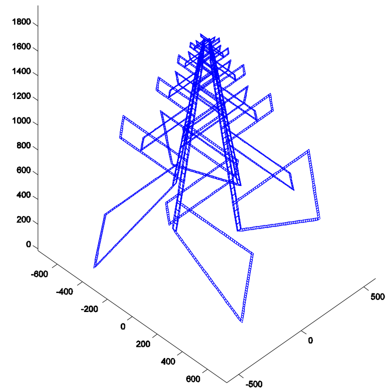

Figure 3: Antenna meshing for the dual polarized element.

In Figs. 4-7 we present the pattern of the dual polarized SKALA antenna over an infinite metallic ground plane simulated both with CST and with the MoM code. Good agreement is found across the band. This represents an important step towards full EM simulations of SKA stations containing SKALA elements.

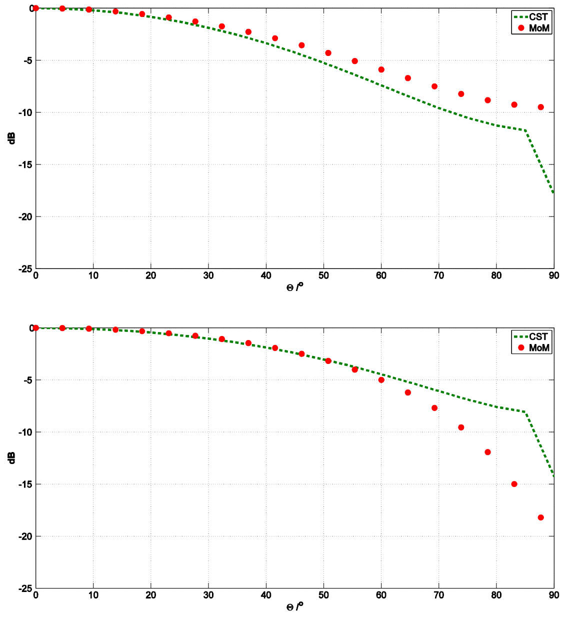

Figure 4: E- (top) and H- (bottom) plane cuts at 70 MHz.

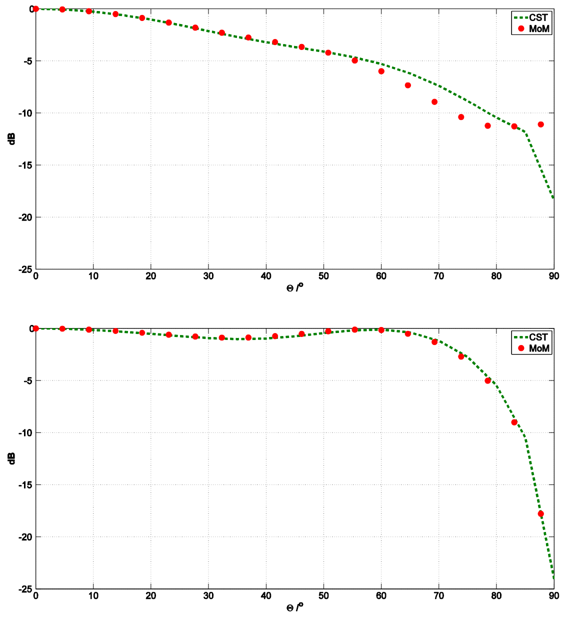

Figure 5: E- (top) and H- (bottom) plane cuts at 150 MHz.

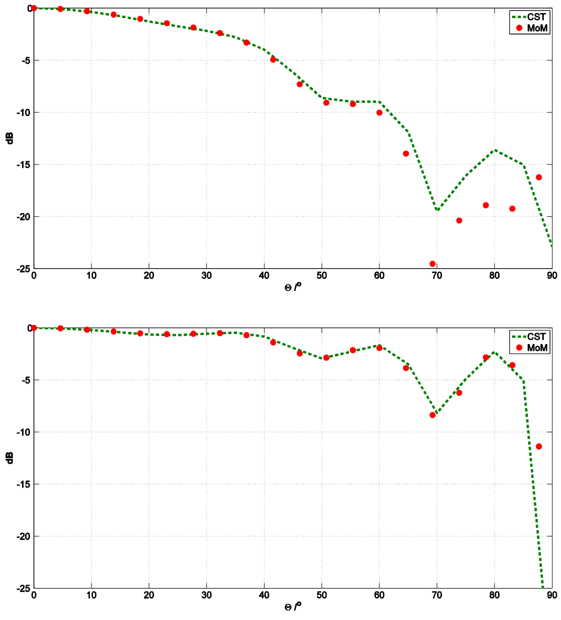

Figure 6: E- (top) and H- (bottom) plane cuts at 300 MHz.

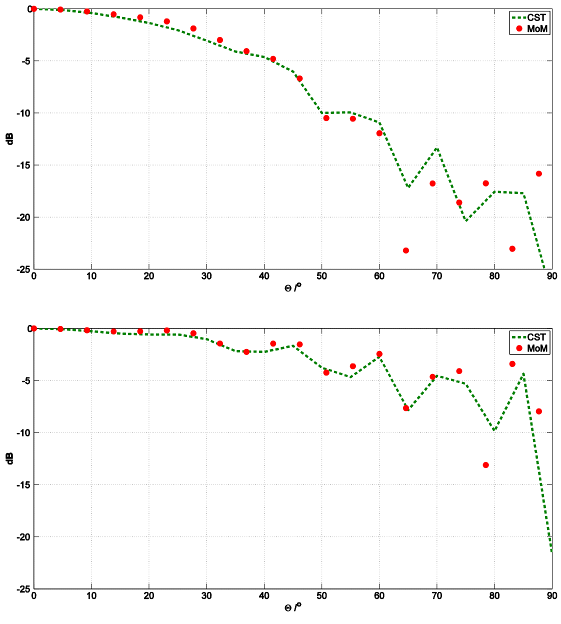

Figure 7: E- (top) and H- (bottom) plane cuts at 450 MHz.

Fig. 8 shows the configuration for the near field experiment using the MoM code. The dipole is located 3 m away from SKALA in the horizontal direction and 2 m above it.

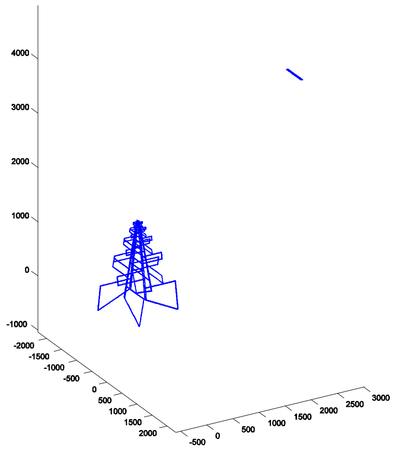

Figure 8: MoM mesh for the near field experiment.

IV. MEASUREMENTS

In this section simulations are compared with measurements. Firstly, Fig. 9 shows the coupling S parameter between the central element and a central-side element in a 3 by 3 regular array of dual polarized SKALA elements separated 1.5 m. The measurements are compared with simulated results from CST and the MoM code. The agreement is good across the band.

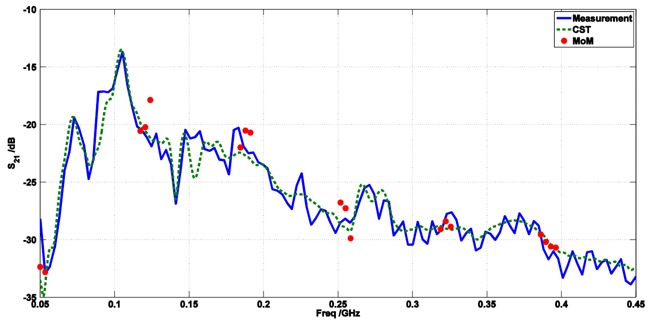

Figure 9: Coupling results.

The results of the near field experiment described in Section II are presented here. The first results are for a single dual polarized SKALA element placed on top of a steal mesh 2.5 mm wide and 15 m in diameter. This ground mesh is represented in the simulations as an infinite ground plane. In Fig. 10 we can see the agreement between the measurements and simulations. Fig. 10 (top) is for a scan along the E-plane of SKALA and Fig. 10 (bottom) is for a scan along the H-plane. Each curve in those figures represents the coupling between SKALA and the test antenna with respect to the coupling when the test antenna is right above SKALA. A number next to the curves indicates the horizontal position of the test antenna along the scan line.

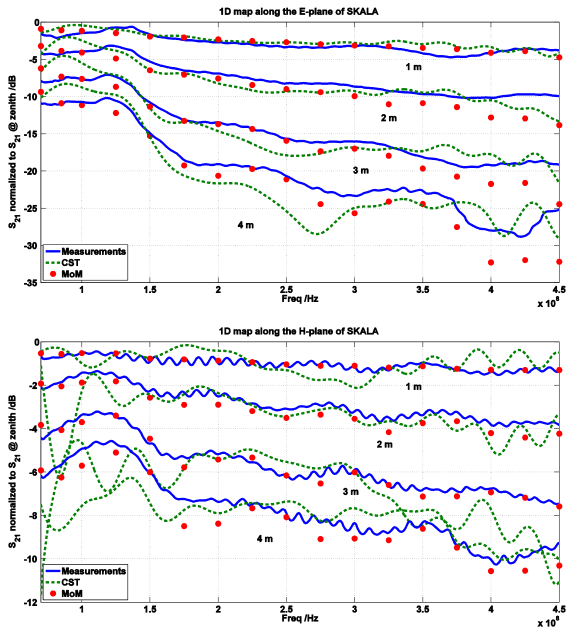

Figure 10: E- (top) and H- (bottom) plane near field scans of a single antenna.

Finally, we can observe in Fig. 11 how the same can be done for a SKALA element embedded in an array. In this way we can assess the effects of mutual coupling as well. At this point only CST has been used to compare against the measurements and the MoM code results will be available soon. The array consists of 8 SKALA elements arranged in a 3 by 3 regular grid (element separation is 1.5 m). One of the elements in one of the sides was missing in this case for easiness in the measurements. Again, we see a match between the measurements and the simulations.

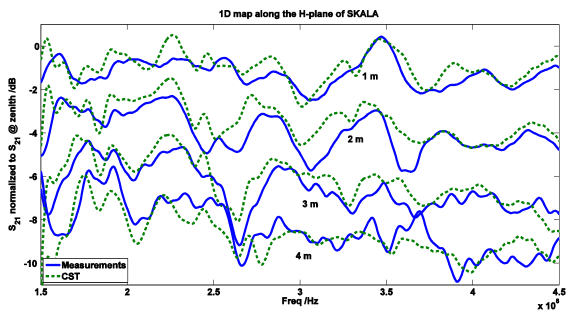

Figure 11: H-plane near field scans of the central antenna in a 3 by 3 regular array missing one antenna in the side.

ACKNOWLEDGMENT

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V. Conclusions

A low-cost technique for aperture array characterization in the field is presented in this paper. This technique can be useful for low frequency radio telescopes such as the SKA where pattern measurements in the field can be troublesome due to the long wavelengths involved. It consists on measuring points of the near field pattern in a 2D plane above the array/element. The measured results can then be compared with simulated results to validate the simulation engine.

A Method of Moment code was used for the simulations as well as CST. One of the objectives of this experiment is to validate the simulation engines used to design and to model the array antennas. In particular, the MoM code has now been validated for patterns and for the near field experiment over 1 element. This code can then be used to simulate electromagnetically full stations of the SKA telescope with thousands of SKALA elements placed in irregular positions. One can then study how much the mutual coupling effects randomize out for a specific configuration and antenna. This code can also be used to generate models for the telescope calibration accounting for the effects of mutual coupling.

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