Novel Modeling of LOFAR`s High Band Antenna, Using the Finite Element Method

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Abstract. LOFAR (Low Frequency Array) is a radio telescope consisting of two types of antenna arrays – for low and high frequency. In this paper we discuss the High Band Array – HBA and represent option to better its accuracy, using the FEM (Finite element method), that can help us increase the precision of the modeling of antenna elements in large antenna arrays, which is the case of the HBA.

Keywords: Radio astronomy, High-band antenna, Finite element method, Component array,

INTRODUCTION

LOFAR – Low Frequency Array is a European low-frequency antenna array radio telescope, designed and build by ASTRON, NL. It consists 3 types of stations – core and remote –in the Netherlands, and many single international stations in other countries in Europe. Every single station consists of two antenna arrays – Low frequency array (LBA, 10-90MHz) and High frequency array (HBA, 110-250MHz). These single stations are interconnected with high-speed fiber optics and can operate in as a single station (array) mode or the whole array network mode.

The frequencies from 90MHz to 110MHz are unobservable, because of the FM radio range, which takes place at these frequencies and makes ground-based radio astronomy observations there impossible for the Radio-frequency interference (RFI) that occurs. The LOFAR high band antennas have been designed to operate in the 110–250 MHz range. But the actual frequency range they observe is up to 240 MHz, because again the RFI heavily contaminates the higher frequencies, so in practice the band is limited to 110–240 MHz [1]. The design of the single element of the HBA with its dimensions is shown in FIGURE 1. Array element consists of two orthogonal broadband "bat wing" dipoles (for picture clarity only one set is displayed on FIGURE 1b). The dipole shows very broadband properties (like fractional bandwidth of >400%), however due to limitations in the speed of signal processing hardware the practical bandwidth is limited between 100MHz and 250MHz (FIGURE 2b). A single HBA tile consists of a square, 4×4 element, dual polarized, phased array with built-in amplifiers and an analog beam-former consisting of delay units and summations. In order to minimize cost and at the same time maintaining adequate collecting area the design clusters the 4x4 elements into tiles, with one "tile beam" being formed by combining the signals from all the 16 elements in phase for a given direction. The 5 bit time delay can be up to 15 ns long and is

set by a signal received from the MAC system. Each 16 element tile measures 5×5 meter and is made of an expanded polystyrene structure which supports the aluminum antenna elements. The distance between tile centers is 5.15 m resulting in a spacing between tiles of 15 cm. The contents of the tile are protected from weather by two overlapping flexible polypropylene foil layers. A light-weight ground plane consisting of a 5 × 5 cm wire mesh is integrated into the structure. The resulting signals are transported over coaxial cables to the receiver unit in the electronics cabinet. [2]

Original LOFAR array is designed with employment of combined Method of Moments (MoM) + Far Field Pattern Superposition (MATLAB) techniques which although deliver some simulation results, have inherent shortcomings like poor handling of dielectrics (MoM) and mutual coupling (Pattern Superposition Method). Due to the problem size, explicit modeling and solution of the array is impossible at the current state of the art. The presented paper employs an emerging simulation technique that employs the accuracy of the FEM method, but with much less computational recourse and time required.
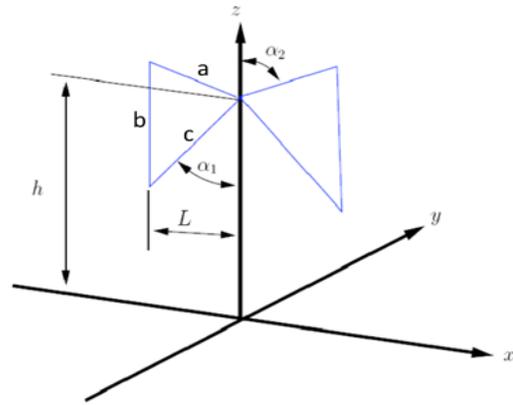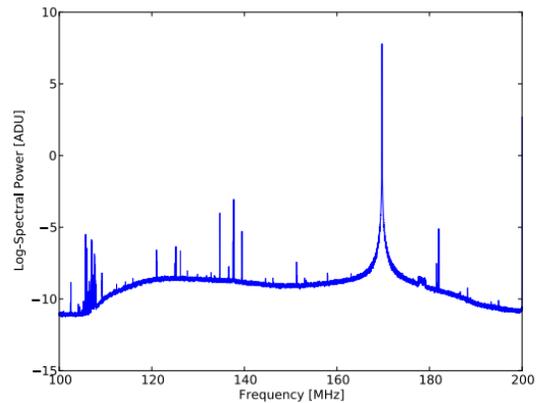

(a)   (b)

FIGURE 1: Outside look on the field (a) [3] and dimensions (b) [4] of a LOFAR HBA single element. Dimensions: a=305.6mm. b=348mm, c=393mm, h= 521mm. α1=55deg, α2=82deg, L=521.6mm. Conductor tape width=50mm (in dipole plane).

(a)   (b)

FIGURE 2: . (a): Single LOFAR HBA tile. The protective covering has been partially removed; (b): median averaged spectrum for all HBA tiles in station CS003. [2]

# THE HIGH-BAND ANTENNA SIMMULATION

In this section are presented the model of the simulated LOFAR HBA antenna and its radiation patterns for several frequencies.

Using the Ansys HFSS Software® [5] the following model, shown at figure 5 is designed to better the accuracy:
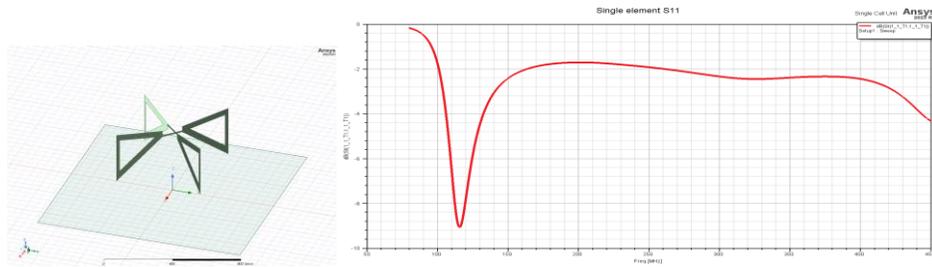

FIGURE 3: Simulated design for LOFAR`s HBA, S11 parameter

As we can see in FIGURE 3 and FIGURE 4, the antenna model has a very good radiation pattern and directivity in the frequency range of the original, with the best being in the initial frequency, but can also expand it, as it is presented in the radiation patterns for 300MHz and 400 MHz.
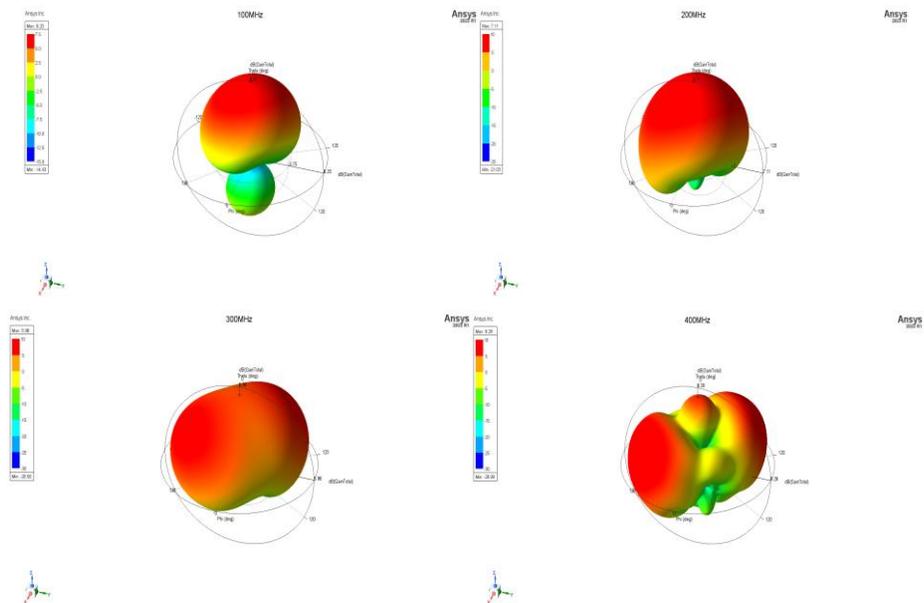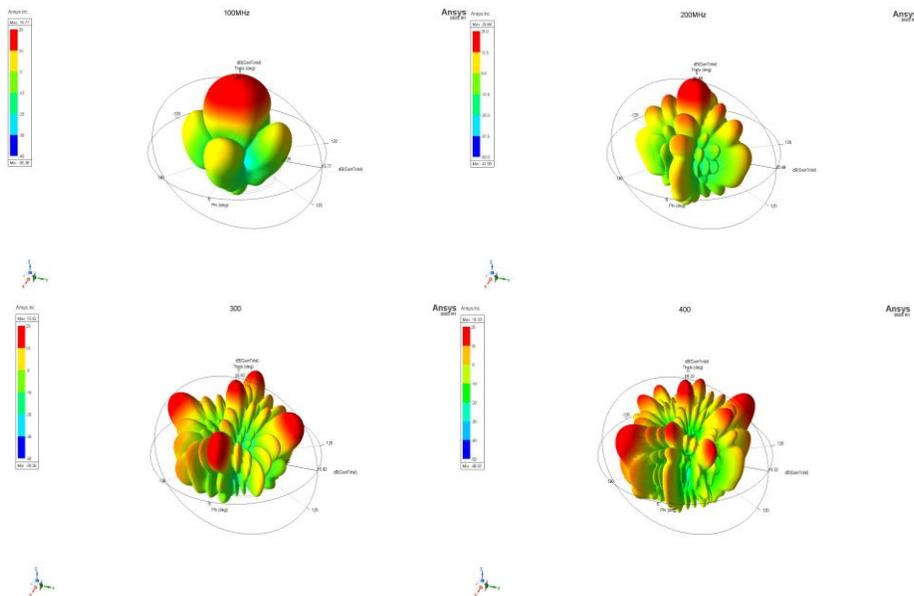

FIGURE 4: Radiation patterns of the simulated model for 100MHz, 200MHz, 300MHz and 400MHz for a single element
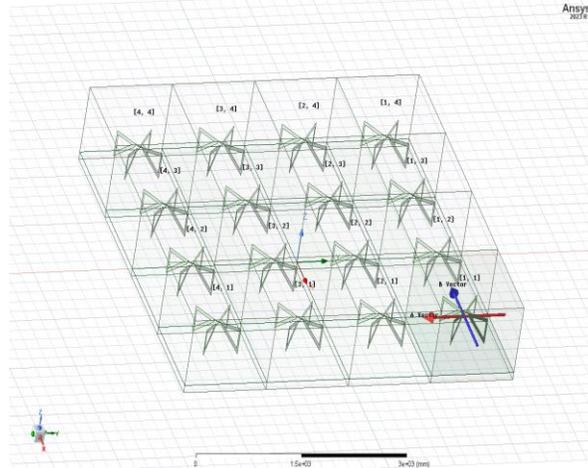
FIGURE 5: Ground currents of the HBA (single station)

In FIGURE 5 is presented the antenna array. For this specific simulation is used combination of FEM (Finite Element Method) and Component Array Technique. Here the radiated fields are determined on the encompassing box – FeBi – Finite element Boundary integral. The greatest benefit is that the FEM mesh is created only of one single element and the fused to the identical mesh of the other elements, saving memory and computational time. Change of the excitation coefficients results in an almost instant pattern update. This technique allows us to model not only the antenna element, but also to account for ground currents, leakage of EM wave behind the ground mesh and antenna active impedances.

FIGURE 6: Radiation patterns of the simulated model for 100MHz, 200MHz, 300MHz and 400MHz for a single station

At FIGURE 6 are presented the radiation patterns of the array for 100MHz (up-left), 200MHz (up-right), 300MHz (down - left).
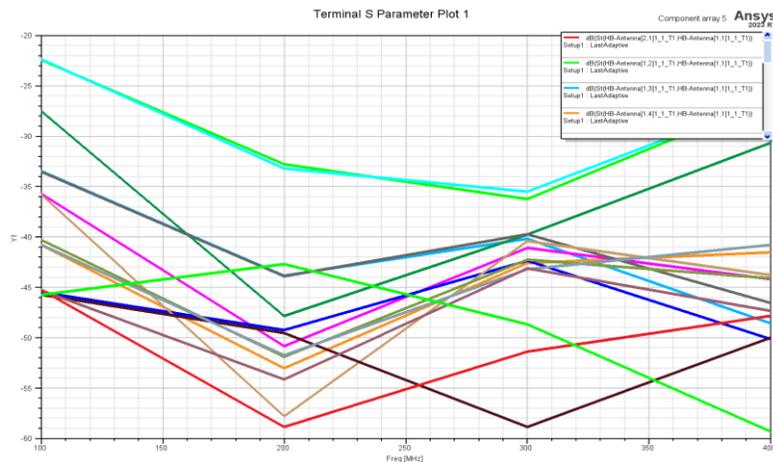
FIGURE7: Mutual coupling between the array elements

FIGURE 7 shows the mutual coupling of the antenna elements within the array. The analysis is performed with mesh fusion, therefore all coupling effects are considered in the result. The simulation time is an order of magnitude (51min on a medium-size desktop computer) less, compared to FEM technique.

CONCLUSION

Given the presented results in the paper we can confidently come to the conclusion that the FeBi method, used for the simulations of the model, essentially improves the directivity and accuracy of the HBA of LOFAR radio telescope and it confirms that using this method there are higher chances of optimizing large antenna arrays in ways that they can be more efficient as a single element, but most importantly as a part of the array, as in the presented case – being a part of an international interferometer.

ACKNOWLEDGMENT

REFERENCES

1. „Antennas", ASTRON Science, https://science.astron.nl/telescopes/lofar/lofar-system-overview/technical-specification/antennas/ (accessed 24April, 2023)
2. M. P. van Haarlem et al., "LOFAR: The LOw-Frequency ARray", (van Haarlem, M. P., Wise, M. W., Gunst, A. W., Heald, G., McKean, J. P., et al. 2013, A&A, 556, A2)
3. "LOFAR - a new radio telescope in Germany", Max Planck Institute for Astrophysics, https://wwwmpa.mpa-garching.mpg.de/mpa/institute/news_archives/news0605_lofar/news0605_lofar-en.html (accessed 11 April, 2023)

4. Labropoulos, Panagiotis & Koopmans, Leon & Jelic, Vibor & Yatawatta, Sarod & Thomas, Rajat & Bernardi, Gianni & Brentjens, M. & Bruyn, Ger & Ciardi, Benedetta & Harker, Geraint & Offringa, A. & Pandey, Vishambar & Schaye, Joop & Zaroubi, Saleem. (2009). The LOFAR EoR Data Model: (I) Effects of Noise and Instrumental Corruptions on the 21-cm Reionization Signal-Extraction Strategy.
5. Ansys HFSS, Ansys, https://www.ansys.com/products/electronics/ansys-hfss (accessed 11 April, 2023)