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Compact Dual-polarized 1.2 - 10 GHz Eleven Feed by Folding Outer Elements for Large Decade-bandwidth Radio Telescopes

Jian Yang[1], Miroslav Pantaleev[2], Per-Simon Kildal[1], Leif Helldner[2]
[1]Dept. of Signals and Systems, [2]Onsala Space Observatory
Chalmers University of Technology, Gothenburg, Sweden
jian.yang, miroslav.pantaleev, per-simon.kildal, leif.helldner@chalmers.se

***Abstract*—The Eleven antenna is a log-periodic folded-dipole-pair array which has two unique radiation characteristics: constant beamwidth and fixed phase center location over decade bandwidth. Therefore, the Eleven antenna is very suitable as a feed for reflector antennas. This paper presents a new compact design of 1.2 - 10 GHz Eleven antenna by folding down the outermost elements of the array. By doing so, it is possible to put the Eleven feed inside a compact cryostat, which is critical for applications in radio telescopes. The new compacted Eleven antenna has only 40% volume of the original standard Eleven antenna with similar performance. Simulations and measurements have verified the design and are presented in the paper.**

I. Introduction

Large decade-bandwidth radio telescopes provide many advantages over the narrow band ones: super-sensitivity, simultaneous multi-channel observations, time-response observations, and etc. Many proposals for the future radio astronomy requires such wideband systems, for example, 1-10 GHz mid-frequency dish array of the SKA (Square Kilometer Array) [1] and 2-14 GHz reflectors for VLBI2010 (Very Long Baseline Interferometry 2010) [2]. One important issue in radio telescopes is that the system must have an extremely low system noise temperature (about 35 K). Therefore, integrated and cryogenically-cooled LNAs and feed are critical in both VLBI2010 and mid-frequency SKA systems. In addition, the feed and its cryogenic chamber (cryostat) should be sufficiently compact in order to fit in the focal area of the reflector with minimum blockage of the reflector aperture. Consequently, size and cryogenic cooling concerns (such as out-gassing and thermally-induced mechanical stress) play important roles in the design of decade-bandwidth feeds for VLBI2010 and SKA radio telescopes.

The Eleven antenna is a decade-bandwidth log-periodic dual-dipole array, developed at Chalmers University of Technology (Chalmers) since 2005. It has two unique radiation characteristics: constant beamwidth and fixed phase center location over decade bandwidth. In addition, it has low profile and simple geometry. Therefore, the Eleven antenna is a perfect candidate for decade bandwidth feed for reflectors for radio telescopes, which has been demonstrated in [3]-[12].

In addition to applications in radio telescopes, the Eleven antenna can be used in other areas, e.g., to produce the radiation patterns with nulls on axis required for mono-pulse tracking in e.g. satellite communication terminals [13], and ultra-wideband MIMO antenna [14], and digital television antenna [15] . In some applications it may also be advantageous to combine the Eleven antenna with a centrally located high frequency horn in order to reach Ka-band, as monitoring antennas in satellite communication systems, see [16].

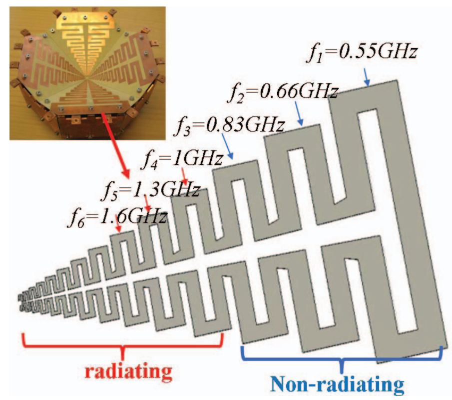
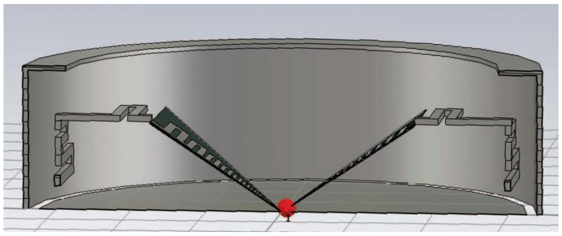


Fig. 1. Array configuration of the 1.2 - 10 GHz Eleven antenna

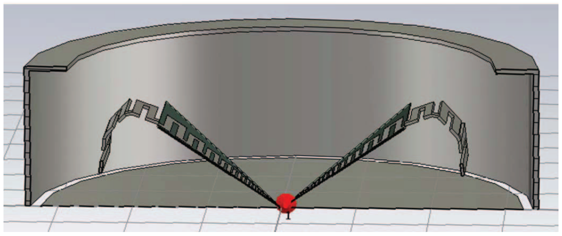
The purpose of this work is to design a compact 1.2 - 10 GHz Eleven feed for SKA project, which fits in the same cryostat as the 2 - 13 GHz Eleven feed for VLBI2010 [12]. The compacting is done by folding down the outermost three non-radiating elements in the array. Measurements have verified the design which is carried out with the simulations by CST MS [17].

II. Compacting the Eleven Antenna by Folding Down Outermost Elements

The Eleven antenna consists of four petals of cascaded log-periodic array for dual polarizations. Each petal of the standard non-compacted array configuration for the 1.2 - 10 GHz Eleven feed is shown in Fig. 1, which is created by the same geometry parameters (scaling factor k, length and widths of the folded dipole in term of wavelength L, w, and height of the dipoles over the ground plane h, etc.) as those used in the 2 - 13 GHz Eleven feed presented in [12]. The reason for this is that we want to use the same center puck, feeding network



(a) 90° bent folding



(b) Curve bent folding

Fig. 2. Folding the outer elements for compacting the 1.2 - 10 GHz Eleven feed.

and ports for both the 1.2 - 10 GHz and 2 - 13 GHz Eleven feeds. The center operating frequencies for the last 6 elements (folded dipoles) are shown in Fig. 1, where it can be seen that the outermost 3 elements will radiate at the frequencies below the low end of the frequency band of 1.2 - 10 GHz. In other words, the outermost 3 elements are non-radiating elements for the band of 1.2 - 10 GHz. The function of these outermost 3 non-radiating elements is to create a termination of the log-periodic array in order to have the same radiation performance at the lower end of the band as at the rest frequency points and a good input reflection coefficient over the total operating band [18].

Since the outermost 3 elements are non-radiating ones, it is possible to re-arrange them to have a compact geometry while keeping the same performance for the array. Two re-arrangements have been tested: 90 degree bent folding and curved bent folding, as shown in Fig. 2. Note that in order to present the re-arrangements clearly, we show in the figure a cut through half of the geometry of the whole array for single polarization.

Mainly due to mechanical considerations and manufacture cost, the 90 degree bent folding was chosen. Then, a global optimization scheme, implemented in a Genetic Algorithm, was applied to optimize the geometry of the three outermost folded dipoles. The rest of the array is kept the same as that in the previous 2 - 13 GHz Eleven feed during the optimization. The GA optimization could be carried out efficiently because the optimization of the outermost three elements concerns performance only at the low frequencies, corresponding to 1 - 3 GHz. Fig. 3 shows a mechanical drawing of the final optimized geometry of the antenna.

A comparison of the volume between the standard Eleven feed design and the present compact design is shown in Fig. 4. It can be seen that the compact design has only 40% volume of the standard one. Therefore, the same compact cryostat for 2 - 13 GHz Eleven feed can be used for the 1.2 - 10 GHz feed.

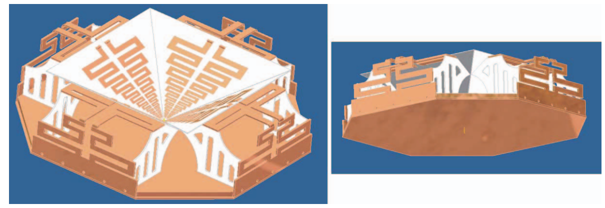


Fig. 3. Final geometry of the 1.2 - 10 GHz Eleven feed after optimization.

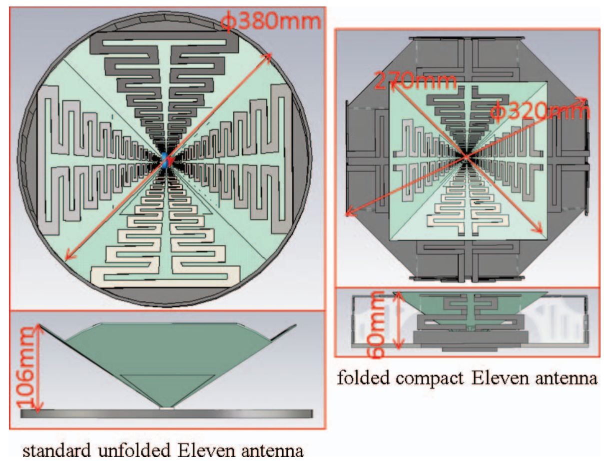


Fig. 4. Compact 1.2 - 10 GHz Eleven feed has only 40% volume of the standard one.

III. Simulated and Measured Results

The manufactured hardware of the compact 1.2 - 10 GHz Eleven feed with a cylinder emulating the cryostat is shown in Fig. 5. The measurement setup in anechoic chamber for the radiation patterns of the antenna is shown in Fig. 6.

The measured and simulated reflection coefficients of the Eleven feed are shown in Fig. 7. It can be observed that the measured reflection coefficient is below -10 dB over the most part of the 1.2 - 10 GHz band, and there are only a few peaks above the -10 dB level, and all of them are below -8 dB.

Fig. 8 shows the measured and simulated co- and cross-polar radiation patterns in $45°$ plane. It can be seen that the beamwidth of the pattern is nearly constant. The agreement between the measurements and the simulations is OK in general. Some discrepancy may be caused by the measurement setup, specially the cross-polar level in the far-out region. We are in the process of investigating the reasons in order to have better agreement.

Fig. 9 presents the simulated sub-efficiencies for the 1.2 - 10 GHz Eleven feed when it illuminates a parabolic reflector with a subtended angle of $2 \times 60°$. The BOR_1 efficiency requores expensive and extensive measurements of the radiation field

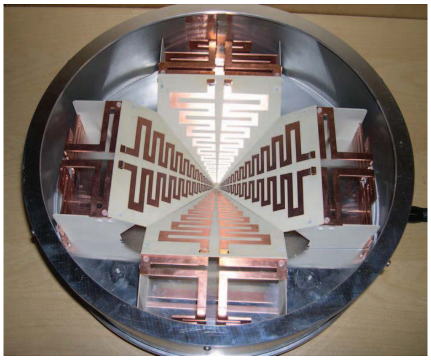


Fig. 5. Photo of the hardware of the compacted 1.2 - 10 GHz Eleven feed with a cylinder emulating the cryostat.

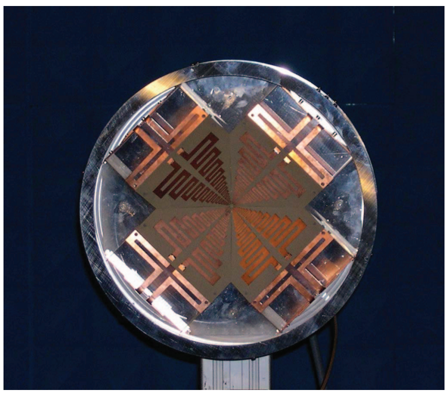


Fig. 6. Set-up for radiation pattern measurement for the new Eleven feed.

in many ϕ-planes. Therefore, we have not yet measured data for efficiencies yet. From the previous experience we had in [12], we believe that the simulated sub-efficiencies are reliable. Then, the figure states that the 1.2 - 10 GHz Eleven feed has good efficiencies, such as almost 0 dB phase efficiency e_{ϕ}, better than -0.2 dB polarization efficiency e_{pol}, better than -0.4 dB spillover efficiency e_{sp}, about -0.5 dB BOR_1 efficiency e_{BOR1} except at 1.2 GHz, almost constant illumination efficiency e_{ill}, and better than -2.5 dB total aperture efficiency e_{ap}.

IV. Conclusion

The paper presents a new compact design of 1.2 - 10 GHz Eleven feed by folding down the outermost elements. Therefore, the feed can be set in a compact cryostat, which minimizes the blockage and reduces the requirement for cryogenical cooling system. The reflection coefficient is below -10 dB over the most part of the band with a few peaks below - 8 dB. The radiation patterns are kept as the same as a standard Eleven feed: constant beam width and low cross polar level. The method of compacting design can be also applied to other log-periodic array antennas.

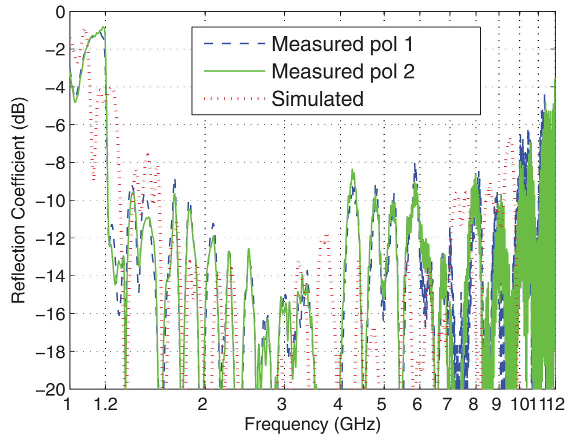


Fig. 7. Measured and simulated reflection coefficients of the compacted 1.2 - 10 GHz Eleven feed.

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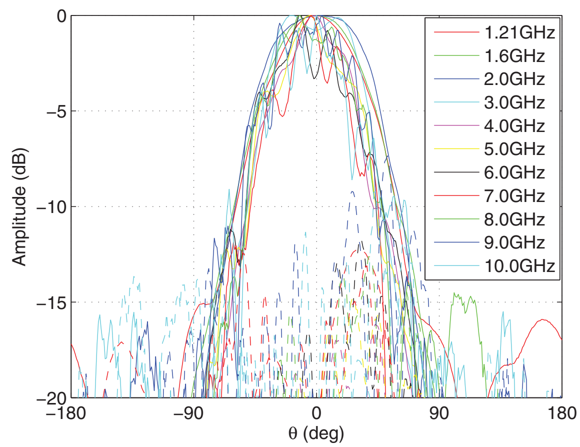
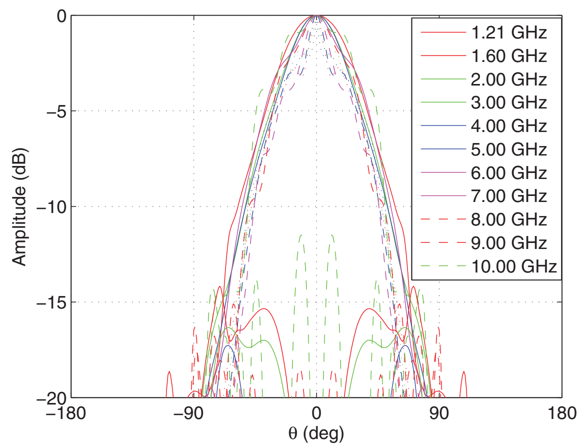


(a) Measurement



(b) Simulation

Fig. 8. Measured and simulated co- and cross-polar radiation patterns in 45° plane.

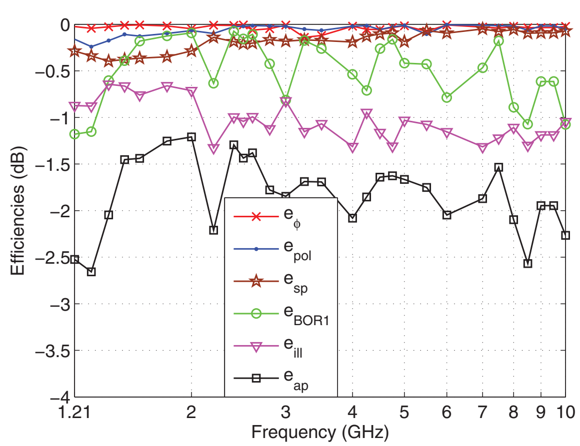


Fig. 9. Simulated efficiencies of the 1.2 - 10 GHz Eleven feed for a reflector with subtended angle of $2 \times 60^\circ$.

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