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Improvement of Input Reflection Coefficient of Eleven Antenna – a Compact Wideband Feed for Reflector Antennas

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1. Introduction

The Eleven antenna which has been recently developed at Chalmers University of Technology is a new dual polarized ultra wide band (UWB) antenna with more than one decade bandwidth [1]-[5], and over this bandwidth the beam width is nearly constant with 11 dBi directivity and the phase centre is almost at the same location. In addition, the Eleven antenna has low profile. It can therefore find several applications in radio astronomy and UWB systems.

The paper presents the improvement of input reflection coefficient of the Eleven antenna .. This improvement plays an important role when it is used as a feed for a reflector in radio telescopes, because high reflection coefficient will increase system noise temperature. The reflection coefficients of the previous Eleven antennas had peaks up to -5 dB [3], whereas the goal of the present work is to keep it below -10dB. Therefore, an optimization on input reflection coefficient has been performed. The solver is a commercial moment method code – WIPL-D [6] and the optimization is done by running WILP-D from self-made Matlab program. We perform the optimization in connection with the development of an Eleven feed for the RATAN radio telescope with the goal to cover a frequency range from 0.5 to 3 GHz. The final measurements confirm a reflection coefficient close to -10 dB over 80% of the frequency band. Measured radiation patterns are also presented in the paper.

2. Description of the Eleven antenna

The basic geometry of the Eleven antenna is two parallel folded dipoles separated by half wavelength and located above a ground plane, see Figure 1. This geometry gives equal E- and H-plane patterns and locks the phase centre to the ground plane [2]. Figure 2 shows the model of a single folded dipole element. The large bandwidth is obtained by adding more dipole pairs and scaling them logarithmically in size relative to each other, see Figure 1. The configuration provides a constant radiation performance over the band, but the input reflection coefficient S_{11} needs tuning. Therefore, the length of the dipoles *L*, the distance between the transmission line and the center line *dc*, the width of the folded dipole *w*, the distance between the two arms in a folded dipole *da* and the scaling factor *k* are optimized in order to reduce S_{11}.

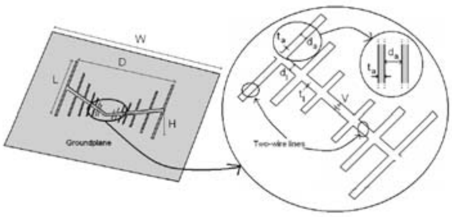

Figure 1 Configuration of the Eleven antenna for linear polarization

3. Optimization Procedure

The optimization was carried out for the frequency band 0.5 – 3 GHz when the Eleven feed is connected to two 50 Ω coaxial cables per polarization (balanced feeding), and these two 50 Ohm

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port were excited with opposite phase. In practice this is done with two LNAs followed by a 180 deg hybrid. Due to the large computation time, we use a simple algorithm corresponding to optimizing each dimension as if it is independent of the others. The initial starting point for the optimization is Rikard’s optimum design [7]. The optimization algorithm is shown in the flow chart below. The optimizations within each box took a couple of days, and the results were checked manually before starting optimization of the next parameters in the series. The complete optimization procedure was repeated 2-3 times.

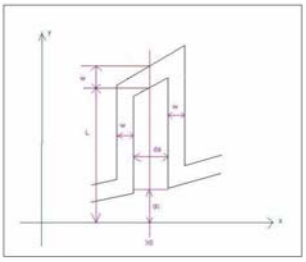
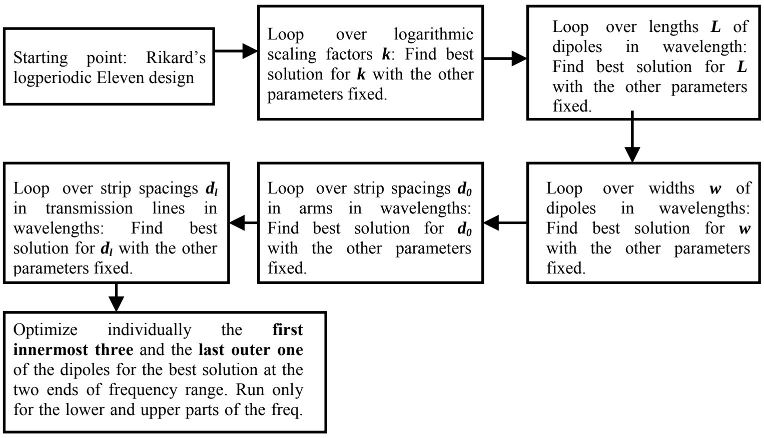


Figure 2 Model of a single folded dipole

4. Result of Optimization



Starting point: Rikard’s logperiodic Eleven design

Loop over logarithmic scaling factors **k**: Find best solution for **k** with the other parameters fixed.

Loop over lengths **L** of dipoles in wavelength: Find best solution for **L** with the other parameters fixed.

Loop over widths **w** of dipoles in wavelengths: Find best solution for **w** with the other parameters fixed.

Loop over strip spacings **d_0** in arms in wavelengths: Find best solution for **d_0** with the other parameters fixed.

Loop over strip spacings **d_l** in transmission lines in wavelengths: Find best solution for **d_l** with the other parameters fixed.

Optimize individually the **first innermost three** and the **last outer one** of the dipoles for the best solution at the two ends of frequency range. Run only for the lower and upper parts of the freq.

Figure 3 Procedure of optimization

Table 1 presents the general parameters which define the Eleven Feed after the optimization. Figure 4 shows the Eleven feed for the RATAN telescope. The inner part of 17 folded dipole pairs was manufactured by etching a 0.5mm thick copper sheet and the outer part of 3 folded dipole pairs was manufactured by laser cutting a 0.5mm thick steel sheet. The steel part was later Silver plated and the two parts were connected by soldering. Figure 5 shows the simulated efficiencies of the feed with definitions as follows. The realized gain G_0 and directivity D_0 of a reflector antenna are related by $G_0 = e_{tot} D_0$, and $e_{tot} = e_{totrad} e_{ap}$ where e_{tot} is the total antenna efficiency, e_{ap} is the aperture efficiency and $e_{totrad} = e_{ref} e_{rad}$ is the total radiation efficiency. $e_{ref} = 1 - |r|^2$ accounts for the input reflection coefficient r, i.e. impedance mismatch, and e_{rad} for the dissipation losses in the antenna itself. The input reflection coefficient r is calculated by assuming 50 Ω input feed line impedance. The aperture efficiency is factorized into sub-efficiencies according to $e_{ap} = e_{BOR1} e_{sp} e_{pol} e_{ill} e_{\phi} e_{foc}$, where e_{BOR1} measures how close the far-field function resembles that of a BOR_1 (Body Of Revolution) antenna [8] e_{sp} is the spillover efficiency that measures the fraction of the radiated power that hits the reflector; e_{pol} measures the power loss in the cross-polar pattern; e_{ill} measures how much the gain decreased due to the tapered aperture distribution of the reflector; e_{ϕ} measures the gain decrease due to the phase error in the feed pattern ; e_{foc} accounts for defocusing effects when the actual phase center is different from the best average phase center location over the frequency band. The BOR_1 efficiency already mentioned accounts for the power radiated in higher order φ-variations in the pattern and therefore cannot contribute to the gain of a symmetrical reflector antenna and thus presents a power loss.

Table 1 Definition of the geometry

Name	**Symbol**	**Value**
Lowest operational frequency	f_{low}	0.5 GHz
Scaling factor	k	1.18
Number of dipole pairs	N	20
Geometrical lowest frequency	f_{min}	0.31 GHz
Geometrical highest frequency	$f_{max}=k^{N-1}f_{min}$	7.28 GHz
Feed realized by		0.5 mm thick metal plate with Rohacell foam support

Dimension name	**Symbol**	**Value in λ**
Length of dipole arm	*L*	0.41
Spacing between two parallel dipoles	*D*	0.50
Height of dipole over ground plane	*h*	0.15
Strip spacing in arm	*da*	0.01
Strip width in arm	*w*	0.012
Strip spacing in line	*dc*	0.03

Figure 4 The Eleven feed for RATAN telescope

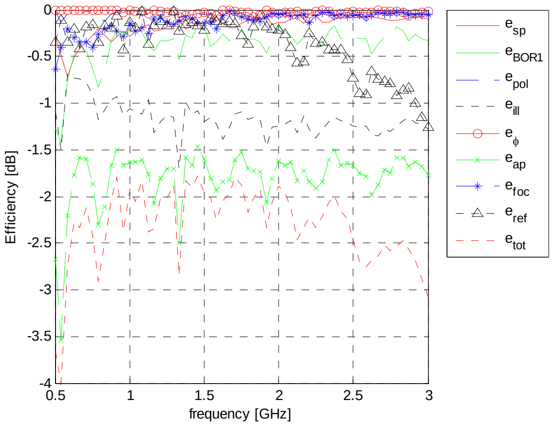


Figure 5 Simulated efficiencies when the RATAN feed illuminates a reflector with 60 deg half subtented angle

5. Measurements

The measurement set-up is shown in Fig. 6. We calibrate the set-up at ports 1 and 2 of the hybrid so that the input reflection coefficient S_{33} is effectively seen at the input of cables 1 and 2 of the antenna when correctly excited. Fig. 7 shows the simulated and measured input reflection coefficients. We observe that the measured input reflection coefficient is below -8 dB over most part of the frequency band except for three points. The differences between the simulated and measured values are believed to due to manufacturing and mounting tolerances. Figure 8 shows the simulated and measured radiation patterns in the 45 degree plane, which are in very good agreement. We have also measured the total radiation efficiency in a reverberation chamber, see Fig. 9.

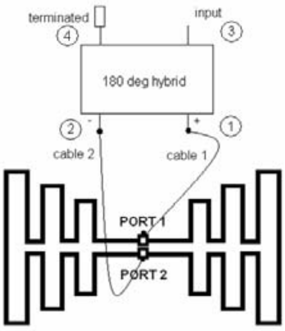


Figure 6 Set-up of measurement

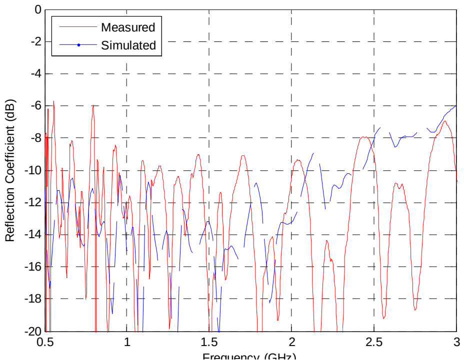


Figure 7 Comparison of reflection coefficient between simulation and measurement

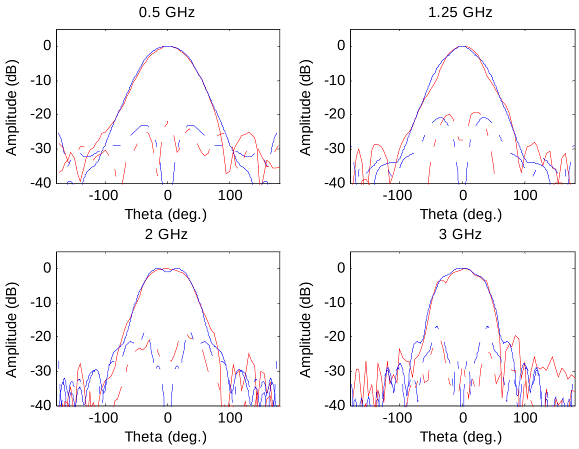


Figure 8 Measured and simulated radiation patterns in 45 degree plane at selected frequencies. The red lines are measured and the blue are simulated. Solid lines are co-polar patterns. Dashed lines are cross-polar patterns.

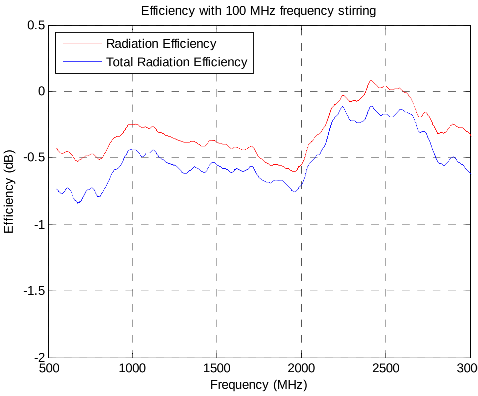


Figure 9 Measured radiation efficiency by using a 2.45m x 3.07m x 2.43m reverberation chamber at the Swedish National testing and Research Institute (SP). The accuracy of the chamber is 0.5 dB RMS.

5. Conclusion

The reflection coefficient of the Eleven feed has been improved when designing a feed for the RATAN radio telescope. The theoretical results are better than the measured ones, so we believe that further improvements are possible.

6. Acknowledgment

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