A 2-5 GHz circular Eleven antenna with improved BOR1 efficiency

2011 IEEE International Symposium on Antennas and Propagation, Spokane, USA, 3-8 July, 2011 (ISSN: 1522-3965)

Citation for the published paper:
Yin, J. ; Yang, J. (2011) "A 2-5 GHz circular Eleven antenna with improved BOR1 efficiency". 2011 IEEE International Symposium on Antennas and Propagation, Spokane, USA, 3-8 July, 2011 pp. 1247-1250.

http://dx.doi.org/10.1109/APS.2011.5996513

A 2-5 GHz Circular Eleven Antenna with Improved BOR_1 Efficiency

Jungang Yin
Dept. of Electronics and Telecommunications
Norwegian University of Science and Technology
Trondheim, Norway
jungang.yin@iet.ntnu.no

Jian Yang
Dept. of Signals and Systems
Chalmers University of Technology
Gothenburg, Sweden
jian.yang@chalmers.se

***Abstract*—This paper presents an improved Eleven antenna – the circular Eleven antenna, which has 0.3 dB higher BOR_1 efficiency than previous models. In this way the aperture efficiency becomes higher when it is used as a feed for reflector antennas. The new feed is constructed by using circularly curved folded dipoles which are printed on four flat circuit boards, referred to as then petals as in previous models. The demonstration of the improvement is shown over the limited frequency range 2 – 5 GHz to reduce computation time.**

Keywords-Eleven Feed; BOR_1 efficiency; Aperture efficiency; Reflector Antennas

I. INTRODUCTION

The Eleven feed for reflector antennas, featured as a low-profile, log-periodic and ultra-wideband antenna, has during the past few years been developed at Chalmers University of Technology in Sweden. It is referred to as the Eleven feed because its basic geometry consists of two parallel folded dipoles located half-wavelength apart above a ground plane, and it can be used over more than a decade bandwidth with 11 dBi directivity by extending the basic configuration logarithmically [1]-[6]. Multi-port Eleven antennas have been studied in terms of its versatility, such as for use in monopulse tracking [7] and diversity and MIMO [8][9] systems.

Until now, all ultra-wideband or decade bandwidth feeds for reflector antennas are non-rotationally symmetrical. Therefore, one important measure of the performance of these wideband feeds is the so-called BOR_1 efficiency [10][11] which characterizes how rotationally symmetric the radiation field function is.

In order to improve the BOR_1 efficiency for the Eleven feed, it is natural to make circularly curved folded dipoles. It was reported in [3] that a flat circular single-folded dipole pair Eleven antenna had an improved BOR_1 efficiency, compared to the straight folded dipole pair one. However, it is very difficult to cascade this flat circular version of the Eleven feed to achieve wideband performance.

In this paper, we propose a new circularly curved wideband Eleven feed, where the four petals of the circular folded dipole array are made in four pieces of flat printed circuit boards (PCB) in the same way as the 1-13 GHz model described in [5][6]. The present work was carried out over the frequency band of 2-5 GHz as a preliminary investigation so that the simulation time by using CST could be reasonably acceptable and an optimization procedure could be performed. Wider frequency bands can be obtained by extending the geometry presented here by cascading more logarithmically scaled circularly curved folded dipoles. Simulations show that the new circularly curved Eleven feed has a BOR_1 efficiency of -0.25 dB over the band, which is a 0.3 dB improvement over the previous model in [5].

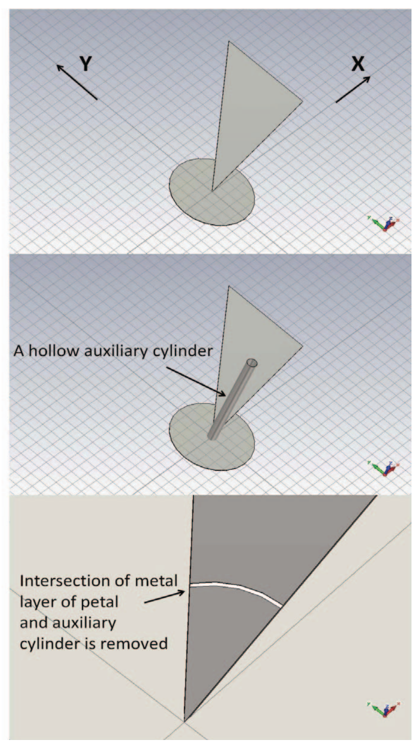

Figure 1 Flat petal plate above ground disc with angle 'ang_0' from the ground plane (top); example of auxiliary circular cylinder used to find the circularly curved shape of the folded dipoles on the petal. The shape appears circular when seen from above (middle, bottom).

I. GEOMETRY OF THE NEW CIRCULAR ELEVEN FEED

The geometry of the new circular Eleven feed can be described as follows, with help from the modeling in CST.

A. Ground Disc and Antenna Petal

Due to the symmetry, we only need to model half of one petal of the circular Eleven antenna. Thereafter, the complete four petals can readily be constructed by mirroring with respect to the symmetrical planes. As illustrated in Figure 1, a metal disc is built as a ground in the XY-plane, which center coincides with the center of the rectangular coordinate system. Then, a large triangular plate is added above the ground disc with an angle (ang_0) from the ground plane. This plate models a printed-circuit board (TMM3 material from Rogers), which consists of two layers - a metal layer of 0.07 mm thickness and a dielectric layer of 0.381 mm thickness. The apex of the dielectric layer coincides with the center of the ground disc. Afterwards, the circularly curved folded dipole strips is formed by a series of auxiliary cylinders.

B. Curved Dipoles Shaped by Auxiliary Cylinders

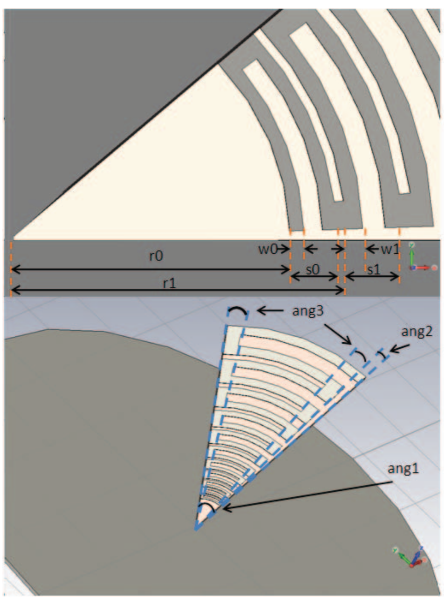

Figure 2 Dimensions that define the antenna structure (the denoted lengths are projected lengths in the XY-plane; the denoted angles are the projected angles in the XY-plane).

An auxiliary cylinder is parametrically designed to intersect the tilted metal layer, and the intersection as well as the cylinder itself will be removed afterwards. Presented in Figure 1 (middle, bottom) is an example of how an auxiliary cylinder is used to obtain a curved shape which is circular when seen from above. In this way, it is feasible to determine the circularly curved printed dipole shapes on each of the PCB boards forming the four petals. As shown in Figure 2 (top), r_0, w_0 and s_0 are, respectively, measures of the XY-plane projections of the radius of curvature, strip width and arm width of the first folded dipole. It implies that auxiliary cylinders can be applied to conveniently shape the curved printed dipole arms. For instance, an auxiliary cylinder with an inner radius (r_0+w_0) and an outer radius (r_0+s_0-w_0) can be used to produce the curved arm gap between the strips of the first folded dipole. Similarly, the projected displacement, strip width and arm width of the second folded dipole is r_1, w_1 and s_1, respectively; moreover, these subsequent dimensions can be derived by scaling the initial dimensions with a scale factor (k):

$$r_1 = r_0 \cdot k,\ w_1 = w_0 \cdot k,\ s_1 = s_0 \cdot k \qquad (1)$$

In a log-periodic fashion, the projected displacement, strip width and arm width of the n^{th} ($n > 1$) folded dipole in an array can be expressed as follows:

$$r_n = r_0 \cdot k^{(n-1)},\ w_n = w_0 \cdot k^{(n-1)},\ s_n = s_0 \cdot k^{(n-1)} \qquad (2)$$

So a series of auxiliary cylinders extended in such a log-periodic fashion can make it quite easy to lathe the metal layer to form circular dipole strips. In addition, the angles ang_2 and ang_3 denoted in Figure 2 (bottom) are actually projected angles between the XY-plane projections of the corresponding dashed lines. This is to make it convenient, similar to the previous depiction of ang_1, to shape the petal by using flat surfaces.

TABLE I. DIMENSIONS THAT DEFINE THE ANTENNA

Dimension	Value
r_0	$0.3000 \cdot \lambda_{geo\_min}$
s_0	$0.0500 \cdot \lambda_{geo\_min}$
w_0	$0.0150 \cdot \lambda_{geo\_min}$
k	1.2000
ang_0	33.0°
ang_1	42.0°
ang_2	2.0°
ang_3	4.0°

The 8 dimensions that define the whole antenna structure are listed in Table 1. The first 3 length dimensions are in terms of λ_{geo_min} (= 37.5 mm, corresponding to 8 GHz in free space), which is the geometrical minimum wavelength that is predefined as a design goal. Note that the geometrical minimum wavelength may be somewhat smaller than the operational minimum wavelength at which the simulation model can actually perform. This is because the relative dielectric constant (ε_r) of the printed-circuit board is not accounted for in λ_{geo_min}.

C. Complete Simulation Model

Presented in Figure 3 are different views of the complete simulation models of the circular 9-pair-dipole Eleven Feed with dual linear polarizations.

A discrete port is placed across the feed gap of the innermost dipole strips on the petal in the X>0 region. In order to simplify the calculation by CST, the XZ-plane is set as an electric symmetrical plane, whereas the YZ-plane is set as a magnetic symmetrical plane. The time-domain solver of CST (based on FDTD method) is used to simulate the 9-pair-dipole dually-polarized Eleven model as depicted in Figure 3. The hexahedral mesh type is applied in the calculation volume and the mesh density is 50 lines per wavelength. It takes about 60 hours to finish one run of simulation on our workstation (Intel Core 2 Quad CPU @ 3.00 GHz, 8 GB RAM).

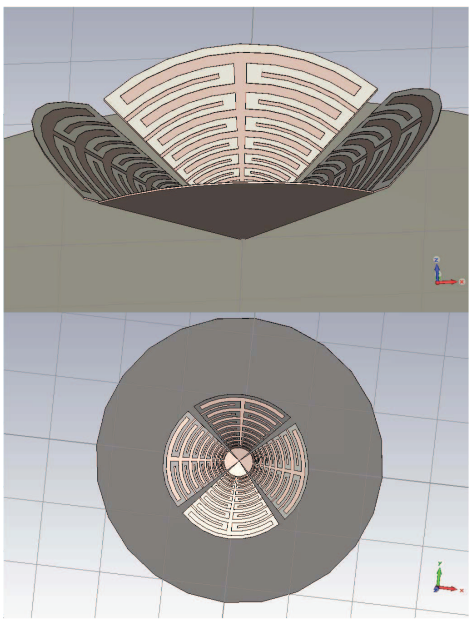

Figure 3 Different views of complete circularly curved 9-pair-dipole Eleven antenna for dual linear polarization.

II. SIMULATION RESULTS

Below present we the simulation results for the final circularly curved Eleven feed designed by using CST.

A. Impedance Match

Presented in Figure 4 is the simulated reflection coefficient with reference to 300 Ω port impedance.

As can been seen from the figure, the reflection coefficient is better than -10 dB between 1.8 and 5.1 GHz, except for 3 narrow spikes; in particular, the worst spike tip, about -7.3 dB, occurs around 4.5 GHz. We believe that it is possible to further improve the impedance match by using advanced optimization techniques in future work.

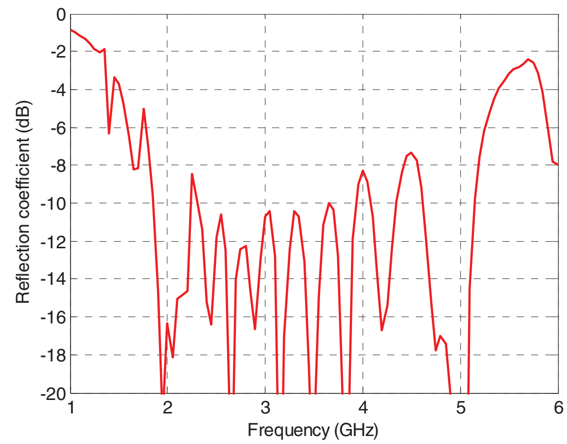

Figure 4 Simulated input reflection coefficient (with reference of 300 Ω port impedance) of the dually polarized circularly curved Eleven antenna.

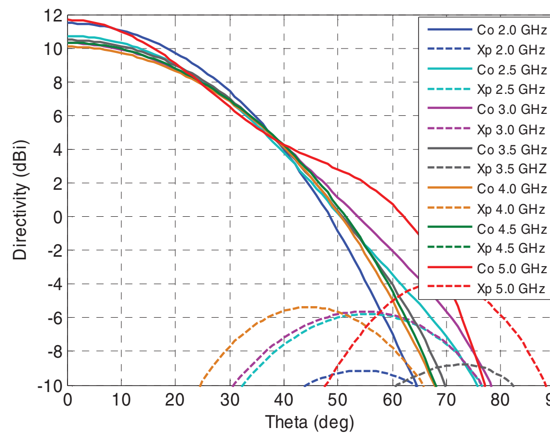

Figure 5 Co- and cross-polar radiation patterns (in Φ=45° plane) of the simulated total far field of the dually polarized circularly curved Eleven antenna (the ground plane is set as an infinite perfect electric conductor (PEC) plane in CST).

B. Radiation Far Field

Figure 5 shows the co- and cross-polar directive gains of the simulated total far field of the dually polarized Eleven feed. It can be observed that the co-polar directivities are approximately 11 dBi, and that the relative cross-polar level is below -15 dB over 2-5 GHz.

C. Efficiencies when Feeding Reflectors

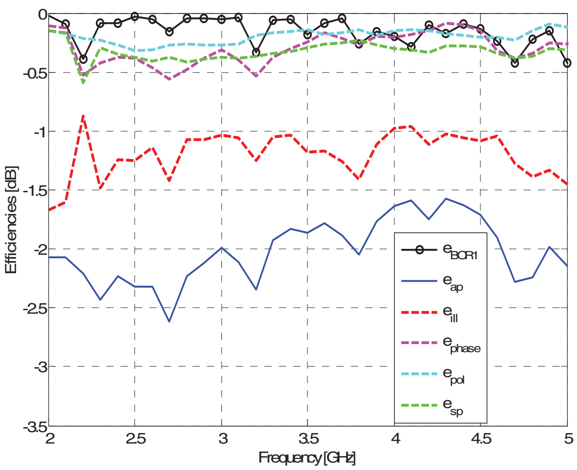

Figure 6 Calculated efficiencies when the dually polarized circularly curved Eleven antenna feeds a reflector with semi-subtended angle of 60°, based on the simulated far field by using CST.

The BOR_1 component of the far field function of a feed antenna is the most part the total radiation field that adds to the directivity in a rotationally symmetric reflector. The BOR_1 efficiency measures how closely the total far field resembles a BOR_1-type field with only first order $\sin\phi$ and $\cos\phi$ variations of the far field, and it quantifies how much power is lost due to the non-BOR_1 components. Based on the extracted BOR_1 component from the total far field of the Eleven feed, the aperture efficiency (due to the BOR_1 component) and several sub-efficiencies (i.e., illumination efficiency e_{ill}, phase efficiency e_{phase}, polarization efficiency e_{pol} and spillover efficiency e_{sp}) of a paraboloidal reflector (semi-subtended angle 60°) can be calculated by using formulas in [10][11][13]. In Figure 6, all the above-mentioned efficiencies are plotted in steps of 0.1 GHz over 2-5 GHz. We can readily find that the BOR_1 efficiency varies around -0.25 dB while the aperture efficiency due to BOR_1 component varies around -2.0 dB over 2-5 GHz. These two major efficiencies seem better than any previous design of Eleven feed. As a result, the total aperture efficiency, which is the sum of the previous two major efficiencies in dB, is quite promising to be improved when the circular version of Eleven feed is applied.

III. Conclusion

A new circularly curved wideband Eleven feed made from four flat printed petals and a ground plane has been studied and demonstrated to improve the BOR_1 efficiency and therefore the total aperture efficiency when used to feed reflector antennas. The simulations of a 2-5 GHz model show that the BOR_1 efficiency reaches around -0.25 dB over the whole band, which represents an improvement of 0.3 dB compared to previous models. At the same time, the reflection coefficient is below -10 dB over the most of the band. We believe that the circular Eleven feed is a promising solution that can improve the BOR_1 efficiency even over a wider frequency band.

Acknowledgment

The authors would like to thank the technical and financial support from the Radio Systems Group at Norwegian University of Science and Technology (NTNU) in Trondheim, Norway.

References

[1] R. Olsson, P.-S. Kildal and S. Weinreb, "The Eleven antenna: A Compact Low-profile Decade Bandwidth Dual Polarized Feed for Reflector Antennas," *IEEE Transactions on Antennas and Propagation*, vol.54, no. 2, pp.368-375, 2006.

[2] J. Yang, X. Chen, N. Wadefalk and P.-S. Kildal, "Design and Realization of a Linearly Polarized Eleven Feed for 1-10 GHz," *IEEE Antennas and Wireless Propagation Letters*, vol.8, 2009.

[3] J. Yang, D. Nyberg and J. Yin, "Impedance matrix of a folded dipole pair under Eleven configuration," *IET Microwaves Antennas Propagat.*, vol. 4, no. 6, pp. 697-703, June, 2010.

[4] J. Yang, "On conditions for constant radiation characteristics for log-periodic array antennas," *IEEE Trans. on Antennas Propagat.*, vol. 58, no. 5, pp. 1521-1526, May, 2010.

[5] J. Yang, M. Pantaleev, P.-S. Kildal, B. Klein, Y. Karandikar, L. Helldner, N. Wadefalk, C. Beaudoin, "Cryogenic 2-13 GHz Eleven Feed for Reflector Antennas in Future Wideband Radio Telescopes," *IEEE Transactions on Antennas and Propagation*, vol. 59, no. 3, March 2011.

[6] J. Yang, P.-S. Kildal, "Optimizing large log-periodic array by computing a small part of it," *IEEE Transactions on Antennas and Propagation*, vol. 59, no. 3, March 2011.

[7] J. Yin, J. A. Aas, J. Yang and P.-S. Kildal, "Monopulse Tracking Performance of Multi-port Eleven Antenna For Use in Satellite Communication Terminals," *2nd European Conference on Antennas and Propagation*, Edinburgh, Nov. 2007.

[8] J. Yin, D. Nyberg, X. Chen and P.-S. Kildal, "Characterization of Multi-port Eleven Antenna For Use in MIMO System," *13th International Symposium on Antennas and Propagation*, Taipei, Oct. 2008.

[9] J. Yang, S. Pivnenko, T. Laitinen, J. Carlsson and X. Chen "Measurements of Diversity Gain and Radiation Efficiency of the Eleven Antenna by Using Different Measurement Techniques," Proceedings of the *4th European Conference on Antennas and Propagation*, Barcelona, Apr. 2010.

[10] P.-S. Kildal and Z. Sipus, "Classification of Rotationally Symmetric Antennas as Types BOR0 and BOR1," *IEEE Antennas Propag. Mag.* vol.37, no.6, p.114, Dec. 1995.

[11] J. Yang, S. Pivnenko, P.-S. Kildal, "Comparison of two decade-bandwidth feeds for reflector antennas: the eleven antenna and quadridge horn," *4th Eur. Conf. on Antennas Propagat. (EuCAP2010)*, Barcelona, Spain, 12 - 16 April 2010.

[12] A. Yasin, J. Yang and T. Östlin, "A Compact Dual-Band Feed for Reflector Antennas Based on Choke Horn and Circular Eleven Antenna," *IEEE Transactions on Antennas and Propagation*, vol..57, no.10, pp. 3300-3302, Oct. 2009.

[13] P-S. Kildal, "Factorization of the feed efficiency of paraboloids and Cassegrain antennas", *IEEE Trans. Antennas Propagat.*, Vol. Ap-33, No. 8, pp.903-908, Aug. 1985..