FDTD ANALYSIS OF A BROADBAND FEED WITH CHOKES FOR THE RADIO TELESCOPE IN ARECIBO

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1.Introduction

The Gregorian dual-reflector feed of the radio telescope in Arecibo [1] is designed by geometrical optics (GO) to operate between 500 MHz and 8 GHz. To obtain optimimum performance the Gregorian must be illuminated by a feed which has a 15 dB half dB width of 60°, i.e. the same requirement as for many primary feeds of paraboloids. This beam width should be constant over as large bandwidth as possible in order to cover the total bandwidth with as few feeds as possible.

The frequency range and beam width requirements call for choke horns [2] and small corrugated horns [3]. We optimized a choke horn for nearly constant beam width over a relative bandwith of 1.8 by means of a moment method code for bodies of revolution [4]. The results are presented in [5].

The moment method is well known as an accurate method to design small horn antennas, and it has also been demonstrated to work for large dual frequency horns [6], but in the latter case there are known problems with instable field solutions due to internal structure resonances.

The purpose of the present paper is to present a study of the same horn by the finite difference time domain technique (FDTD). The FDTD does not suffer from instable field solutions due to resonances. It can also provide results over the entire frequency band of interest in one single simulation by using a pulse source followed by Fourier transforms, whereas the moment method must be rerun for each freqnency. We use the FDTD algorithm for bodies of revolution [7] with superabsorbtion and near to far field transforms [8] as implemented in the V2D program of W.K.Gwarek. This algorithm is by orders of magnitude faster than the classical FDTD scheme, because the grid cells are modified to follow the material boundaries by means of local integral approximations. Furthermore, a novel differential method for reflection coefficient extraction improves accuracy [9].

2.Calculated and measured results

The horn is rotationally symmetric with the cross section shown in figure 1. The dimensions are given in [5]. Figure 1b shows actually the grid used in the FDTD model. With this grid size one FDTD simulation covering the whole desired bandwidth takes approximately one minute on a Pentium 90 computer. To economise memory occupation the radiation patterns are only calculated at three user-defined frequencies, and the calculations are therefore repeated to get enough sample points. The return loss is available over the whole frequency band after one run. The FDTD results are compared with measured results in figures 2,3,4 and 5. We see that the agreement is excellent. The agreement with measurements is actually equally good as in the moment method calculations in [5]. Figure 6 shows also how the return loss prediction is improved by making use of the differential scheme for extracting it from the field values [9].

We have evaluated the phase center from the calculated radiation patterns by making use of the algorithm in [10], and the aperture efficiencies when the horn is feeding a paraboloid (Figure 7) [11], and when it is feeding the Gregorian dual-reflector feed of the radio telescope in Arecibo (Figure 8). The latter has been evaluated by using geometrical optics ray tracing and aperture integration [12]. The phase center variation is small and gives negligible reduction in aperture efficiency over the band (Figure 5). The presented aperture efficiencies have actually been calculated for a fixed optimum location of the horn, so the losses due to the phase center variations over the frequency band are included.We see that the aperture efficiency is nearly constant between 9 and 17 GHz when the subtended half angle of the paraboloid is 60°. The obtained aperture efficiency of the Arecibo radio telescope is also nearly constant and very close to the theoretical design value obtained by a theoretical $(\cos(\theta/2))^n$ feed.

3.Conclusion

We have presented a choke horn which has nearly constant beam width over a relative bandwidth of 1.8. The horn is an almost perfect feed for the Gregorian dual-reflector feed of the radio telescope in Arecibo. We have analyzed the horn with FDTD and have compared the results with measurements. The agreement is nearly perfect. From this study it is clear that the FDTD method is fully competitive with the moment method in analyzing small rotationaly symmetric horn antennas.

4.References

[1] P-S. Kildal, L. Baker, T. Hagfors, " The Arecibo upgrading: Electrical design and expected performance of the dual-reflector feed system ", Proceedings of the IEEE , Vol. 82, No. 5, pp. 714-724, May 1994.
[2] A.D. Olver, P.J.B. Clarricoats, A.A. Kishk and L. Shafai, "Microwave Horns and Feeds" , IEEE Press, New York, 1994.
[3] B.M. Thomas, K.J. Greene, and G.L. James, "A wide-band prime-focus horn for low-noise receiver application", IEEE Trans. 1990, AP-38, (11), pp.1898-1900.
[4] Kishk. A.A. and Shafai. G.L: "Different formulations for numerical solution of single or multi-bodies of revolution with mixed boundary conditions", IEEE Trans Antennas Propagat., Vol AP-34, pp. 666-673, 1986.
[5] Z. Ying, A.A. Kishk and P-S Kildal, " Broadband compact horn feed for prime-focus reflector", Electronics letters, Vol 31, No. 14, 6th July, 1995, pp. 1114-1115.
[6] J. Flodin, P-S Kildal, A. Kishk, " Moment method design of a large S/X band corrugated horn", submitted to IEEE AP-S Symposium in Baltimore, July 1996.
[7] W.K. Gwarek, T. Morawski. C. Mroczkowski, " Application of the FD-TD method to the analysis of circuits described by the two-dimensional vector wave equation ", IEEE Trans. Microwave Theory Tech., Vol. MTT-41, No. 2. Feb. 1993, pp. 311-317.
[8] C. Mroczkowski, M. Celuch-Marcysiak, W.K. Gwarek, "Joint application of superabsorption and near-to-far field transform to FDTD analysis of axisymmetrical antennas", Proc. 24th European Microwave Conf., Cannes, Sept. 1994, pp. 899-904.

[9] W.K. Gwarek, M. Celuch-Marcysiak, " A differential method of reflection coefficient extraction from FD-TD simulations ", accepted for publication in IEEE Microwave and Guided Wave Letters, 1996.
[10] P-S Kildal, " Combined E- and H-plane centres of antenna feeds ", IEEE Trans. Antennas Propagat., Vol. AP-31, pp. 199-202, 1983.
[11] P-S Kildal, " Factorization of the feed efficiency of paraboloids and Cassegrain antennas ", IEEE Trans. Antennas Propagat., Vol. 33, No. 8, pp. 903-908. Aug. 1985.
[12] P-S Kildal, " Analysis of numerically specified multi-reflector antennas by kinematic and dynamic ray tracing ", IEEE Trans. Antennas Propagat., Vol. 38, No. 10, pp. 1600-1606, Oct. 1990.

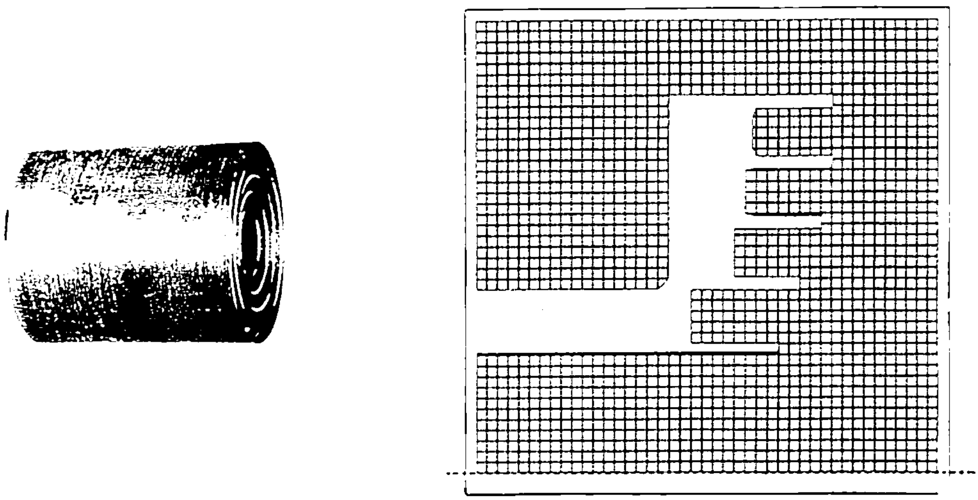

Fig. 1. The broadband choke horn and its half cross section as gridded in the FDTD program.

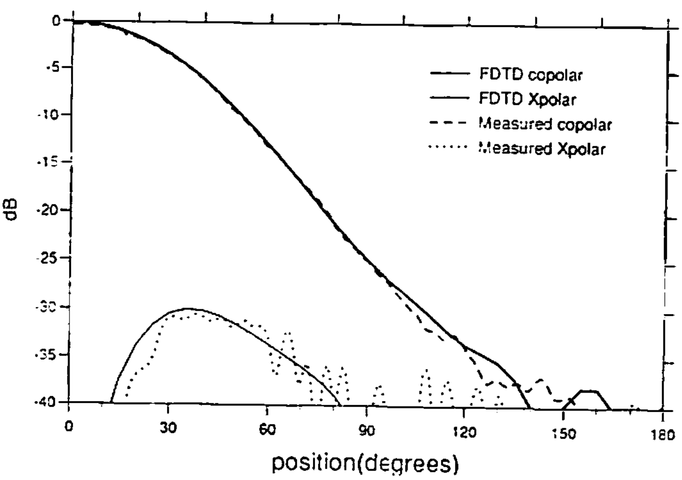

Fig. 2. Calculated and measured co- and cross-polar radiation patterns at 10 GHz.

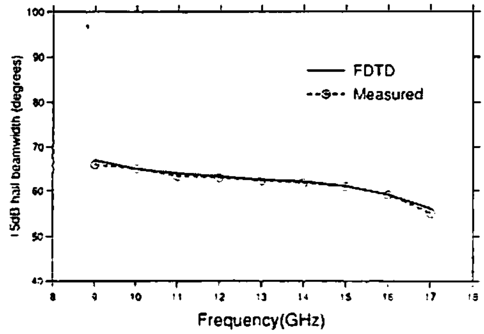

Fig. 3 15 dB half beam width of the copolar radiation patterns as a function of frequency.

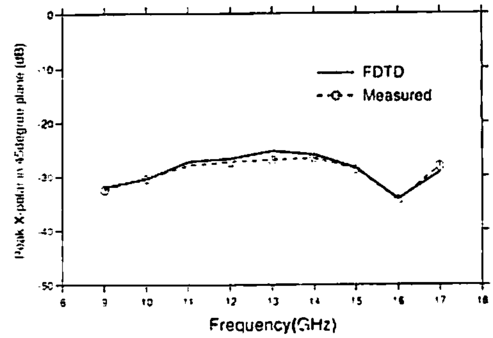

Fig. 4 The level of the first cross polar sidelobe in the 45° plane as a function of frequency.

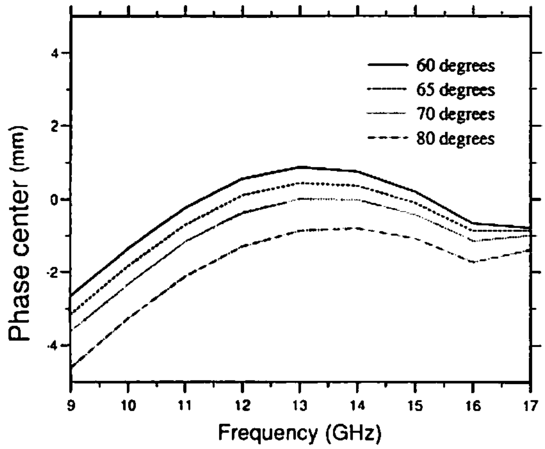

Fig. 5 Phase center variation for different subtended angles of the paraboloid.

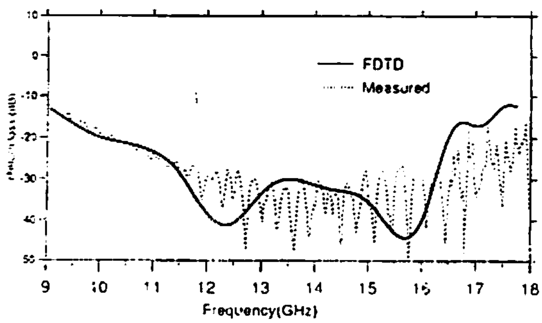

Fig. 6 Return loss measured (dotted line), calculated with return-loss-extraction based on-Bessel functions (continous line), and calculated with the new differential scheme for return loss extraction (broken line).

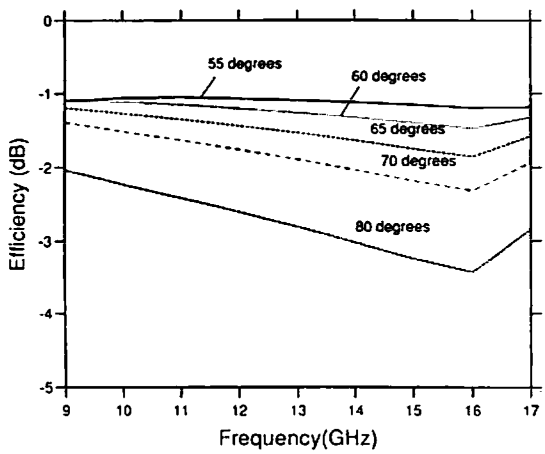

Fig. 7 Efficiency when used as a primary feed in a paraboloid.

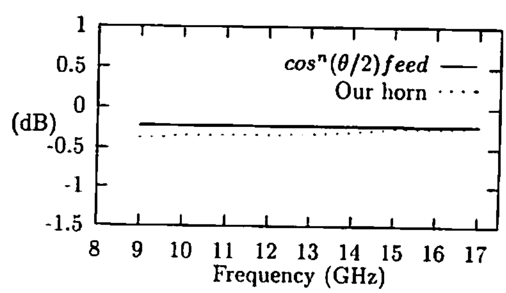

Fig. 8 Efficiency when the horn is feeding the Arecibo tri-reflector system.