Designing of Offset Gregorian Dual-Reflector Antennas with Non-circular Aperture using FEKO

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Abstract: this paper presents a procedure of designing an offset Gregorian dual-reflector antenna with a non-circular aperture of the main reflector using FEKO. A 1.2m Ku band offset dual-reflector antenna is set as an example to compare the results from two solvers in FEKO with the measurement data. There are good agreements on the radiation patterns simulated in FEKO with those by measurement.

Keywords: offset reflector antenna， dual-reflector antenna， FEKO

I. Introduction

Offset reflector antennas including offset dual-reflectors are in widespread use, because of their low aperture blockage and simplicity. The optimization of classical offset dual-reflector systems, especially offset Gregorian dual-reflector antennas with circular aperture, for electrical performance has been derived by several authors [1]-[2]. For some special purposes of application and integration with whole systems, the aperture of main reflector should be non-circular. Therefore, based on the classical offset Gregorian dual-reflector antennas, this paper presents a design of the main reflector with a non-circular aperture using FEKO.

II. Geometry of the Antenna

As known to all, all the offset dual-reflectors should be satisfied with the Mizugutch condition [3] for zero cross-polarized radiation. The partial paraboloidal main reflector is described by the diameter Dm, focal length F, and the offset distance h, while the sub-reflector, i.e. the partial ellipsoid surface, could be derived by the tile angle between main reflector axis and sub-reflector axis β, and the maximum length of the two-reflector combination Lt, which is restricted by requirement of the whole integration system. Fig.1 shows the side view of offset Gregorian dual-reflector antenna. The whole geometry system of antenna needs at least five parameters listed above to yield the other parameters as in [2]. In practice of engineering design, not all of 21 parameters as shown in [2] but seven more parameters including the offset angle θ0, θL and θU, the sub-reflector parameters a, 2c, e, and θe, and tile angle between sub-reflector axis and feed axis α, could accomplish the whole geometry of the offset dual-reflectors.

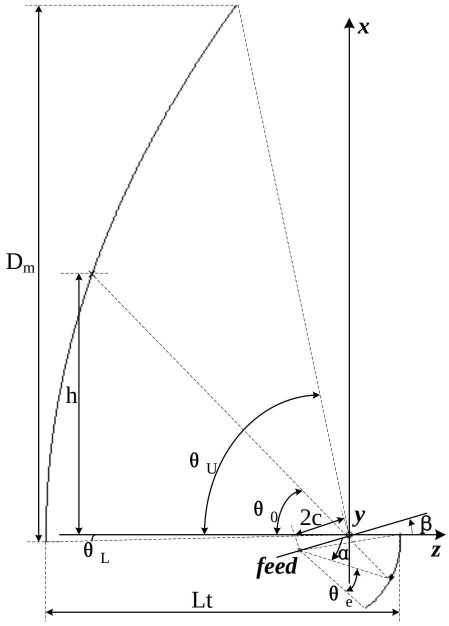

Fig. 1. Side view of offset Gregorian dual-reflector

Starting with the initial parameters D_m, F, h, β and Lt, the remaining seven parameters could be developed as following procedures.

$$\theta_0 = -2\arctan(h/2F) \qquad (1)$$

$$e = \frac{1-\sqrt{\tan(\frac{\beta}{2})/\tan(\frac{\beta-\theta_0}{2})}}{1+\sqrt{\tan(\frac{\beta}{2})/\tan(\frac{\beta-\theta_0}{2})}} \qquad (2)$$

$$\alpha = 2\arctan\left[\frac{e+1}{e-1}\tan(\beta/2)\right] \qquad (3)$$

$$\theta_U = -2\arctan(\frac{2h+D_m}{4F}) \qquad (4)$$

$$\theta_L = -2\arctan(\frac{2h-D_m}{4F}) \qquad (5)$$

$$a = -\frac{Lt+(2h-D_m)^2/16F-F}{(e^2-1)\cos\theta_L/\left[e\cos(\beta-\theta_L)+1\right]} \qquad (6)$$

$$2c = ae \qquad (7)$$

$$\theta_e = \alpha - 2\arctan\left[\frac{1+e}{1-e}\tan(\frac{\theta_U - \beta}{2})\right] \qquad (8)$$

To make the sub-reflector capture more illumination from the feed, in practice of engineering design, the sub-reflector edge angle θe is adopted one or two degree more than the value yielded by (8) as in [1] and [2].

Considering lowering the centroid of the whole geometry system, the main reflector is designed as a non-circular aperture, i.e. the projected aperture in the axis z is less than the whole aperture Dm. In this paper, meanwhile, offset Gregorian dual-reflector chooses the offset distance h less than Dm/2, difference from the classical offset antenna, but it is not worried about the blockage of sub-reflector because of the non-circular aperture. In this case, the projected aperture in the axis y should be some larger than the whole aperture Dm to compensate the lack of illumination in the vertical plane.

III. Modeling and Analyzing in FEKO

The Method of Moments (MoM), a full wave solution of Maxwell's integral equations, is quite suitable for analyzing reflectors since its meshes are based on surfaces, while it has an N2 scaling of memory requirements and N3 in CPU-time [4]. For electrically large problems such as reflector or multi-reflector antennas, therefore, the solver is not available because of limited memory and time for designing. The Multilevel Fast Multipole Method (MLFMM), based on the MoM, provides an efficient solver to radically accelerate the full-wave current-based solutions of electrically large structures, while the Physical Optics (PO), based on equivalent electric currents on the surface, is an asymptotic high frequency numerical method especially for electrically large ones. The MLFMM reduces the cost of resources to NlogN scaling in memory and Nlog2N in CPU-time [4], and while the PO needs even much fewer resources than the MLFMM with reducing the precision.

FEKO is a software suite with some numerical analysis techniques including the MLFMM and the PO, implemented to solve electrically large problems such as reflector or multi-reflector antennas in limited PC's resources. A general procedure of designing an antenna in FEKO is as shown in Fig. 2.

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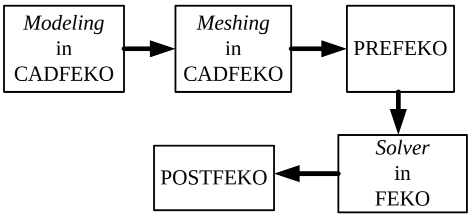

Fig. 2. Procedure of the design using FEKO

In CADFEKO, there are GUI models of basic geometry structure by inputting certain parameters, such as paraboloid, cone, ellipse, etc. The main reflector could be modeled by intersecting between a paraboloid with radius $D_m/2+h$ and a cylinder with the certain ellipse rim, and while the sub-reflector could be the intersection of ellipsoid and a cone with the semi-angle θ_e.

In practice of engineering design, models of the offset dual-reflector antennas in FEKO are analyzed by the solver of MLFMM or PO to obtain the directivity and the radiation patterns. The results from the PO are dependable for narrow-angle radiation patterns and directivity, while those from the MLFMM are reliable for wide-angle radiation patterns and directivity.

IV. Design Example

In this work, a Ku band offset Gregorian dual-reflector satellite terminal antenna with 1.2m aperture is presented as an example.

For some purposes of application and integration with whole systems, several parameters are given and fixed. It is known that β=15.6°, h=498mm, F=538mm, Lt=613mm, and D_m=1200mm. Therefore, other parameters calculated through (1)-(7) are that θ_0=49.7°, θ_U=-91.2°, θ_L=10.8°, e=0.3675, a=128.4mm, $2c$=94.38mm, and α=-33.0°; and the angle θe is actually considered as 32° for engineering application. Fig. 3 shows the scale drawing of the design example of the antenna.

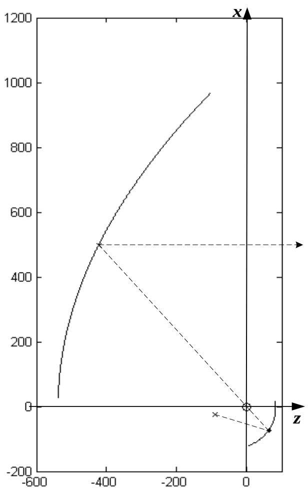

Fig. 3. Scale drawing of the design example

Fig.4 shows the modeling of the example of the antenna in FEKO. The feed horn modeled in FEKO is selected as a wide-angle corrugation conical horn antenna for Ku satellite band of 12.25-12.75 GHz (RX) and 14.0-14.5GHz (TX). Considering the efficiency of the illumination grasped by the sub-reflector and the diffraction from secondary reflection, the corrugation conical horn feed is design with a ten-to-twelve dB edge taper in the whole Ku satellite band.

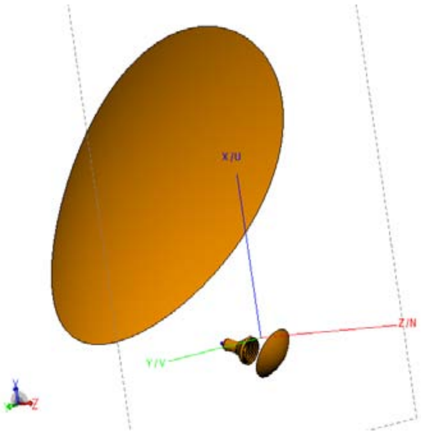

Fig. 4. The antenna example in FEKO

In this work, one example of 1.2m Ku band offset Gregorian dual-reflector is simulated within the workstation (with Intel Xeon E5504 x64 @ 2.0GHz CPU and 48GB RAM) by the MLFMM. Meanwhile, to accelerate the simulation and also save memories, the PO method is applied with far-field aperture [4-5] as well. Firstly, far-field aperture with only feed and the sub-reflector as a simulating source is calculated rapidly because of non-electrically-large structures by the MLFMM. The radiation performance of main reflector, secondly, with the radiation pattern source calculated in the first step, could be solved by the PO shown in Fig. 5. By both the MLFMM and the PO with far-field aperture pattern source, the radiation patterns are obtained at the frequency of 12.5GHz (RX) and 14.25GHz (TX) in practice of design, respectively.

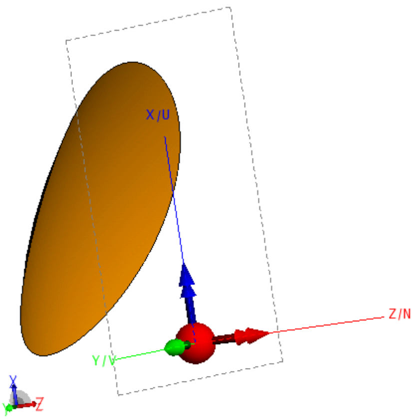

Fig. 5. The PO with radiation pattern source in FEKO

In Table1, the numbers of meshing and costs of PC's resources by the two methods are compared. It is presented that although numbers of meshed by two methods are almost same, the costs of peak RAMs usage and CPU-time by PO with far-field aperture source are huge less than those by MLFMM. In this work, the requirements of RAMs and CPU-time to obtain the far-field aperture source of the feed horn with sub-reflector are not count in the table in that only feed horn with the sub-reflector is not considered as electrically-large structure and it could be calculated by the MLFMM rapidly within normal PCs but not workstations.

TABLE I. numbers of meshing and costs of PC's resources in the rusults simulated At the frequency of 12.5GHz (RX) and 14.25GHz (TX) By two methods respectively

Methods	**Number of Meshes**	**Cost of PC's Resources**	
		Peak RAMs	***CPU-time***
MLFMM	479587	28.515 GB	53895.6 sec
PO with far-field aperture source	444186	173.1 MB	2211.4 sec

In Fig.6 and Fig.7, it is presented that the radiation patterns in the horizontal plane, simulated by the MLFMM and the PO with far-field aperture source, at the frequency of 12.5GHz (RX) and 14.25GHz (TX), respectively. Meanwhile, the results measured at the same frequency points in the horizontal plane are shown in the figures as well.

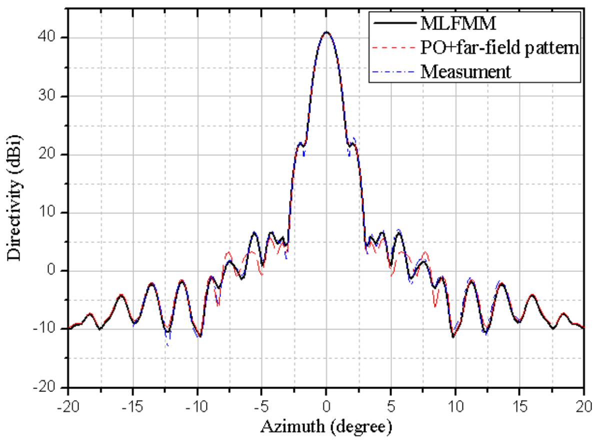

Fig. 6. The radiation patterns at 12.5GHz with two meathods compared with the results measured

The radiation patterns should be symmetrical in the horizontal plane as shown in the results from both the MLFMM and PO with far-field aperture source, in that the whole geometry of the offset Gregorian dual-reflector system is symmetrical in the horizontal plane. However, because of the errors of testing system, some deviations by manufacturing and assembling, and environmental conditions, the patterns measured are some un-symmetrical.

The calculated results by the MLFMM and PO with far-field aperture source are presented the almost the same in the narrow-angle ranges, within the +/-15 or 20 degrees, which the satellite terminal antennas are mainly focused in the practice of engineering. Furthermore, the patterns by MLFMM are much more similar to the results measured, because the patterns by the PO with far-field aperture source are just an asymptotic method to reduce the resources of simulation instead of some accuracy.

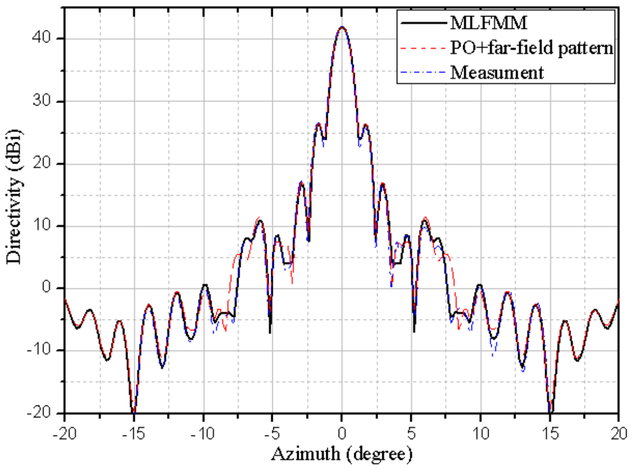

Fig. 7. The radiation patterns at 14.25GHz with two meathods compared with the results measured

V. Conclusions

In this works, a procedure of designing an offset Gregorian dual-reflector antenna with a non-circular aperture of the main reflector using FEKO is present. The example shows the good agreement on the results simulated by FEKO with the measurements. It is preferred that if the sources of PC are sufficient, the solver of the MLFMM in FEKO is first choice to design the dual-reflector antennas. Meanwhile, when under limition of calculation resources, the results by PO with far-field aperture source in FEKO are also acceptable and reliable in the practice of engineering

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VII. References

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