A Quadratic Backscatter Antenna with Ring Focus Feed

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1. Introduction

In the modern world of telecommunications, the concept of wireless global coverage is of the utmost importance. Only satellite system can achieve real global coverage. Recently, low earth orbit satellite (LEO satellite) communication systems are exciting development for applications where a short round trip time such as mobile satellite service. Because the coverage area provided by a single LEO satellite only covers a small area that moves as the satellite travels at the high angular velocity needed to maintain its orbit. Many LEO satellites are needed to maintain continuous coverage over an area. Thus, an antenna on the satellite must have a wide beamwidth in order to provide more time for ground station-satellite communication. Shaped beam reflector antenna has become key element of communication satellites having requirement of irregular shaped coverage area. The highly shaped-beam antenna was first developed to give approximately uniform coverage of the earth from satellite antenna [1]. Recently, the similar requirement but different application, a shaped reflector antenna for 60-GHz indoor wireless LAN access point was developed [2]. However, shaping the reflector to obtain shaped beam becomes complicated. This yields a discontinuous surface and more complicated manufacturing process. Thaivirot *et al.* [3] presented the synthesis of radiation pattern of variety of the shaped backscatters antenna. It was found that, the quadratic backscatter will provide the appropriate characteristics. Therefore, it is suitable for using as an antenna for realizing earth coverage beam in LEO satellite application as shown in Fig.1. To improve gain and efficiency of reflector antenna, the displaced-axis dual reflector antenna was discussed. It was found that the axially displaced ellipse (ADE antenna) provides an excellent choice for compact high-gain spacecraft antenna applications. As a result, this paper presents the axially displaced ellipsoid antenna. The proposed antenna is a centrally fed displaced axis quadratic backscatter antenna with a ring focus feed. A backscattering technique is used with the main reflector to achieve wide beamwidth for earth coverage in LEO satellite. Moreover, this approach is fruitful for high-gain antenna applications, especially for Wireless Local Area Network (WLAN) large-scale indoor base station as shown in Fig.2. Physical theory of diffraction (PTD) is utilized to analyze the radiation pattern of proposed antenna and verified with the experimental result.

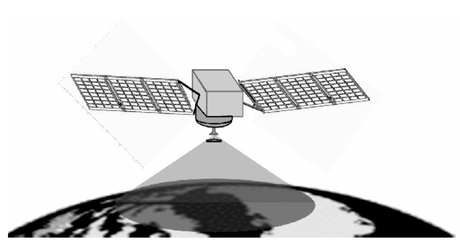


Figure 1: Application of shaped backscatter antenna for LEO satellite communications.

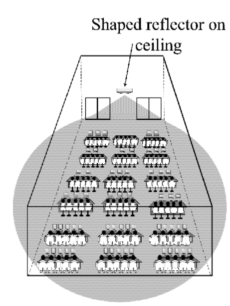


Figure 2: Application of shaped backscatter antenna for indoor WLAN in the large hall.

2. Design of the ADE reflector antenna

Fig.3 shows the cross section of the quadratic backscatter antenna with ring focus feed. This antenna is called the axis-displaced ellipse reflector antenna or ADE reflector antenna because subreflector is a portion of an ellipse and it is displaced axis from the quadratic main reflector. The antenna has axial symmetry. The two foci of the ellipse are located at the phase-center of the feed. The design procedure in this section is base on the works in [4], [5]. The main reflector and subreflector are defined in their own coordinate systems ($O_{MR}, X_{MR}, Y_{MR}, Z_{MR}$) and ($O_{SR}, X_{SR}, Y_{SR}, Z_{SR}$), respectively. The general antenna coordinate system (O, X, Y, Z) of the main reflector and subreflector are finally expressed. Note that the proposed antenna arrangements have $O_{MR} \equiv O_{SR} \equiv O$.

For the classical symmetric Cassegrain or Gregorian reflector antenna, we are dealing with a system of nine parameters defining the overall geometry of the antenna, D_m, L, A, D_s, θ_e, L_m, L_s, a, and f where, D_m is a diameter of main reflector, D_s is a diameter of the elliptical subreflector, A is parameter to define the convexity of the main quadratic backscatter, L is parameter to define distance between main reflector and subreflector, and the other parameters see Figs.3-5. However, these parameters can not be specified arbitrarily. Therefore, we choose five input parameters, i.e. D_m, A, D_s, L and θ_e to define the antenna, and then calculate from these the other design parameters in closed form.

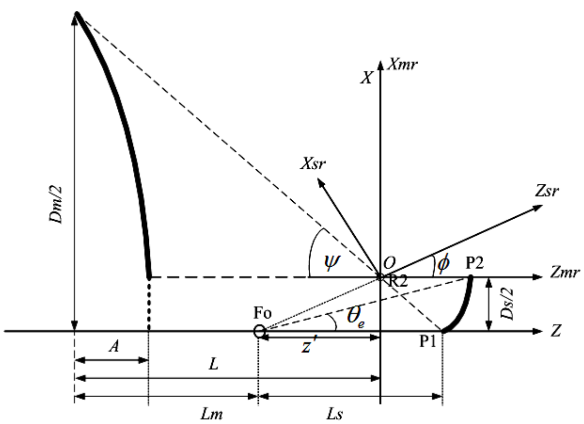


Figure 3: Cross-sectional view of the axially displaced ellipse antenna system

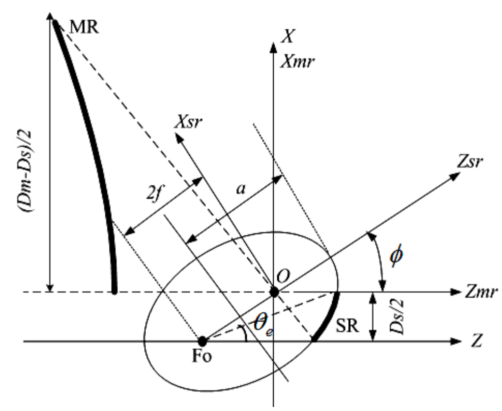


Figure 4: Cross-sectional view of the elliptical-subreflector coordinate system with its parameters

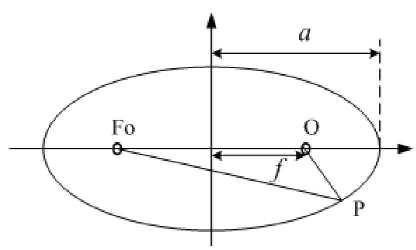


Figure 5: Distance relationship in an ellipse

For the definition of the main reflector geometry, we consider only the upper part of the (O_{MR}, X_{MR}, Z_{MR}) plane. The main-reflector profile, $z_{mr}(x_{mr})$, depends on the two real parameters A and L. The equation of a quadratic backscatter is of the form

$$z_{mr}(x_{mr}) = A\left(1-\left(\frac{2}{D_m}x_{mr}\right)^2\right)-L, \tag{1}$$

with $\quad 0 \le x_{mr} \le \dfrac{D_m - D_s}{2}$.

The elliptical subreflector profile, $z_{sr}(x_{sr})$, is defined in the (O_{SR}, X_{SR}, Z_{SR}) plane, and depends on the two real parameters a and f (In the case an ellipsoid, $a > f > 0$). It is of the form

$$z_{sr}(x_{sr}) = a\sqrt{1 + \frac{(x_{sr})^2}{f^2 - a^2}} - f. \tag{2}$$

To design the antenna, we use the distance relationship in an ellipse [5]. (see Figs.3-5)

$$\|F_0P\| + \|OP\| = 2a \tag{3}$$

From the five input parameters D_m, A, D_s, L and θ_e, and using the distance relationship in an ellipse in (3) the other design parameters i.e. L_m, L_s, a, and f are in closed form [5]. Using this concept, the design of an antenna has been carried out at 18.75 GHz. The value of the input parameters are $D_m = 30$ cm, $D_s = 5.6$ cm, L= 30 cm, $A = 5.8$ cm and $\theta_e = 25°$. The main reflector edge illumination is taken at a level of -15 dB. The antenna is fed by a conical horn with a diameter of 5.4 cm. The designed antenna is presented in Fig. 6. The radiation pattern of the antenna, without any studs, is analyzed by using physical theory of diffraction (see Fig.7) [3], [6]. First of all, one observes that the radiation patterns are symmetry in both the E-plane and H-plane. The maximum gain of the ADE antenna is 11.7 dBi. The gain at $\theta = \pm 70°$ is 4.2 dBi. There is not severe effect of edge effect. In the case of a single quadratic backscatter antenna, the maximum gain is 9.4 dBi and gain at $\theta = \pm 70°$ is 2.7 dBi. The main conclusion of this brief analysis is that quadratic backscatter antenna with ring focus feed produces higher gain and smaller diffraction effects than a single quadratic backscatter antenna.

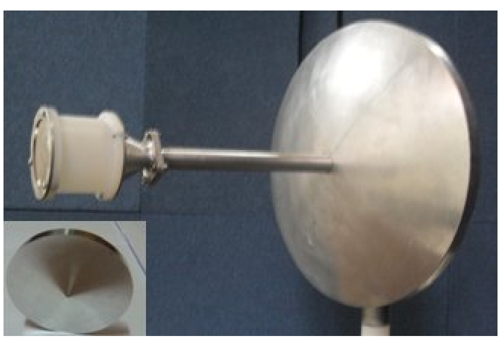


Figure 6: Antenna prototype : $D_m = 30$ cm, $D_s = 5.6$ cm, A=5.8 cm, $L = 32$ cm, $\theta_e = 25°$, $a = 6.7411$ cm, $f = 1.4634$ cm, $L_s = 7.7458$ cm, $L_m = 31.1478$ cm

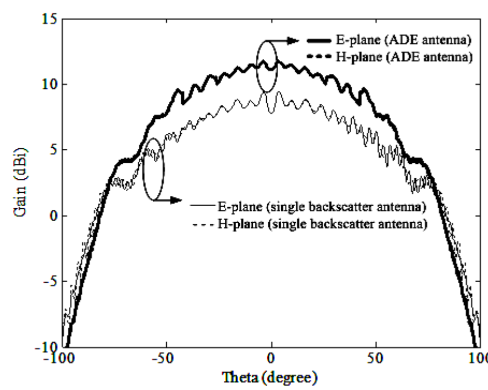
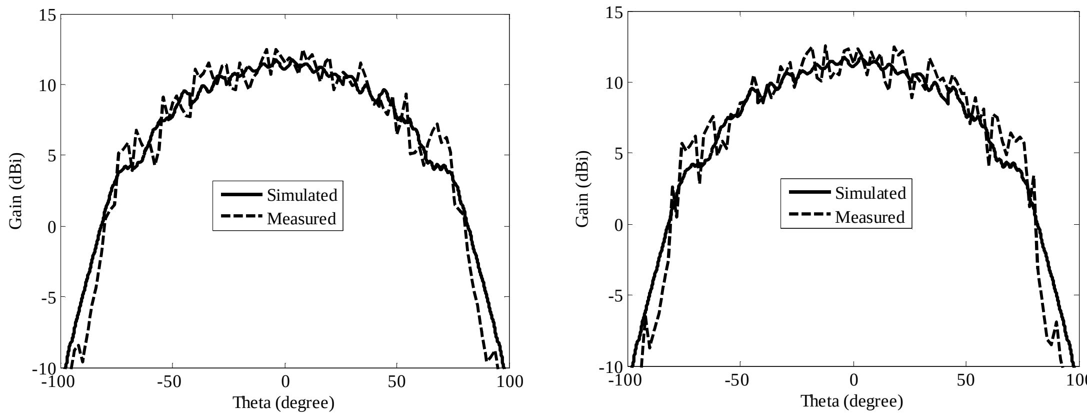


Figure 7: Radiation pattern at 18.75 GHz

3. Measured Results

To verify the performance of the antenna discussed, a prototype has been fabricated on aluminium as shown in Fig.6. The subreflector is supported from the horn using cylindrical superlene cavity of 1 mm thickness. The antenna has been tested in an anechoic chamber. The measured radiation pattern is plotted together with the simulated pattern as shown in Fig.8. This plot shows good agreement between the measured and simulated both in E-plane and H-plane patterns. The measured gain in E-plane and H-plane are 12.51 dBi and 12.56 dBi, respectively. The gain at $\theta = \pm 70°$ of the measured result is around 5.9 dBi in E-plane and 6.2 dBi in H-plane. It is found that, the gain of measured result in E-plane and H-plane are higher than simulated results about 0.91 dBi and 0.96 dBi, respectively. Therefore, it can be summarized that the gain between simulated and measured results can show some minor differences both in E-plane and H-plane patterns. An additional cause of asymmetry observed in the measured patterns is (the combination of) the small defocusing and mispointing of the feed, i.e., feed displacements and tilts.



(a) E-plane (b) H-plane

Figure 8: Far-field patterns of a quadratic backscatter antenna with ring focus feed

4. Conclusion

The design of quadratic backscatter antenna with ring focus feed (or ADE antenna) was presented. The antenna was analyzed by using the PTD technique. From the simulation results, we can conclude that quadratic reflector antenna with ring focus feed produces higher gain and smaller diffraction effects than a single quadratic backscatter antenna. The antenna prototype was fabricated on aluminium by using high-precision CNC machine and measured field patterns in the anechoic chamber. The measured maximum gain is 12.56 dBi, and the maximum gain at $\theta = \pm 70°$ is around 6.2 dBi. Good agreement between simulated and measured results is obtained.

Acknowledgments

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References

[1] S.G. Hay, D.G. Bateman, T.S. Bird, and F.R. Cooray, “Simple Ka-band Earth Coverage Antennas for LEO Satellites,” IEEE Antennas Propag. Soc. Int. Symp., vol.1, pp. 11-16, 1999.

[2] P.F.M. Smulders, S. Khusial, and M.H.A.J. Herben, “A Shaped Reflector Antenna for 60-GHz Indoor Wireless LAN Access Points,” IEEE Trans. on Vehicular Technology, vol.50, pp. 584-591, 2001.

[3] V. Thaivirot, P. Krachodnok, and R. Wongsan, “Radiation Pattern Synthesis from Various Shaped Reflectors Base on PO and PTD Methods for Point-to-Multipoint Applications,” WSEAS Transactions on Communications, vol. 7, pp. 531-540, 2008.

[4] C. Granet, “A Simple Procedure for the Design of Classical Displaced-Axis Dual-Reflector Antennas Using a Set of Geometric Parameters,” IEEE Antennas and Propag. Magazine, vol. 41, no. 6, pp. 64-71, 1999

[5] W. Thaiwirot, R. Wongsan, and M. Krairiksh, “Design of a Quadratic Backscatter Antenna with Ring Focus Feed,” Proceeding of ISAP2009, pp.815-818, 2009

[6] A. Michaeli, “Elimination of Infinities in Equivalent Edge Currents, Part I: Fringe Current Components,” IEEE Trans. Antennas Propag., vol. AP-34, pp. 912-918, 1986.