Design of a Quadratic Backscatter Antenna with Ring Focus Feed

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1. Introduction

Low Earth Orbit Satellite (LEO Satellite) communication systems are one of the new and exciting developments in providing global communication services. Since satellites in low earth orbit change their positions relative to the ground positions quickly, therefore, time required for ground station-satellite communications is limited. Hence, wide beam antennas are needed. At present, the antenna can be used for realizing earth coverage beam in LEO satellite such as shaped reflector antennas. 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, the indoor high speed data transmission: wireless LAN operating in the millimeter wave, attracts considerable attentions [2]. A shaped reflector antenna for 60-GHz indoor wireless LAN access point was developed [3]. However, shaping the reflector to obtain shaped beam becomes complicated. This yields a discontinuous surface and more complicated manufacturing process. Thaivirot *et al.* [4] 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 ellipse 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. The proposed antenna will be installed on the centre point of ceiling in the large hall and can illuminate a predefined circular area for all users without substantial spatial variation as shown in Fig.2. Physical theory of diffraction (PTD) is utilized for analysis and design. The input parameters of the proposed antenna are derived in closed form.
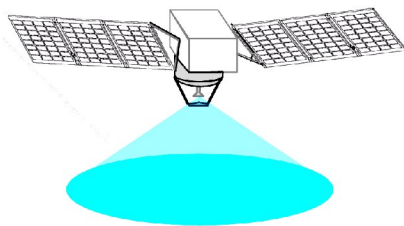

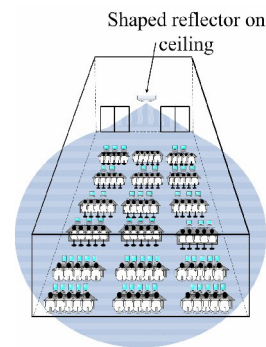Figure 1: Application of shaped backscatter antenna for LEO satellite communication.

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

2. Antenna Geometry and Design Parameters

The cross section of the axially displaced ellipse antenna system is shown in Fig.3. The antenna has axial symmetry. The curvature of main reflector is quadratic, and the subreflector is a portion of an ellipse. 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 [5]-[6]. 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, $D_m, L, A, D_s, \theta_e, L_m, L_s, a,$ and f (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.
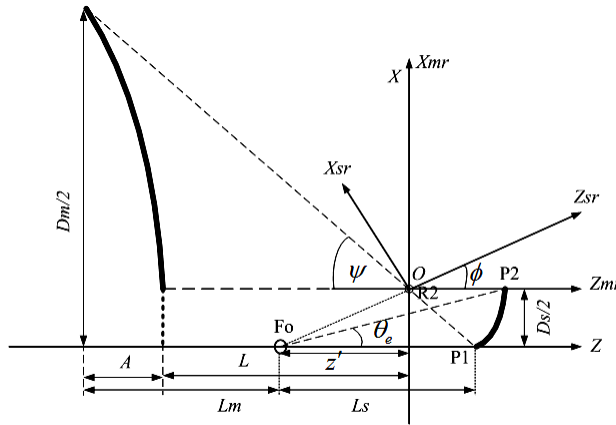

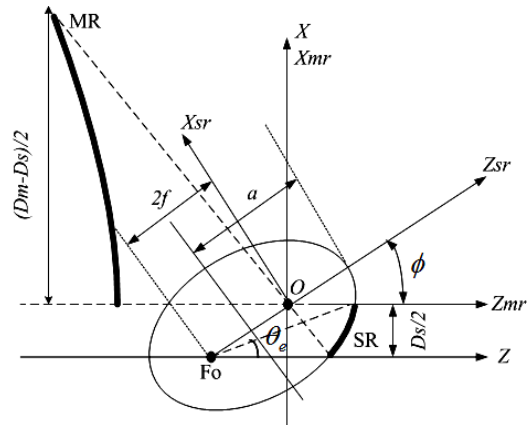Figure 3: Cross-sectional view of the axially displaced ellipse antenna system

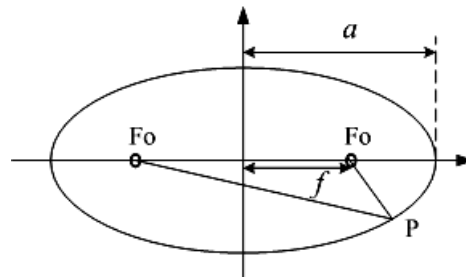Figure 4: Cross-sectional view of the elliptical-subreflector coordinate system with its parameters

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

$$0 \le x_{mr} \le \frac{D_m - D_s}{2}.$$

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. It is of the form

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

Note: In the case an ellipsoid, $a > f > 0$

The points defining the subreflector are such that when x_{sr} is expressed in the main-reflector coordinate system,

$$-\frac{D_s}{2} \leq [x_{sr}]_{Expressed\ in\ the\ MR\ coordinate\ system} \leq 0.$$

To design the antenna, we use the distance relationship in an ellipse [6]. (see Figs.3-5)

$$\|F_0 P\| + \|OP\| = 2a \tag{3}$$

From the five input parameters D_m, A, D_s, L and θ_e, and using the distance relationship in an ellipse, we find that

$$\tan(\psi) = \frac{D_m^2(D_m - D_s)}{2\left[LD_m^2 - A\left(D_m^2 - (D_m - D_s)^2\right)\right]}, \tag{4}$$

$$\tan(\phi) = \frac{2}{\left[\dfrac{\cos(\theta_e)+1}{\sin(\theta_e)} - \dfrac{\cos(\psi)+1}{\sin(\psi)}\right]}, \tag{5}$$

$$f = \frac{D_s}{4\sin(\phi)}, \tag{6}$$

$$a = \frac{D_s}{8}\left[\frac{\cos(\theta_e)+1}{\sin(\theta_e)} + \frac{\cos(\psi)+1}{\sin(\psi)}\right], \tag{7}$$

$$Ls = 2f\cos(\phi) + \frac{D_s}{2\tan(\psi)}, \tag{8}$$

$$L_m = L - \frac{D_s}{4}\left[\frac{\cos(\theta_e)+1}{\sin(\theta_e)} - \frac{\cos(\psi)+1}{\sin(\psi)}\right] + A. \tag{9}$$

The parameters necessary to represent the axially displaced ellipse reflector antenna system are defined.

3. Radiation Pattern

The antenna was designed using the input parameters, i.e., $D_m = 30$ cm, $L = 32$ cm, $D_s = 5.6$ 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 corrugated conical horn, operating at 18.75 GHz. The designed antenna is presented in Fig. 6. The radiation pattern of the antenna is analyzed by using physical theory of diffraction (see Fig.7) [4],[7]. 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 11.6 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 feeding produces higher gain and smaller diffraction effects than a single quadratic backscatter antenna.
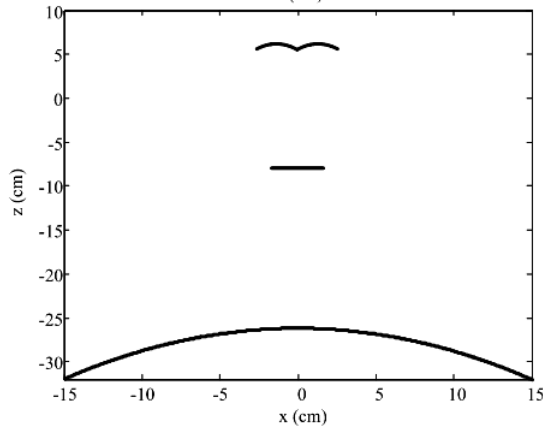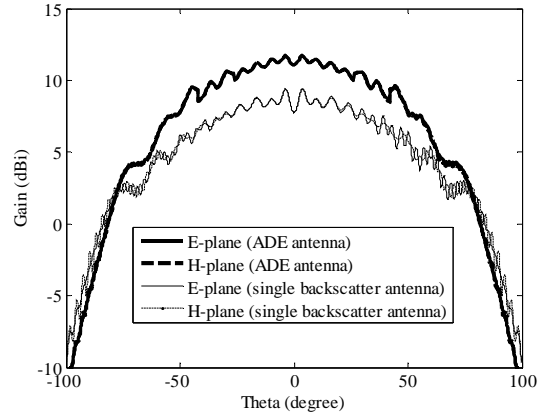

Figure 6: Antenna geometry

Figure 7: Radiation pattern at 18.75 GHz

4. Conclusion

The design of quadratic backscatter antenna with ring focus feed (ADE antenna) was presented. The antenna was analyzed by using the PTD technique. The radiation pattern in E-plane and H-plane can provide gain of 4.2 dBi at $\theta = \pm 70°$ and maximum gain is 11.6 dBi. From these results we can conclude that quadratic reflector antenna with ring focus feed produces higher gain and smaller diffraction effects than a single quadratic reflector antenna.

Acknowledgments

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] T.S. Bird, J.S. Kot, N. Nikolic, G.L. James, and S.J. Barke, "Millimeter-Wave Antenna and Propagation Studies for Indoor Wireless LANs," Antennas Propag. Soc. Int. Symp., vol.1, pp. 336-339, 1994

[3] 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.

[4] 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.

[5] A.P. Popov and T. Milligan, "Amplitude Aperture-Distribution Control in Displaced-Axis Two Reflector Antenna," IEEE Antennas and Propag. Magazine, vol. 39, no. 6, pp. 58-63, 1997.

[6] 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

[7] 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.