Performance Improvement of a Gaussian Backscatter Antenna with Ring Focus Feed

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1. Introduction

Low Earth Orbit Satellites (LEO Satellite) are often deployed in satellite constellations, 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. Since satellite travels at the high velocity, 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, 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. Each of shape single backscatter antenna is easy to realize and manufacture because the shape of backscatters are elementary geometrical functions. It was found that, the Gaussian 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 Gaussian 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 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. An effective technique for performance improvement of a Gaussian backscatter antenna using ring focus feed is proposed.

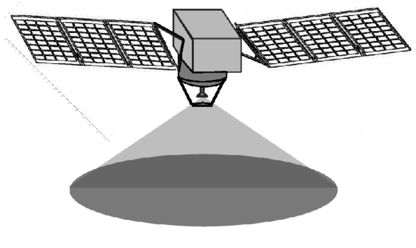


Figure 1: Application of shaped backscatter antenna for LEO satellite communications.

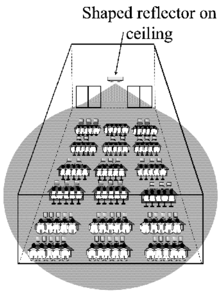


Figure 2: Application of shaped backscatter antenna for indoor WLAN in the large hall.

2. Design of the ADE reflector antenna

The cross section of the axially displaced ellipse antenna system is shown Fig.3. The antenna has axial symmetry. The curvature of main reflector is Gaussian, and the subreflector is a portion of an ellipse. The design procedure in this section is based on [4].

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 a Gaussian main reflector, D_s is a diameter of the elliptical subreflector, A is parameter to define the convexity of the main Gaussian 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.

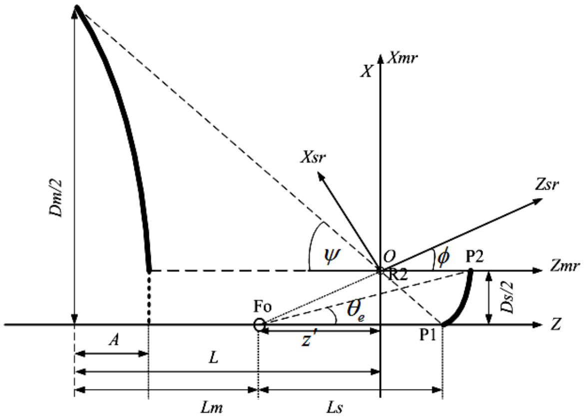


Figure 3: Cross-sectional view of the axially displaced ellipse antenna system

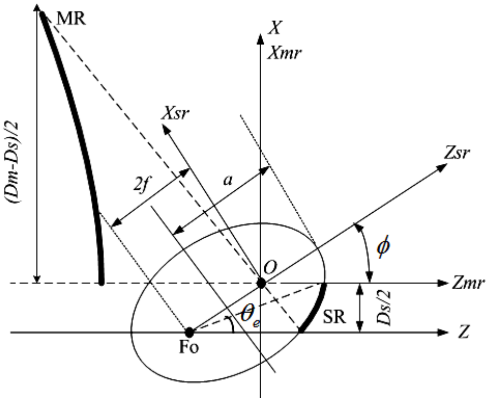


Figure 4: Cross-sectional view of the elliptical-subreflector coordinate system with its parameters

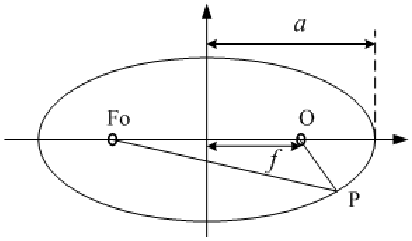


Figure 5: Distance relationship in an ellipse

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 Gaussian backscatter is of the form

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

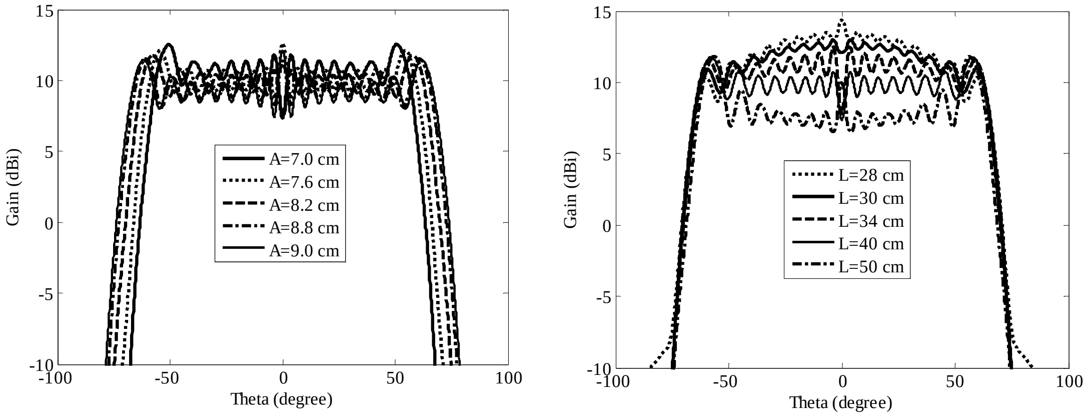
The elliptical subreflector profile, $z_{sr}(x_{sr})$, is defined in the (O_{SR}, X_{SR}, Z_{SR}) plane, and depends on the two real parameters a and f (In the case an ellipsoid, $a > f > 0$). It is of the form

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

From the five input parameters D_m, A, D_s, L and θ_e, and using the distance relationship in an ellipse the other design parameters i.e. L_m, L_s, a, and f are in closed form [5].

3. Performance Improvement of the Antenna

To illustrate the radiation pattern of the axially displaced ellipse antenna, we need to choose five input parameters, i.e. diameter of the main Gaussian backscatter (D_m), diameter of the elliptical subreflector (D_s), parameter to define the convexity of the main Gaussian backscatter (A), parameter to define distance between main reflector and subreflector (L), and the angle θ_e. The antenna is fed by a corrugated conical horn, operating at 18.75 GHz. We start with the input parameters, i.e., $D_m = 30$ cm, $D_s = 5.6$ cm, $A = 7$ cm, $L = 40$ cm and $\theta_e = 25°$. From five input parameters, we can find the remaining design parameters in terms of these input parameters [5]. The radiation pattern of the proposed antenna has been simulated by using physical theory of diffraction [6]. The aim of this paper is the proposed antenna must have the gain more than 10 dBi and must have the coverage angle at gain 4 dBi more than $\pm 65°$. In order to optimize coverage angle of wide beam ADE antenna, we vary the parameter A in the 7 cm to 9 cm range. Each of the convexity of the main Gaussian backscatter provides different radiation patterns which are shown in Fig.6(a). The characteristics of ADE antenna are reported in Table 1. For average consideration, it is apparent that the maximum convexity of the main Gaussian backscatter provides the widest coverage angle. It can be concluded that increasing of the convexity of the main Gaussian backscatter can improves the coverage area of ADE backscatter antenna. However, it is generally observed that when the antenna beam is enlarged, the antenna gain is reduced. With the optimum design requirement, the convexity of the main Gaussian backscatter is chosen at 8.2 cm ($A = 8.2$) because this parameter provides appropriate gain and coverage angle.



(a) Various convexity of the main Gaussian backscatter

(b) Various parameters to define distance between main reflector and subreflector

Figure 6: Radiation pattern in E-plane of ADE antenna

Table 1: Characteristics of ADE antenna for the various convexity of the main Gaussian backscatter

A (cm)	Gain (dBi)	Coverage angle at gain 4 dBi (degree)
7.0	10.76	±60°
7.6	9.82	±64°
8.2	9.66	±68°
8.8	8.97	±70°
9.0	8.78	±71°

Now, we have the new input parameters, $D_m = 30$ cm , $D_s = 5.6$ cm , $A = 8.2$ cm , $\theta_e = 25°$ .and $L = 40$ cm . In order to optimize the gain of the ADE backscatter antenna, we vary the parameter to define distance between main reflector and subreflector (L) in the 28 cm to 50 cm range. The various of parameters L provides different radiation patterns which are shown in Fig.6(b). The characteristics of ADE backscatter antenna are reported in Table 2. For average consideration, it is observed that the minimum parameter L provides the highest gain. It can be concluded that decreasing of the distance between main reflector and subreflector can improves the gain of ADE backscatter antenna. However, the designer must compromise between the gain and the other characteristics such as coverage angle and ripple level. With the optimum design requirement, the parameter to define distance between main reflector and subreflector (L) is chosen at 30 cm. This parameter yields accomplishment of the gain about 12.98 dBi (> 10 dBi) and the coverage angle at gain 4 dBi around $\pm 68°$ ($> \pm 65°$).

Table 2: Characteristics of ADE antenna for the various parameter to define distance between main reflector and subreflector

L (cm)	Gain (dBi)	Coverage angle at gain 4 dBi (degree)
28	13.55	±68°
30	12.98	±68°
34	11.38	±68°
40	9.66	±68°
50	7.81	±68°

4. Conclusion

The design of Gaussian backscatter antenna with ring focus feed (ADE antenna) was presented. The antenna was analyzed by using the PTD technique. The performance improvement of the proposed antenna is discussed. Simulation of proposed antenna demonstrates that increasing of convexity of the main reflector can enhance coverage area but its gain is reduced. In addition, decreasing of the distance between main reflector and subreflector can enhance gain of the antenna. With the optimum design, the radiation pattern in E-plane can provide gain 12.98 dBi and gain 4 dBi at $\theta = \pm 68°$.

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