A NEW SATELLITE ANTENNA CONCEPT USING REFLECTARRAY ANTENNAS

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ABSTRACT

In this paper, a new satellite antenna concept involving a Tx and an Rx reflectarray antenna is proposed. Each antenna is composed of multiple horns and a single-layer flat reflectarray. It radiates scanning beams with different radiation directions in the azimuth due to polarization. Each scanning beam has a different radiation direction depending on the frequency and covers an elongated area in elevation. Each user in the service area selects the optimum frequency band, and the polarization is determined by the position of the user. If a 3 dB gain reduction is allowed, half of the frequency band can be used, similar to the conventional multiple-spot beam antenna.

Key words: Satellite antennas; Reflectarray antennas; Multibeam Antennas.

1. INTRODUCTION

In recent years, antennas used in satellite communication have a configuration with four types of beams, A, B, C, and D; these beams are produced by combining two frequency bands, f_1 and f_2, and two orthogonal-polarized polarizations, V and H, as shown in Fig. 1. As both a transmission frequency band (Tx) and reception frequency band (Rx) are necessary for satellite communication, a total of eight types of beams are required. If each beam is produced by a parabolic reflector and multiple horns, a total of eight antennas is required. However, the beams are generally produced with four antennas, each using a Tx and a Rx reflector.

Various antenna configurations using reflectarrays[1] have been reported to reduce the number of antennas. Reference [2] demonstrates how to create a parabolic reflectarray. In this case, for example, a C_{Tx} beam can be produced by the reflectarray and two beams, A_{Tx} and A_{Rx}, can be produced by the parabolic reflector, resulting in the production of three types of beams. As a result, eight types of beams can be produced with a total of three reflectors. Reference [3] shows a flat reflectarray that produces four kinds of beams by combining Tx/Rx and V/H. In this case, the four kinds of beams are A_{Tx}, A_{Rx}, C_{Tx}, and C_{Rx}; hence, eight types of beams can be produced with a total of two reflectors. In any of the above antenna configurations, only one reflector is used for both Tx and Rx. When Tx and Rx are far apart, for example, in the Ka band, isolation between beams of the same type is an issue because Tx has a greater beam width. For Rx, since the beam width is narrower, it is possible that the gain at the beam edge will decrease.

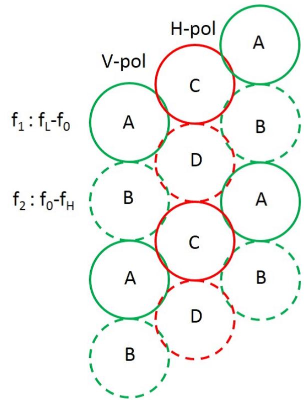

Figure 1. Conventional beam arrangement.

In this paper, a new satellite antenna configuration containing a Tx and an Rx reflectarray antenna is proposed. Each antenna is composed of multiple horns and a single-layer flat reflectarray. It radiates scanning beams with different directions in the azimuth due to polarization by using the phasing elements, as shown in [3][4]. Each scanning beam has a different direction depending on frequency and covers an elongated area in elevation using multiple horns and beam squint characteristics of the reflectarray[5][6]. Each user in the service area selects the optimum frequency band and polarization depending on their position. If 3 dB gain reduction is allowed, half of the frequency band can be used, similar to conventional multiple-spot beam antenna configurations.

2. PROPOSED REFLECTARRAY

We consider the case where the whole frequency band is used, from f_L to f_H. The center frequency, f_0, and the frequency bandwidth, B_W, can be expressed by Eq. 1

and Eq. 2, respectively.

$$f_0 = \frac{f_L + f_H}{2} \tag{1}$$

$$B_W = f_H - f_L \tag{2}$$

The proposed antenna is composed of multiple horns and a single-layer flat reflectarray. The horns are arranged such that the corresponding beams at f_0 form an equilateral triangle with a two-beam-width period.

The geometrical configuration of the reflectarray is designed to have beam squints with ± 1 beam widths at f_L and ∓ 1 beam widths at f_H. Hence, as the frequency changes from f_L to f_H, the beam direction varies continuously and linearly from -1 beam width to 1 beam width. Fig. 2 shows the frequency characteristics of radiation patterns when three beams are present in elevation; here, the beam squints at f_L and f_H are at -1 beam width and 1 beam width, respectively. The f_H beam of Beam 1 and the f_L beam of Beam 2 overlap at EL=-1 beam width; the same occurs at the EL=+1 beam width. Here, if a 3-dB gain reduction is allowed, the user can have a bandwidth of $B_W/2$, which is similar to a conventional multiple-spot beam antenna configuration. Similarly, a user at EL=-1 beam width can use the $B_W/2$ bandwidth, i.e., from f_L to f_0 of Beam 2. A user at EL=-2 beam width can use the $B_W/2$ bandwidth, from $f_H - B_W/4$ to f_H of Beam 1 and from f_L to $f_L + B_W/4$ of Beam 2. Therefore, users within the range of El=-2.5 beam widths to El=2.5 beam widths can avail similar services. Generally, by using N beams in elevation, it is possible to provide similar services to users within the range of El=-N+0.5 to El=N-0.5 beam widths. Therefore, as shown in Fig. 3, vertically long areas having a beam width of 2N-1 are arranged in the azimuth direction, with a beam width period of $\sqrt{3}$.

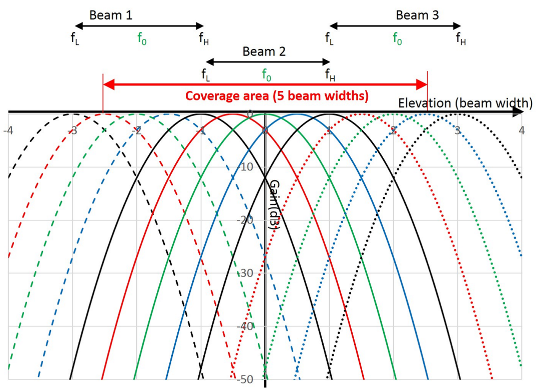

Figure 2. Frequency characteristics of radiation patterns.

Next, the phasing elements are designed so that the beam direction in the azimuth differs by $\sqrt{3}/2$ beam widths between the V-pol and H-pol beams, which corresponds to a horn. Therefore, the service area is covered with elongated beams that are staggered by V-pol and H-pol, as shown in Fig. 4. In the case of a conventional multiple-spot beam antenna, users who are in the

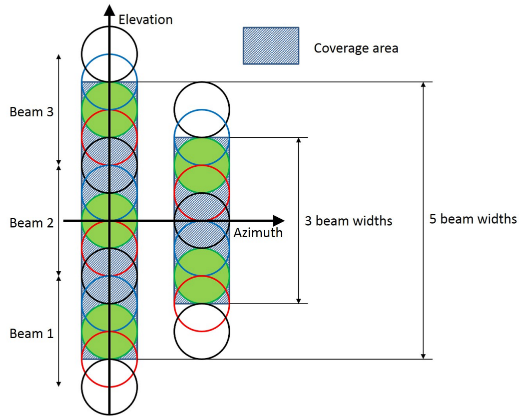

Figure 3. Coverage areas for a single polarization direction.

same area use the same frequency band, f_1 or f_2 with a $B_W/2$ bandwidth. The gain reduction amount is 0 to 3 dB depending on the position in the spot beam, which is a fixed value independent of the frequency. On the other hand, for the proposed antenna, although the user uses a different frequency band (depending on their position), the bandwidth is $B_W/2$, which is the same as that for a conventional multiple-spot beam antenna. Further, the amount of gain reduction is 0 to 3 dB and depends on the frequency.

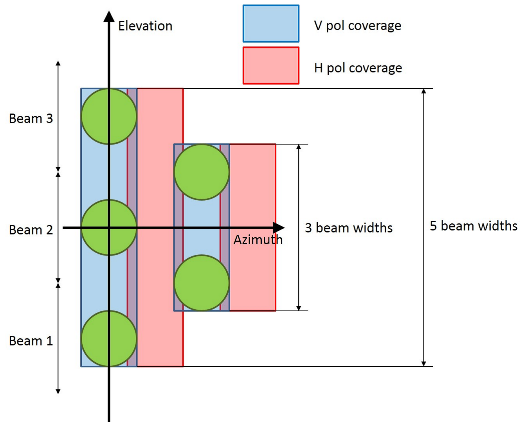

Figure 4. Coverage areas for dual polarization directions.

3. DESIGN EXAMPLE OF A REFLECTARRAY WITH SCANNING BEAM

Fig. 5 shows the geometrical configuration of an offset reflectarray antenna. In the figure, F is the position of a horn antenna used as a primary radiator, F' is the position of an image horn produced by a plane reflector, and O is the center position of the plane reflector. In this case, there are four degrees of freedom for the design parameters. The following four parameters are selected: the aperture diameter D, the distance from O to F, R, the angle formed by the straight line OF' and a straight line passing through O in the beam radiation direction, θ, and a clearance, c, to avoid blockage. The position of F' is determined by R and θ, whereas the position of F is determined by D, R, and c; then, the position and orientation of the plane reflector are determined.

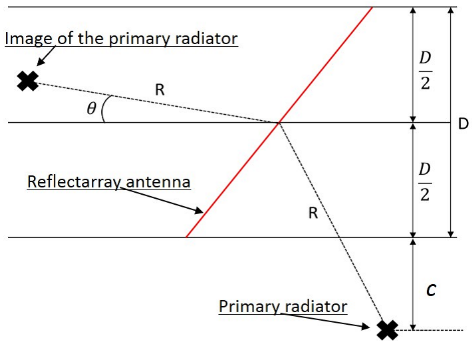

Figure 5. Design parameters of reflectarray geometrical configuration.

The beam squint angle, θ_s, depends on the inclination angle, θ, which is determined by Eq. 3[7],

$$\tan\theta_s = \frac{\lambda - \lambda_0}{\lambda_0}\tan\theta \qquad (3)$$

where λ_0 and λ are wavelengths at f_0 and f, respectively. The required beam shift amount is 1 beam width at a frequency of f_L or f_H. The 3-dB beam width Θ_3 can be approximated by Eq. 4,

$$\Theta_3 = \alpha\frac{\lambda_0}{D} \qquad (4)$$

where α is a constant dependent on the amplitude distribution on the aperture and is generally equal to approximately 70 deg. Using Eq. 3 and Eq. 4, the design parameter θ is determined by Eq. 5.

$$\theta = \tan^{-1}\left(\frac{\lambda_0}{\lambda - \lambda_0}\tan\left(\alpha\frac{\lambda_0}{D}\right)\right) \qquad (5)$$

λ is a wavelength at a frequency of f_L or f_H. If f_L is selected, the f_L beam deflects to El=+1 beam width and the f_H beam deflects to El=-1 beam width, and vice versa.

Design examples are shown below, where f_L is 19.0 GHz, f_H is 20.0 GHz, and D is 1600.0 mm. θ is 24.6 deg, calculated using Eq. 5. In this case, the 19 GHz beam deflects to El=+1 beam width. Then, R and c are selected to be 2880.0 mm and 1280.0 mm, respectively, and three horns are placed. The reflectarray is a single-layer flat type as the ring-type phasing element is unable to change the beam direction by polarization.

Fig. 6 shows the analyzed frequency characteristics of the radiation patterns. In the figure, the red, green, and blue lines indicate the radiation patterns at 19.0 GHz, 19.5 GHz, and 20.0 GHz, respectively. The broken, solid, and dashed lines represent Beam 1, Beam 2, and Beam 3 from the horns, respectively. For all three beams from the horns, the 19.0 GHz, 19.5 GHz, and 20.0 GHz beams cross another beam at a level 3 dB blow their peaks. Further, the 19.0 GHz beam of Beam 1 and the 20.0 GHz beam of Beam 2 as well as the 19.0 GHz beam of Beam 2 and the 20.0 GHz beam of Beam 3 almost overlap each other. The deviation of the gain is 1 dB or less. Hence, we can confirm that the aimed beam arrangement was successful.

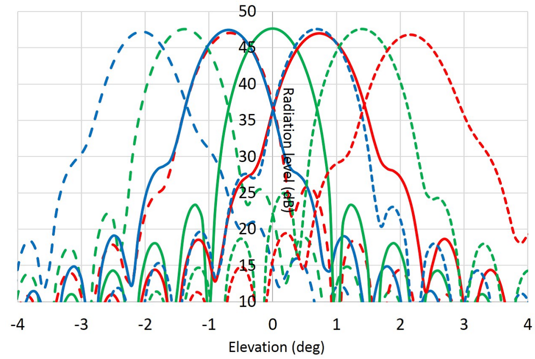

Figure 6. Frequency characteristics of radiation patterns.

4. CONCLUSION

In this study, a new satellite antenna concept accomplished using a Tx and an Rx reflectarray antenna is proposed. This configuration utilizes two characteristics of the reflectarray: the beam squint characteristics, which can be realized using the geometric configuration, and a phasing element, which can change the beam direction by polarization.

REFERENCES

[1] J.Huang and J. A. Encinar, "Reflectarray antennas", Wiley, New Jersey, 2007.

[2] M. Zhou et al., "Multiple Spot Beam Reflectarrays for High Throughput Satellite Applications", 2016 IEEE AP-S, 2016.

[3] E. Martinez-de-Rioja et al., "Reflectarray in K and Ka Bands with Independent Beams in Each Polarization", 2016 IEEE AP-S, 2016.

[4] R. Florencio et al., "Reflectarray Antennas for Dual Polarization and Broadband Telecom Satellite Applications", IEEE Trans. Antennas Propag., 2015.

[5] E. Almajali et al., "On Beam Squint in Offset-Fed Reflect Arrays", IEEE Antennas Wirel. Propag. Lett., 2012.

[6] D. Martinez-de-Rioja et al., "Multibeam Reflectarray for Transmit Satellite Antennas in Ka Band Using Beam-Squint", 2016 IEEE AP-S, 2016.

[7] S.Makino et al., "Estimation of Frequency Characteristics of Reflectarray by Introducing AberrationTheory", EuCAP2017, 2017.