Multiple Scanning Beam Antenna Configuration for Space Applications Using Reflectarrays

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***Abstract*—In this presentation, a new satellite antenna configuration realized by a TX and a RX reflectarray antenna will be proposed. Each antenna is composed of multiple horns and a single layer flat reflectarray. It radiates scanning beams with different radiation directions in azimuth due to polarization and each scanning beam with different radiation directions depending on frequency covers an elongate area in elevation. Each user in the service area selects the optimum frequency band and polarization determined by the position of the user. If 3 dB gain reduction is allowed, half of the frequency band can be used like the conventional multiple spot beam antenna configuration.**

I. Introduction

In satellite communication, a multiple spot beam antenna configuration covering a desired service area uses four types of beams, A, B, C, and D, that can be realized by combining two frequency bands, f_1 and f_2, and two orthogonal-polarized polarizations, V and H, as shown in Fig. 1. As 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 a type of beam is to be realized by a parabolic reflector and multiple horns, a total of eight antennas are required; however, it is generally realized with four antennas by sharing Tx and Rx bands with one antenna.

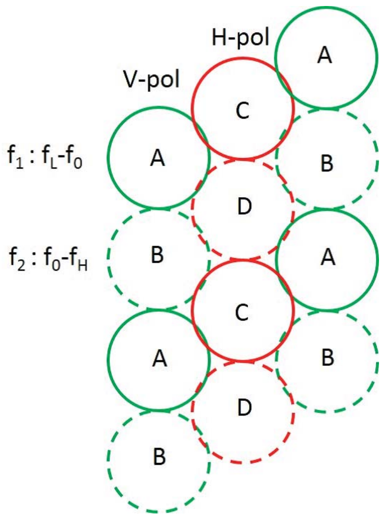

Fig. 1. Conventional beam arrangement.

Various antenna configurations using reflectarrays[1] have been reported for the purpose of reducing the number of antennas. Reference [2] shows a method of constructing parabolic reflectarrays. In this case, for example, in addition to the two beams A_{TX} and A_{RX} that can be realized with a parabolic reflector, the beam C_{TX} can also be realized by the reflectarray, so it is possible to realize three kinds of beam. As a result, the eight types of beams can be realized with a total of three reflectors. And if dual-band phasing elements are possible, C_{RX} beam can also be realized, so a total of two reflectors will realize eight types of beams. Reference [3] shows a flat reflectoarray that realizes four kinds of beams combining Tx/Rx and V/H. In this case, it is possible to realize four kinds of beams such as A_{TX}, A_{RX}, C_{TX} and C_{RX}, so the eight types of beams can be realized with a total of two reflectors. In any of the above antenna configurations, one reflector is used for both Tx and Rx. When Tx and Rx are far apart such as Ka band, isolation between beams of the same type is concerned because Tx has a wider beam width. Also, in Rx, since the beam width is narrower, it is feared that the gain at the beam edge will decrease. In addition, it is necessary to connect Tx/Rx duplexer, Tx OMT (Orthogonal Mode Transducer), and Rx OMT to each horn.

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

II. Proposed reflectarray

Consider the case of using the frequency band from f_L to f_H. The center frequency f_0 and the all frequency band width B_W are as Eq.1 and Eq.2, respectively.

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

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

An antenna is composed of multiple horns and a single layer flat reflectarray. Horns are arranged so that the corresponding beams at f_0 are arranged in an equilateral triangle with 2 beam widths period as shown in Fig. 2.

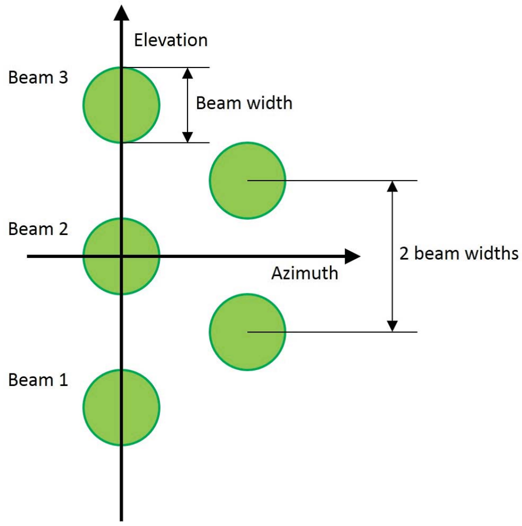

Fig. 2. Beam arrangement at center frequency f_0.

The geometrical configuration of the reflecarray is designed to occur beam squint with ± 1 beam widths at f_L and ∓ 1 beam widths at f_H. So, as the frequency changes from f_L to f_H, the beam direction varies continuously and linearly from -1 beam widths to 1 beam width. Fig. 3 shows the frequency characteristics of radiation patterns when three beams are present in elevation, in the case that the beam squints at f_L and f_H are -1 beam widths and 1 beam width, respectively. The f_H beam of Beam 1 and f_L beam of Beam 2 overlap at EL=-1 beam widths; the same occurs at the EL=+1 beamwidths. Here a user at EL=0 can use the frequency band from $f_0 - B_W/4$ to $f_0 + B_W/4$ of Beam 2, if 3 dB gain reduction is allowed. So, $B_W/2$ band width can be used and is like the conventional multiple spot beam antenna configurations. Similarly, a user at EL=-1 beam widths can use $B_W/2$ band width from f_L to f_0 of Beam 2 and a users at EL=-2 beam widths can use $B_W/2$ band width 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 use similar services. Generally, by using N beams in elevation, it is possible to provide similar service to users within the range of El=-N+0.5 beam widths to El=N-0.5 beam widths. So, the service area is an elongate area in elevation with 2N-1 beam widths lengths. When the beams are arranged two dimensionally as shown in Fig. 2, multiple elongate areas are arranged in azimuth with $\sqrt{3}$ beam widths period as shown in Fig. 4.

Next, the phasing elements are designed so that the beam direction in azimuth differs by $\sqrt{3}/2$ beam widths between V-pol and H-pol beams corresponding to a horn. So, the service area is covered with the elongate beams staggered by V-pol and H-pol as shown in Fig. 5.

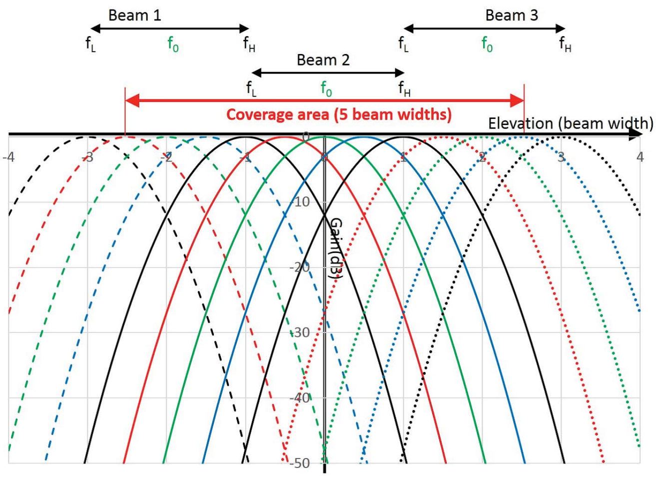

Fig. 3. Frequency characteristics of radiation patterns.

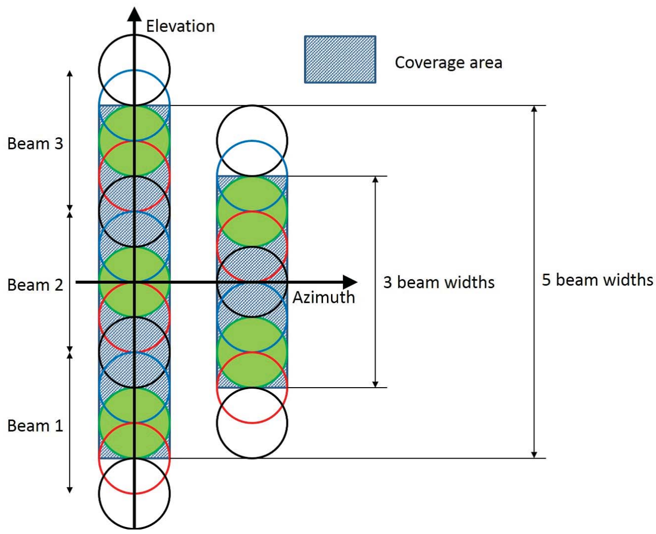

Fig. 4. Coverage areas for single polarization.

In the case of the conventional multiple spot beam antenna, users who are in the same spot beam use the same frequency band f_1 or f_2 with $B_W/2$ band width, and the gain reduction amount is 0 to 3 dB depending on the position in the spot beam, which is a fixed value independent of frequency.

On the other hand in the case of the proposed antenna, although the user uses a different frequency band depending on its position, its band width is $B_W/2$, which is the same as the conventional multiple spot beam antenna. Furthermore, the amount of gain reduction is 0 to 3 dB, which depends on the frequency.

III. Gain Reduction at the Coverage Edge

Here it is assumed that the gain reduction amount G_r dB is expressed by Eq.3,

$$G_r(\Theta) = 12(\frac{\Theta}{\Theta_3})^2 \tag{3}$$

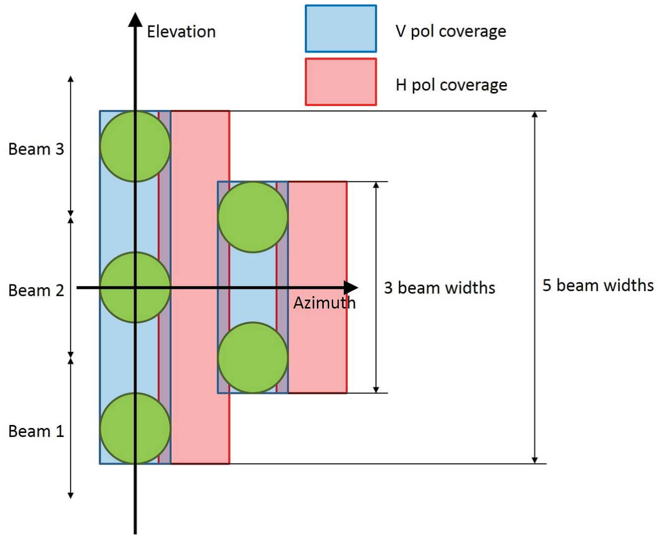

Fig. 5. Coverage areas for dual polarizations.

where Θ is an angle from peak gain direction and $\Theta_3$is a 3dB beam width.

In the case of the conventional multiple spot beam antenna, the maximum gain reduction occurs at the point P of Fig. 6. In such a case, the point P is $\sqrt{3}/3$ beam widths apart from the center of the beam, so G_r=4 dB and is independent of frequency.

On the other hand in the case of the proposed antenna, the maximum gain reduction occurs at the point P on the boundary line between V-pol beam and H-pol beam shown in Fig. 7. In the case where gain reduction is the smallest, the frequency f_0' of the beam spaced by $\sqrt{3}/4$ beam width in azimuth is used, so G_r=2.25 dB at f_0'. The frequency at which gain reduction is the maximum is the frequency separated by $B_W/4$ from f_0', and the beam is further separated by 0.5 beam widths in elevation. Therefore, the point P is $\sqrt{7}/4$ beam widths apart from the center of the beam of this frequency, so G_r=5.25 dB. As a result, the gain decreases from 2.25 dB to 5.25 dB depending on the frequency to be used.

IV. Design Example of a Reflectarray with Scanning Beam

Fig.8 shows the geometrical configuration of a offset reflectarray antenna. In the figure, F is a position of a horn antenna as a primary radiator, F' is a position of an image horn which is a horn image by a plane reflector, and O is a center position of the plane reflector. In the case, 4 degrees of freedom for design parameters exist. Here the following 4 parameters are selected ; an aperture diameter D, a distance R from O to F, an angle θ formed by the straight line OF' and a straight line passing through O and heading in the beam radiation direction, and a clearance c to avoid a blockage. The position F' is determined by R and θ, the position F is determined by D, R, and c, and then the position and the orientation of the plane reflector are determined.

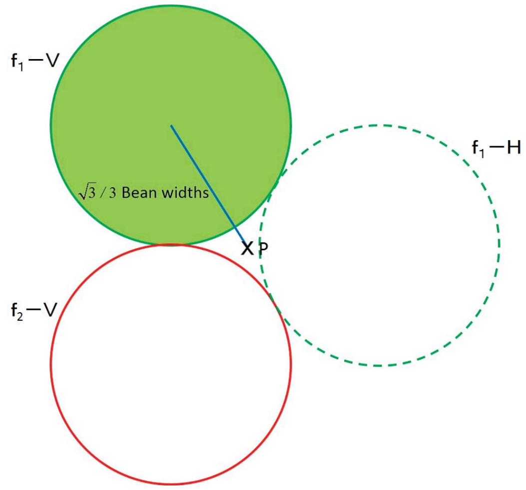

Fig. 6. Maximum gain reduction in service area (conventional multi spot antenna).

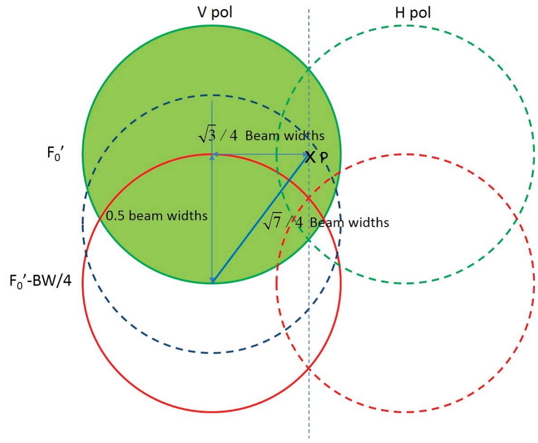

Fig. 7. Maximum gain reduction in service area (proposed antenna).

The beam squint angle θ_s depends on the inclination angle θ and is determined by Eq.4[7],

$$\tan\theta_s = \frac{\lambda - \lambda_0}{\lambda_0}\tan\theta \tag{4}$$

where λ_0 and λ are wavelengths at the frequency f_0 and f, respectively. Required beam shift amount is 1 beam width at the frequency f_L or f_H. The 3dB beam width Θ_3 can be approximated by Eq.5,

$$\Theta_3 = \alpha\frac{\lambda_0}{D} \tag{5}$$

where α is a constant dependent on the amplitude distribution on the aperture and is generally around 70 deg. Using Eq.4 and Eq.5, the design parameter θ is determined by Eq.6.

$$\theta = \tan^{-1}(\frac{\lambda_0}{\lambda - \lambda_0}\tan(\alpha\frac{\lambda_0}{D})) \tag{6}$$

λ is a wavelength at the frequency f_L or f_H, and if f_L is selected, f_L beam deflects to El=+1 beam width and f_H beam deflects to El=-1 beam width, and also, the converse also holds.

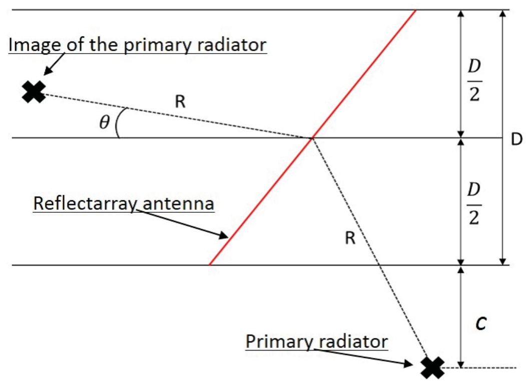

Fig. 8. Design parameters of geometrical configuration of reflectarray.

Below, design examples are shown, where f_L is 19.0 GHz, f_H is 20.0 GHz and D=1600.0 mm. θ is 24.6 deg by using Eq.6. In the case, 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. Fig.9 shows the geometrical configuration of the reflectarray model. And three horns are placed. The reflectarray is single-layer flat type and the phasing element is ring type and is not a type to change the beam direction by polarization.

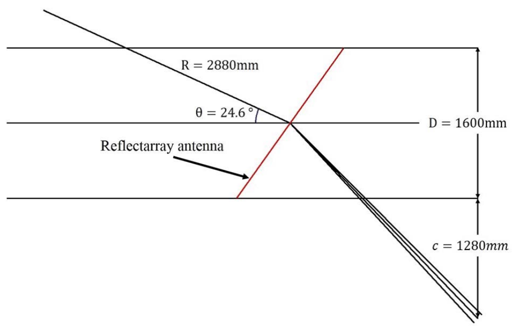

Fig. 9. Geometrical configuration of the reflectarray model.

Fig.10 shows the analyzed frequency characteristics of the radiation patterns. In the figure, red lines, green lines and blue lines indicate the radiation patterns at frequency 19.0 GHz, 19.5 GHz and 20.0 GHz, respectively. The broken, solid, and dashed lines indicate Beam-1, Beam-2, and Beam-3 corresponding to each horn, respectively. For all beams, 19.0 GHz beam, 19.5 GHz beam and 20.0 GHz beam cross at a level 3 dB blow their peak. Further 19.0 GHz beam of Beam 1 and 20.0 GHz beam of Beam 2, and 19.0 GHz beam of Beam 2 and 20.0 GHz beam of Beam 3 almost overlap each other. The deviation of the gain is 1 dB or less.

As a result, it was confirmed that the aimed beam arrangement was realized.

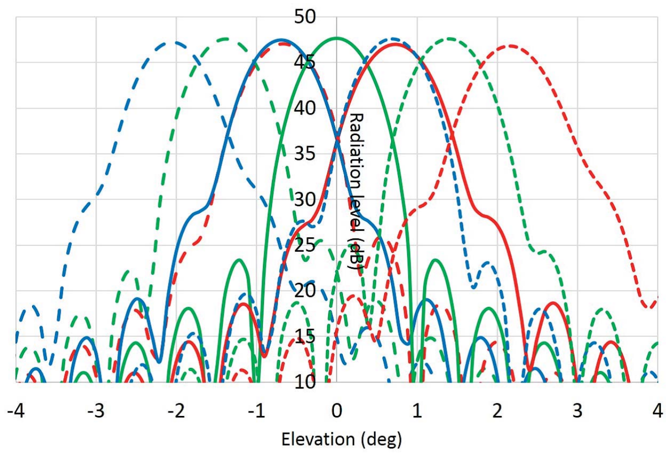

Fig. 10. Frequency characteristics of radiation patterns.

V. Conclusion

In this study, a new satellite antenna configuration, realized using a TX and RX reflectarray antenna, respectively, was proposed. This configuration utilizes two characteristics of the reflectarray: the beam squint characteristics that can be realized by geometric configuration, and a phasing element that can change the beam direction by polarization.

Although this antenna configuration is considered to function satisfactorily as a satellite antenna, there are problems to be solved with respect to the earth station, as mentioned below:

- The frequency band to be used depends on the position, and not on the beam to which the user belongs.
- The frequency band used by the user may be discontinuous, in some cases. In the case of a mobile user, the frequency to be used suddenly changes from f_L to f_H.
- In the frequency band used by the user, the power density varies with the frequency.

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