Multibeam Reflectarray for Transmit Satellite Antennas in Ka Band Using Beam-Squint

Daniel Martinez-de-Rioja, Eduardo Martinez-de-Rioja, Jose A. Encinar

***Abstract*—This contribution describes a design concept based on beam squint effect in printed reflectarrays that allows to produce multiple contiguous beams at 19.5 and 20 GHz, by discriminating in frequency. A 1.6-m reflectarray has been proposed to produce 10 beams separated 0.5 degree using five feeds with frequency reuse. The simulated radiation patterns show a peak gain better than 47.6 dBi, with side-lobe levels close to -22 dB. The proposed concept can be suitable for multiple spot beam satellites in Ka-band.**

Keywords— reflectarray, beam squint, multibeam antennas, satellite antennas.

I. Introduction

A reflectarray antenna is composed of a planar array of printed elements on a dielectric sheet over a ground plane. The phase of the reflected field on each element can be adjusted to produce a focused or a shaped beam (usually by varying the dimensions of the printed elements) when the antenna is illuminated by a feed [1]. The effect of beam-squint in reflectarray antennas implies that beam direction changes with frequency. This phenomenon has been previously studied by other authors [2], proving that it is mainly caused by a shifting of the focal point at off-center frequencies, rather than other factors, such as the type of reflectarray element or the lattice size used. Furthermore, some methods have been already proposed to reduce or suppress it [3] [4]. In this paper, the authors present a preliminary design of a printed reflectarray antenna to generate multiple closely separated beams with frequency reuse (f_1= 19.5 GHz and f_2= 20.0 GHz), using beam squint to achieve discrimination in frequency. The selected frequencies are in the allocated band for transmission in Ka-band multi-spot beam satellites. The proposed concept will allow a reduction in the number of feeds needed to provide the multi-spot coverage.

II. Beam Squint Study

Beam squint will be exploited by computing the feed position to provide two adjacent beams in the appropriate directions at two relatively close frequencies. Let us consider a reflectarray designed to radiate a focused beam in the direction (θ_b, φ_b) at frequency f_1. Our goal is to modify the pointing direction a small angle $\Delta\theta_b$ at frequency f_2 using the same feed. Based on differential spatial phase delay concept, as defined in [1] (pg. 5), and its variation at frequencies f_1 and f_2, an approximate expression can be deduced for the difference of paths from the phase center of the feed to the reflectarray edges (see Fig. 1):

$$\Delta d = d_2 - d_1 = d_1' + \frac{k_0 D \cdot tan\,(\Delta\theta_b)}{2\pi\,\Delta f} \cdot c \qquad (1)$$

where D is the reflectarray diameter and $\Delta f = f_2 - f_1$. The value of d_1' is equal to zero in case of broadside radiation ($\theta_b = 0^o$), when the orthogonal plane matches the reflectarray surface. Otherwise, d_1' can be calculated as follows:

$$d_1' = D \cdot \sin\,(\theta_b) \qquad (2)$$

Then, for a fixed value of d_1, the previous expressions can be used to obtain d_2. The coordinates of the feed phase center so that the beam at frequency f_2 was diverted an angle $\Delta\theta_b$ can be found by tracing two circumferences of radius d_1 and d_2.

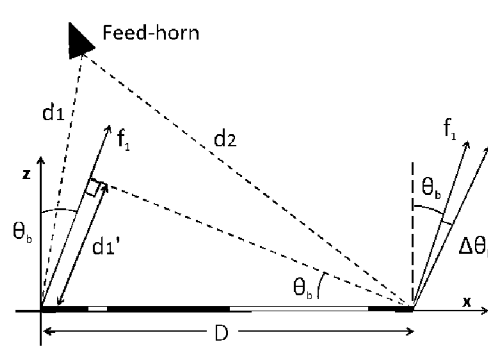

Fig. 1. Reflectarray view for the analysis of beam squint.

III. Reflectarray Design

A circular reflectarray, consisting of 31,428 elements arranged in a 200 x 200 grid with period $P_X = P_Y$ = 8 mm (160-cm diameter), has been designed to produce two focused beams in the directions θ_{b1}= 5°, φ_{b1}= 0° at f_1 = 19.5 GHz, and θ_{b2}= 5.5°, φ_{b2}= 0°at f_2 = 20 GHz. The antenna is illuminated by a feed-horn, whose phase center is placed at coordinates x_F= -109 cm, y_F = 0 cm, z_F = 218 cm with respect to the reflectarray center (the feed position has been obtained as explained in the previous section). The field radiated by the horn is modelled using a $\cos^q(\theta)$ distribution, with q =13 for 19-20 GHz band, which provides -12 dB edge illumination. The required phase-shift to be introduced by each reflectarray element can be calculated using the expression provided in [1] (pg. 34), considering for the design the values of θ_b= 5.25°, φ_b= 0° at 19.75 GHz, in order to reduce the distortion in the radiation patterns at frequencies f_1 and f_2. The resulting phase-shift can be accomplished by adjusting the dimensions of the printed elements, employing variable size patches or parallel dipoles [5], but ideal reflectarray cells providing the same phase-shift at f_1 and f_2 are assumed in the following results.

In addition to the single-fed reflectarray, a multibeam reflectarray has been designed and simulated. Once the phase distribution has been defined for the initial feed, four additional feed positions have been found to generate beams separated 1° respect to the central feed. Note that each feed radiates two beams, and therefore the antenna will produce 10 beams in the XZ plane with 0.5° separation, employing 5 feeds that radiate at 19.5 GHz and 20 GHz.

IV. Simulation Results

The simulated radiation patterns in gain (dBi) in the elevation plane (XZ) for the single-fed reflectarray, shown in Fig. 2, have been obtained from the tangential reflected field at each reflectarray element. The beams are focused in the directions θ_b= 5°, φ_b= 0° at 19.5 GHz and θ_b= 5.5°, φ_b= 0° at 20 GHz, as it was intended A gain of 49.1 dBi is reached at 19.5 GHz, and 49.3 dBi gain is attained at 20 GHz. The beam width at -3 dB is lower than 0.65°, and side-lobe level is close to -22 dB respect to the maximum.

The position of the 5 feeds and the radiation patterns in the elevation plane that resulted from the multibeam reflectarray design are shown in Fig. 3. The distances between the feeds are: 49.7, 50.3, 50.9 and 51.4 mm. The radiation patterns in Fig. 3b show a gain between 49.3 dBi and 47.6 dBi, with low side lobes. The beams near the edge show certain distortion, which can be minimized by optimizing the required phase distribution and the reflectarray cells in a detailed design of the antenna.

V. Conclusions

The results for the conducted simulations are promising, because demonstrate that a single feed can generate adjacent beams at different frequencies in multiple spot beam Ka-band antennas by using beam squint effect. A preliminary design has shown that 10 contiguous beams can be generated in one plane using only 5 feeds with frequency reuse. This concept will be further investigated in the future, as well as their application to the design of multibeam antennas.

Acknowledgment

This work has been supported by the Spanish Ministry of Economy and Competitiveness under the project TEC2013-43345-P and by the Regional Government of Madrid under project SPADERADAR-CM (P2013/ICE-3000).

References

[1] J. Huang and J. A. Encinar, "Reflectarray Antennas", IEEE Press/Wiley, Piscataway, New Jersey, 2008.

[2] E. Almajali, D. A. McNamara, J. Shaker, M. R. Chaharmir, "On Beam Squint in Offset-Fed Reflectarray", IEEE Antennas and Wireless Propagation Letters, vol. 11, pp. 937-940, August 2012.

[3] S. D. Targonski and D. M. Pozar, "Minimization of Beam Squint in Microstrip Reflectarrays Using an Offset Feed," IEEE Antennas and Propagation Soc. International Symposium, pp. 1326–1329, July 1996.

[4] E. Almajali, D. A. McNamara, J. Shaker, M. R. Chaharmir, "Beam Squint Suppression in Offset-Fed Reflectarray", IEEE Antennas and Wireless Propagation Letters, vol. 12, pp. 587-590, December 2013.

[5] R. Florencio, J. A. Encinar, R. R. Boix, V. Losada, G. Toso, "Reflectarray Antennas for Dual Polarization and Broadband Telecom Satellite Applications," IEEE Trans. on Antennas and Propag., vol. 63, pp. 1234-1246, April 2015.

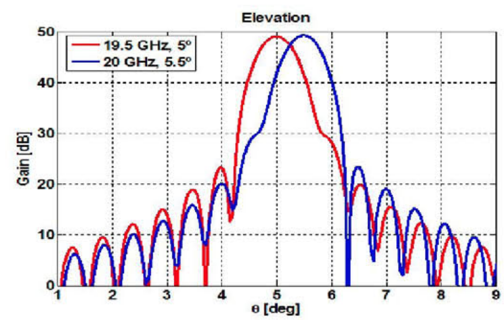

Fig. 2. Radiation patterns in gain (dBi) in the XZ plane for single-fed reflectarray, with one beam at each frequency.

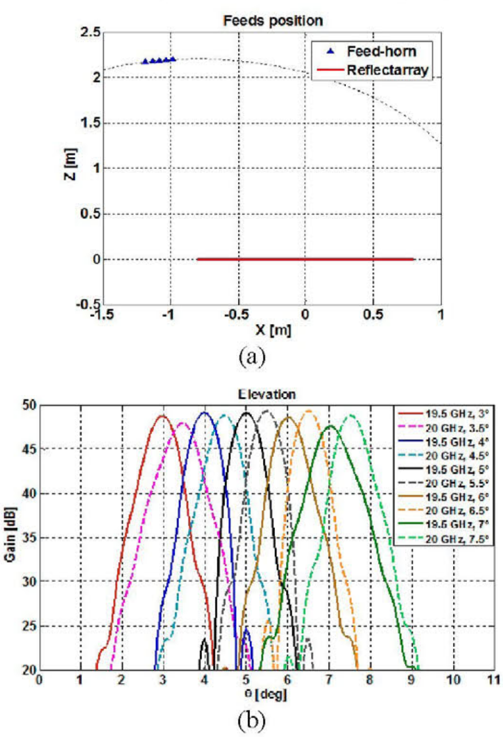

Fig. 3. Multibeam reflectarray: (a) positions for 5 feeds separated around 5-mm, (b) radiation patterns (dBi) in the XZ plane to generate 10 beams at 19.5 GHz and 20 GHz.