Multiple Spot Beam Reflectarrays for High Throughput Satellite Applications

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***Abstract*—The number of main apertures needed to cover a full transmit/receive multiple spot beam mission can be reduced by using reflectarrays with array elements printed on a doubly curved surface. By combining the capabilities of the reflectarray and a parabolic surface, it is shown that three main apertures are sufficient for both transmit/receive operations if single-band array elements are used, whereas only two main apertures are needed if dual-band array elements are considered.**

***Index Terms*—reflectarrays, multiple spot beam, optimization, telecommunication, satellite applications**

I. Introduction

In the last decade, there has been an increased interest in the development of broadband satellites utilizing multiple beam reflector antenna farms for High Throughput Satellites (HTS). Significant attention has been paid on reducing the number of main apertures in order to cover a full transmit (Tx) and receive (Rx) multiple spot beam coverage. For the typical "4-color" frequency (F_1, F_2) and polarization (P_1, P_2) re-use scheme as shown in Fig. 1, the current state-of-the-art is to employ four dual-band (Tx/Rx) single-feed-per-beam (SFB) reflector antennas [1], one reflector for each of the beams A, B, C, and D. The mechanical complexity of accommodating four reflectors instead of two or three is of course high and any technique for reducing the number of main apertures is of great interest.

Printed reflectarrays can be designed to steer the reflected beam away from the specular direction and their properties can be tuned with respect to the frequency as well as polarization. In this paper, we show that the use of a reflectarray can indeed reduce the number of main apertures if the array elements are printed on a doubly curved parabolic surface.

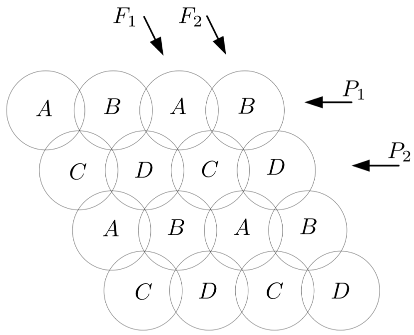

Fig. 1. Beam layout of the typical "4-color" frequency (F_1, F_2) and polarization (P_1, P_2) re-use scheme.

II. Concept Demonstration

The concept of a reflectarray with array elements printed on a doubly curved surface was first suggested in [2] and later investigated in [3], [4] with the aim to improve the bandwidth of contoured beam reflectarrays. For multiple spot beam applications, the curvature of the reflectarray can be used to provide other advantages.

Consider one of the four reflectors that is used to generate e.g. the A-beams in the 4-color re-use scheme. A feed array is used to illuminate this reflector and the connection between feed displacement and beam scan will follow the normal law of reflection. Due to the spacing of the feed array, this reflector will only be able to radiate the A-beams. Now, imagine that array elements are printed on the reflector surface. If all array elements are identical (e.g. identical square patches) the curved reflectarray will work just like the solid reflector, regardless of the polarization, thus radiating the A-beams. However, by adjusting the array elements it is possible to steer the beam for one polarization while fixing the beam for the orthogonal polarization. Consequently, it is possible using a parabolic reflectarray to radiate more than one of the beam types A, B, C, and D.

To demonstrate the concept described above, we present here a parabolic reflectarray that can radiate the A_{Tx}, C_{Tx} and A_{Rx} beams in a traditional 4-color frequency and polarization re-use scheme. For simplicity and the purpose of illustrating the concept, linear polarization is considered. The beams should have a 3 dB beam width of 2.2° with the following characteristics:

A_{Tx} : 20 GHz, x-polarization.
C_{Tx} : 20 GHz, y-polarization.
A_{Rx} : 30 GHz, y-polarization.

The parabolic reflectarray is a single offset paraboloid and has a circular projected aperture of $D = 44.5\,\mathrm{cm}$ and a focal length to diameter ratio of $f/D = 1.35$. For demonstration purposes, we consider 4 horns with an aperture diameter of 3.4 wavelengths at 20 GHz and modelled as Gaussian beams. The spacing of the feed centers is set equal to the diameter of the feed horn and arranged in an hexagonal grid. As array element, single-layer rectangular patches are used. For the analysis and design of the curved reflectarray, we adopt the approach presented in [4] where the procedure is described and validated.

The optimized parabolic reflectarray is shown in Fig. 2. The reflectarray is designed such that the rectangular patches

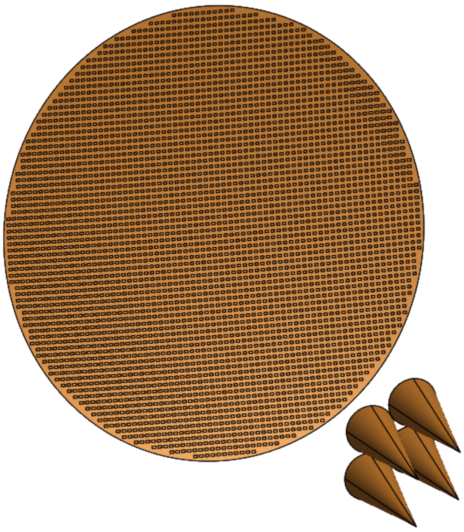

Fig. 2. Optimized parabolic multiple spot beam reflectarrays.

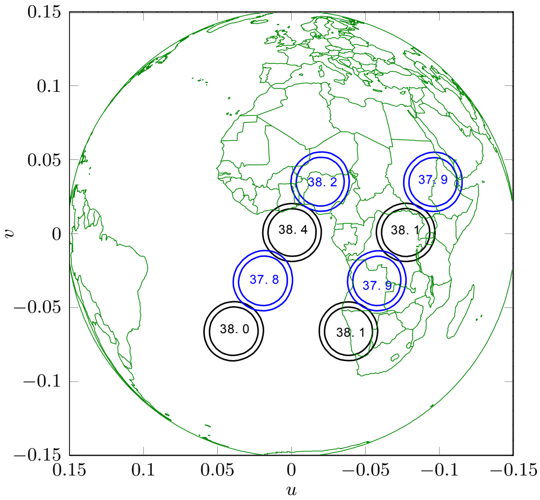

Fig. 3. The radiation pattern of the parabolic reflectarray at 20 GHz. The black and blue beams corresponds to the A_{Tx} and C_{Tx} beams, respectively. The figure shows the -2 and -3 dB contours and the peak of each beam.

are responsible of generating the C_{Tx} beams whereas the parabolic surface generates the A_{Tx} and A_{Rx} beams. This is achieved by optimizing the y-dimensions of the rectangular patches while keeping the x-dimensions equal for all patches.

For y-polarization, a change in phase is obtained by the patches. To yield the C_{Tx} beams, the reflected beams need to be scanned one beamwidth and this requires a linear phase shift of 360° over the surface of the reflectarray. For a parabolic reflectarray, this phase shift is common for all the C_{Tx} beams. For x-polarization the beams are unaffected by the patches since they are identical and the reflectarray will generate the A_{Tx} beams. This is shown in Fig. 3, where the co-polar radiation pattern of the parabolic reflectarray at 20 GHz is shown. The black and blue beams corresponds to the A_{Tx} and C_{Tx} beams, respectively. In the figure, the -2 and -3 dB contours and the peak of each beam are shown. Since the rectangular patches are non-resonant at 30 GHz, the parabolic reflectarray behaves like a solid reflector at this frequency and generates the A_{Rx} beams, regardless of the polarization.

Following the concept described here, a full Tx/Rx multiple spot beam mission using the 4-color re-use scheme can be accomplished with three reflectarrays using single-band patches:

Reflectarray 1: Beams A_{Tx}, C_{Tx}, and A_{Rx}
Reflectarray 2: Beams B_{Rx}, D_{Rx}, and B_{Tx}
Reflectarray 3: Beams D_{Tx} and C_{Rx}.

Reflectarray 1 is the design presented above. Reflectarray 2 is similar except that the patches are resonant at Rx and inactive at Tx. Reflectarray 3 radiates the remaining beams with array elements resonant at either Tx or Rx. Using this approach, the number of main apertures is reduced from four to three for full Tx/Rx operation. If dual-band array elements are considered, the number of main apertures may be reduced to two:

Reflectarray 1: Beams A_{Tx}, C_{Tx}, A_{Rx}, and C_{Rx},
Reflectarray 2: Beams B_{Rx}, D_{Rx}, B_{Tx}, and D_{Tx}.

This configuration is similar to that described above, except that dual-band array elements that can be adjusted independently for the two bands are required. In this approach the number of main apertures can be reduced from four to two for both Tx/Rx operation.

In the above, linear polarization is considered for illustration purposes, but the concept is equally applicable for circular polarization. Representative results for such cases will be presented at the conference.

The proposed concept is to the best of our knowledge the first time where it is shown that reflectarrays can be used to reduce the number of main apertures in a multiple spot beam application. An ESA-funded activity is currently ongoing where the concept is being further developed.

III. Conclusion

We show in this paper that parabolic reflectarrays can be used to reduce the number of main apertures in a multiple spot beam mission based on the "4-color" frequency and polarization re-use scheme. The parabolic reflectarrays can be designed such that the array elements radiate one type of the beams, whereas the curvature of the reflectarray is utilized to radiate another type of beams. Consequently, the number of main apertures can be reduced from four to three for both transmit/receive operations if single-band array elements are used. If dual-band array elements are considered, the number of main apertures may be reduced from four to two.

References

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