Multifocal Approach for Reflectarray Antenna for DTH Applications

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***Abstract*—In this paper, numerical and experimental results on the design of a multifocal, planar Reflectarray with scanning capabilities in both elevation and azimuth, are presented. The antenna is a possible alternative to the conventional parabolic reflectors in Direct-To-Home (DTH) receiving systems, with the planar reflector fixed to a building wall and the pointing obtained mechanically moving the feed to steer the main beam of the reflectarray.**

***Index Terms*—Reflectarrays; DTH systems; Scanning beam**

I. Introduction

The receiving antennas for DTH satellite service in Ku band (10.7-12.75 GHz) usually consist of an offset parabolic reflector, mounted externally to the building and pointed to the direction of arrival of the signal, so that they generally require a strong fixation mast and an azimuth/elevation mount, often with a significant visual impact, in some cases not acceptable (e.g. in historical centers or buildings).

Array antennas, both active and passive, have also been considered for this application, but they have high losses in the BFN and reduced efficiency, and high cost for the active case. Active Reflectarrays (RAs) with electronic scanning represent another possible choice (see e.g. [1]), but also in this case the antenna complexity and cost increase significantly, making this solution not much suitable for consumer applications. Here, a new DTH antenna configuration, based on the use of a passive planar Reflectarray (RA) with mechanical beam scanning, is presented. This is a simpler and cheaper solution, where the beam scanning is obtained by moving the feed along an ad-hoc path. The effect is equivalent to change the field phase distribution on the reflectarray surface, still keeping a dominant linear component to obtain the beam steering.

Taking advantage of the intrinsic nature of a RA, where the direction of maximum radiation can be controlled by properly arranging the phase distribution provided by the re-radiating elements, it is possible to keep the planar reflector always mounted parallel to a wall of the building, reducing therefore its visual impact, with only the adjustable arm supporting the feed protruding from it. A fixed and relatively small number of different reflectarrays can be designed, each covering a predefined angular region both in elevation and in azimuth; inside each of these ranges, the fine pointing is obtained scanning the beam by adjusting properly the position of the feed. Simulations and practical tests have shown that in this way it is possible to cover a wide angular range both in azimuth and elevation, e.g. for European and North Africa regions. In this case, the required elevation is from 10° to 55° depending on the geographic location, while the azimuth range is equal to ±45° and depends on the horizontal relative position between the supporting wall and the direction of arrival of the signal from the desired satellite. As an example, both elevation and azimuth ranges can be divided in three sub-ranges, with approximate amplitude of 15° in elevation and 30° in azimuth. So, the total angle can be covered by 9 different RA configurations, one for each sub-range. Inside each of them, the correct beam pointing is obtained by adjusting properly the position of the feed.

We can assume that each RA configuration is designed to have performance close to those of a parabolic reflector, typically of the order of 60 cm diameter, characterized by a gain of 30 dB or more and a half-power beamwidth (HPBW) around 4°. The feed is usually off-set, with a value of F/D (ratio between the axial distance of the feed to the reflector, and its aperture size) varying between 0.5 and 0.8.

While the performance of a conventional RA, that mimics the behavior of a parabolic reflector, are very good for a predefined direction of maximum radiation, they rapidly decrease in case of beam scanning. In fact, moving the position of the feed, the phase distribution needed to compensate the phase of the incident field changes, and the reflectarray is not able to provide it anymore. To overcome this limitation, several alternative solutions for a passive RA, with improved scanning capabilities, were studied in the past years: among them, the possibility of designing reflectarrays emulating a parabolic cylinder [2], a parabolic torus [3] or a spherical reflector [4] were considered. Their preliminary numerical results are promising, even if these antenna systems have the disadvantage of requiring large planar apertures, partially illuminated for each position of the feed or each feed array configuration. A smaller antenna size, simulating a quasi-spherical phase distribution, is introduced in [5], [6]: the obtained maximum gains for steered beams are good, but at the cost of some frequency dispersion of their position. Another alternative is the design of a bifocal reflectarray [7], whose radiating features could be improved using an optimization algorithm for its design [7], [8], or adopting a dual reflector configuration [9].

To improve the results presented in [5], [6], here a new configuration of RA, designed with a multifocal approach, is introduced: as proposed in [7], [8], it consists of a single reflector, but the scanning range is assumed asymmetrical with respect to the broadside direction, and this requires an off-set starting position of the feed, as in [9], where however a sub-reflector is added to increase the antenna performance. The solution proposed here consists instead in designing a multifocal reflector, that tries to compensate the phase of the field incident from more than two different directions, contrarily to the case of the bifocal design. The numerical results presented in Sect. II are derived for a trifocal configuration and confirm the antenna feasibility showing its good features in terms of radiation patterns and pointing. As a comparison and proof of the possibility of the antenna manufacturing, in the same section, also the results relative to the experimental characterization of a bifocal prototype are shown.

II. Reflectarray design and simulations

In addition to the considerations about each RA configuration discussed above, another aspect that must be considered in the antenna design is the bandwidth, here larger than 17% and centered at the frequency $f_0 = 11.725$ GHz. It is well-known that reflectarrays have intrinsically a narrow band behavior (see e.g. [10] and references therein) and that the frequency sensitivity of a scanning beam RA if also higher, since it is responsible not only for a reduction of the gain, but also for a spread of the directions of maximum radiation.

To improve the RA frequency behavior it is necessary to use a wide-band unit-cell, as shown in Fig. 1 and described in [6], which is a multi-layer structure, with two resonant elements, an external square ring and an inner diamond shaped patch. The element is printed on the inner part of a FR4 layer with thickness $h_1 = 0.5\,\mathrm{mm}$ and it is separated from the ground plane by a Rohacell layer 6 mm thick. The numerical analysis of the unit-cell proves that it provides a phase of the reflected field that remains almost linear over a range larger than $400°$ for the frequencies in the band of interest: the results on the unit-cell characterization are reported in [6].

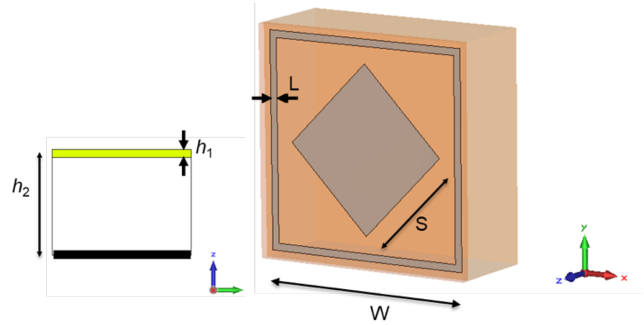

Fig. 1. Unit cell of the reflectarray. On the left, the PCB cross section.

This unit-cell has been used for the design of a RA that covers the central of the 9 sub-ranges mentioned in the Introduction. This is characterized by an angular span $25° - 40°$ in the elevation plane and $\pm 15°$ in azimuth. The position of the feed in correspondence of the elevation angle of $32.5°$, the central value of the considered range, is such that F/D is equal to 0.7, giving a more compact structure; the reflectarray has a size of about 73 cm $\times$ 61 cm and it is discretized by 57 $\times$ 48 unit-cells with size $\lambda/2$ at f_0.

The RA has been designed to provide a phase distribution which is the mean value of the three distributions that would be required to have the direction of maximum radiation at the extremes and at the center of the elevation scanning range: it is therefore a “trifocal design”. The introduction of the central focal point aims to mitigate the main drawback of bifocal configurations, i.e. a degradation of the radiation pattern for scanning angle far from the two design selected values.

The obtained antenna configuration has been analyzed with a Physical Optics (PO) approach, that was verified to give substantially the same results as the full-wave simulation, at least for the most important part of the radiation space. Simulations have been carried out for 6 different feed positions in the subrange (max-center-min elevation in the symmetry axis, that are also used for the design of the multifocal RA, and in the far-left side; the far-right side is omitted because of the symmetry). As an example of results, in Fig. 2 the radiation patterns in the elevation planes for the central and lower beam in the central plane (centered at about $33°$ and

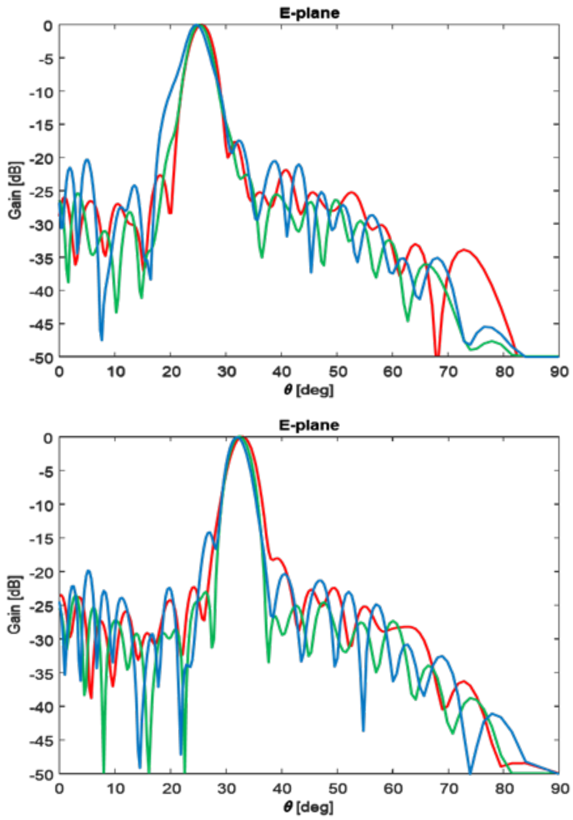

Fig. 2. Radiation patterns in the elevation plane (lower and central beam) at the lower (red), central (green) and upper frequency (blue).

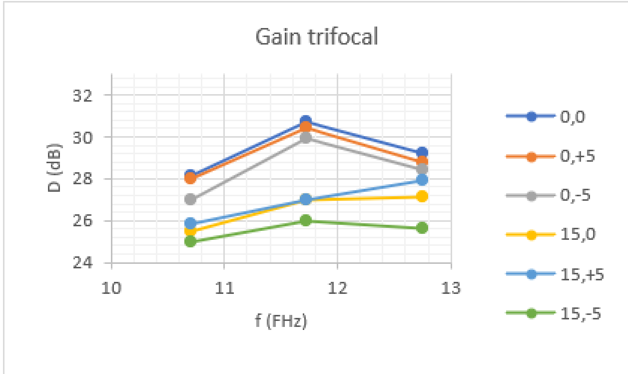

Fig. 3. Simulated gain in the full band for the six feed positions.

Fig. 4. Manufactured prototype mounted in the outdoor test range.

26° of elevation), at the lower-central-upper frequencies (10.7 GHz, 11.725 GHz, 12.75 GHz) are shown. The gain at the three frequencies for the six feed positions is shown in Fig. 3. In the legend, the couple of numbers refer to the nominal conventional position of the feed, also related to the beam displacement.

Other designs have been made for other configurations, for example a bifocal reflectarray. For this latter, a prototype has been manufactured, shown in Fig. 4 mounted in the outdoor test range for the measurements. The multilayer structure consists of a Rohacell foam, 5 mm thick, and the radiating elements are printed on a 0.5 mm thick layer of FR4.

The measurements have been carried out in the Politecnico di Torino test range. Fig. 5 shows the radiation patterns in the azimuth and elevation planes at 6 frequencies in the whole band, for the upper-far right angle, which is expected to be the most critical. A very stable direction of pointing can be seen, within 0.8° in azimuth and 1° in elevation, which are much less than the -1 dB angle (around 2°).

The directions of maximum radiation obtained with all the 6 positions of the feed and for three different frequencies inside the considered band are instead sketched in Fig. 6, that confirm the reduced dispersion of the pointing.

Finally, in Fig. 7 the measurements of the maximum gain for the 6 different pointing directions as a function of frequency are plotted: all of them are very stable, confirming the good frequency behavior of the antenna.

III. Conclusion

A new type of multifocal RA with mechanically beam steering capabilities is introduced, to be used as receiving antenna for DTH systems. The first numerical and experimental results are promising and confirm the expected performance. Other results will be presented at the Conference.

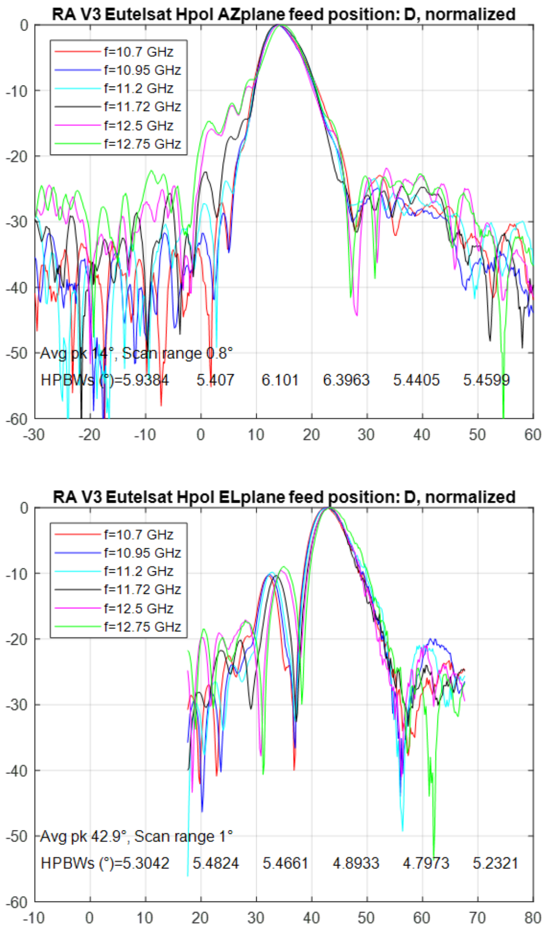

Fig. 5. Example of measured radiation pattern of the bifocal RA in the azimuth (above) and elevation (below) plane.

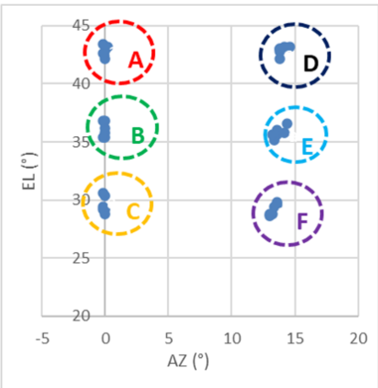

Fig. 6. Beam dispersion for different beam pointing and frequencies.

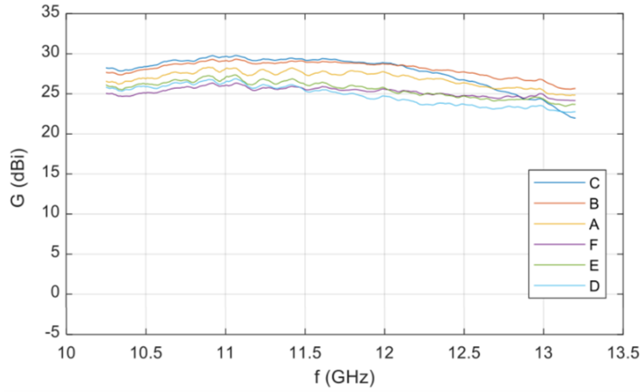

Fig. 7. Measured gain in the full band for the six feed positions.

References

[1] S. V. Hum and J. Perruisseau-Carrier, "Reconfigurable Reflectarrays and Array Lenses for Dynamic Antenna Beam Control: A Review", *IEEE Trans. Antennas Propag.*, vol. 62, no. 1, pp. 183-198, Jan. 2014.

[2] F. Guo, Y. Mao, S. Xu, F. Yang and A. Z. Elsherbeni, "A modified parabolic-cylindrical reflectarray antenna for wide beam scanning capablility", *2014 IEEE AP-S Int. Symp.*, Memphis, TN, pp. 1023-1024.

[3] P. Nayeri, F. Yang and A. Z. Elsherbeni, "Offset parabolic-torus-phase reflectarray antenna", *2014 IEEE AP-S Int. Symp.*, Memphis, TN, 2014, pp. 1025-1026.

[4] P. Nayeri, F. Yang and A. Z. Elsherbeni, "Studies on planar reflectarrays with spherical-phase distribution for 2-D beam-scanning", *2013 IEEE AP Society Int Symposium (APSURSI)*, Orlando, FL, 2013, pp. 1670-1671.

[5] P. Pirinoli, T. Lohrey, M. Orefice, M. Beccaria and G. Dassano, "Beam Scanning Reflectarrays for DTH application: preliminary results", *Procedings EuCAP 2019*, Krakow, April 2019, pp.76-79.

[6] P. Pirinoli, T. Lohrey, M. Orefice, M. Beccaria and G. Dassano, "Reflectarray with mechanically steerable beam for DTH application", *Proceedings 2019* 49^{th} *EuMC*, Paris, Oct. 2019, pp.141-144.

[7] P. Nayeri, F. Yang and A. Z. Elsherbeni, "Bifocal Design and Aperture Phase Optimizations of Reflectarray Antennas for Wide-Angle Beam Scanning Performance", *IEEE Trans. Antennas Propag.*, vol. 61, no. 9, pp. 4588-4597, Sept. 2013.

[8] G. Wu, S. Qu and S. Yang, "Wide-Angle Beam-Scanning Reflectarray With Mechanical Steering", *IEEE Trans. Antennas Propag.*, vol. 66, no. 1, pp. 172-181, Jan. 2018.

[9] E. Martinez-de-Rioja, J. A. Encinar, R. Florencio and C. Tienda, "3-D Bifocal Design Method for Dual-Reflectarray Configurations with Application to Multibeam Satellite Antennas in Ka-Band", *IEEE Trans. Antennas Propag.*, vol. 67, no. 1, pp. 450-460, Jan. 2019.

[10] P. Nayeri, F. Yang, and A. Z. Esherbeni, *Reflectarray Antennas: Theory, Designs and Applications*, Hoboken, NJ, USA: Wiley, 2018.