Ad-hoc feed system for enhanced features Convex Conformal Reflectarray

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***Abstract*—In this paper, some results about the possibility to improve the radiation performances of a Convex ReflectArray (CRA) antenna through an ad hoc 3-D printed feed is carried out. The entire antenna system has been manufactured and experimentally characterized. The measurements, in good agreement with the numerical results, show that the proposed configuration is capable to increase, with respect to the case when a conventional pyramidal horn feed is used, both the efficiency and the 1-dB bandwidth, from the 22% to the 48% and from the 7% to the 11% respectively.**

***Index Terms*— Reflectarray Antennas, Conformal Reflectarray.**

I. INTRODUCTION

Reflectarray Antennas (RA) [1]-[3] possess properties as reconfigurability, the possibility to obtain shaped beams, the reduced weight and volume, the easy deployment, that make them good candidates for radar and satellite communication antennas. In some recent works [6]-[8] the possibility to extend the RA concepts to configurations where the reflector is conformed to a non planar surface has been investigated. In [8] the numerical and experimental results relevant to a $20\lambda \times 20\lambda$, offset Convex ReflectArray (CRA in the following), working in a frequency range centered around 30 GHz prove the antenna feasibility, but also point out its drawbacks, i.e. the poor efficiency and the limited 1-dB gain bandwidth, that suffer for the effects introduced by the curvature.

For what concern the narrow bandwidth, a limitation that affects, although less than in this case, also planar RA, a possible solution for its enhancement could be that of adopting re-radiating elements with a larger bandwidth, as those consisting in patches printed on different layers or in non-conventional shape patches with more degrees of freedom (see in [1]-[3] and references therein, [9]). However, they do not improve the strongly unbalanced illumination of the CRA from the feed, that at its turn is responsible for a quite high spillover and waste of the impinging power. In order to take into account also this effect, in this work the idea is to try to compensate the effect of the curvature with an ad-hoc feed. Some efforts in this sense have been done in [4]-[5] as well, but for a planar RA and the solution obtained there is quite different from the one proposed here, where the designed feed horn has a smooth-wall profile geometry and has been manufactured with 3-D printed technology.

In order to prove the effectiveness of the design, the entire antenna system (CRA and feed horn) has been characterized experimentally, giving as a result a promising solution when is not possible to improve the performances of the reflector.

II. CONFORMAL REFLECTARRAY ANTENNA FEATURES

The CRA considered here has similar features to the one presented in [8]. The working frequency is $f = 30$ GHz ($\lambda = 10$ mm), the array is printed on a Diclad 527 substrate with $\epsilon_r = 2.55$ and $\tan\delta = 0.0022$, and the radius of curvature of the cylinder on which the CRA is bent is $R = 20\lambda$. The position of the feed is offset and its radiated field impinges on the center of the array with an incidence angle $\theta_{inc} = 25°$ with respect to the normal axis of the reflector; the CRA is designed to produce a collimated beam in its specular direction, i.e. $\theta_{max} = \theta_{inc}$ in Fig.1, where the profile of the CRA with the feed is shown. The aperture size here is slightly different than in [8], although even rectangular: in the previous work the CRA consisted of 43×43 re-radiating square patch elements, with a consequent aperture of almost $D = 20\lambda$ where D is the width of the CRA along the cylinder axis; in the present case the aperture is smaller (43×41 re-radiating elements), with an aperture width of $D = 18.5\lambda$. This has been done to make more square the effective area of the CRA.

From the geometry in Fig.1, it is evident that the illumination of the upper and lower borders of the CRA is really unbalanced. In fact, the two view angles α and β are $16.4°$ and $28.3°$ respectively, producing an illumination of -4.06 dB and -5.62 dB at the two edges. Moreover, due to the paths from the feed to the CRA, the spatial attenuation is not the same in the upper and the lower part, and this has to be taken into account. A standard rectangular horn, as the one used in the system presented in [8], is not able to compensate this two phenomenon, and this goes to the detriment of the whole antenna behavior.

III. FEED HORN DESIGN

From the above considerations, it emerges that the CRA performances could be enhanced with a proper feed. For this

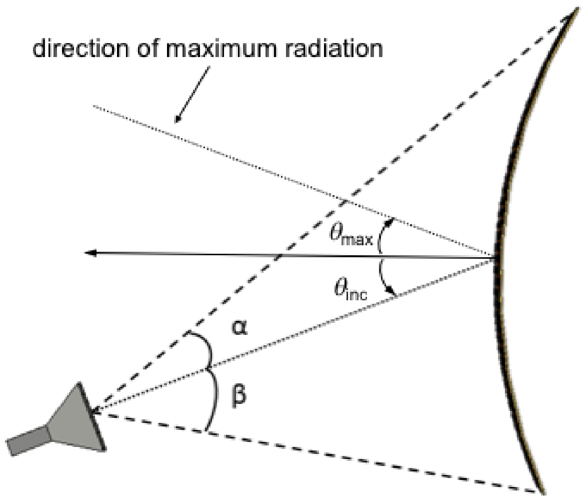

Fig. 1. Side view of the antenna system geometry.

goal, the compensation of the unbalanced illumination at the lower and upper edges, together with the issues related to the system cross-polarization level have been taken into account in the horn design by defining the optimum modal content at the horn aperture. This field distribution has been subsequently synthesized exploiting a smooth-wall horn architecture. By introducing slope discontinuities along the horn profile, the higher order modes are excited and the desired field can be achieved. The usual design procedure for smooth-wall horn consists on a discretization of the profile introducing N internal nodes A_i , with $i = 1, .., N$. The horn shape is then modified by varying the longitudinal and radial nodes coordinates (see Fig. 2).

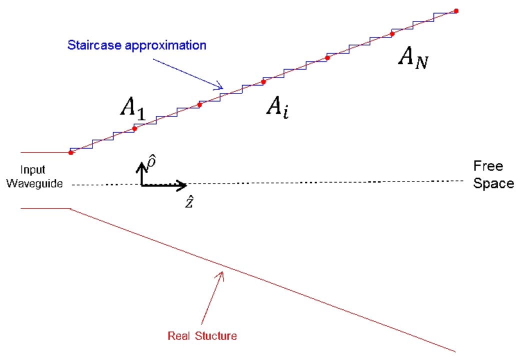

Fig. 2. Smooth wall horn profile, real structure and stair case approximation.

In the design under consideration, this task has been performed using a conjugate gradient method fixing $N = 5$. The horn analysis has been carried out by considering a staircase approximation of the profile (with a discretization step equal to $\lambda/20$ according to [10], see Fig. 1) and subsequently the Mode Matching method on each circular waveguide step discontinuities has been applied for computing the relevant scattering matrix. Since, in this way, a large number of discontinuities has to be considered, a reduced order method has been applied to speed up the computation time [11].

The antenna has been realized in Additive Manufacturing process exploiting the Selective Laser Melting (SLM) technique using an aluminum (AlSi10Mg) alloy. Thanks to the smooth-wall profile geometry, the antenna has been manufactured in the building machine with the same orientation of the laser axis [12]. In this way a better accuracy and surface finishing has been obtained.

Thanks to the adopted expedients, there is a very good agreement between the experimental and simulated results (as is possible to observe in the total system, CRA and feed, results) although the Ka band is usually critical for SLM process.

IV. Antenna System performances

The whole system has been simulated with a commercial software (CST Microwave Studio) and then characterized experimentally. The obtained results have been compared with those in [8], to verify the effectiveness of the new design, and in particular of the feed.

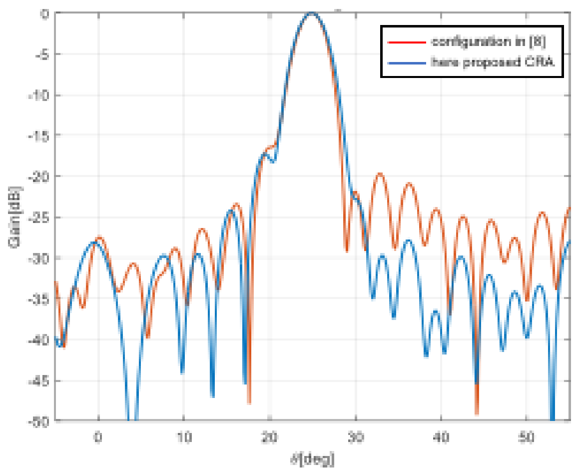

Fig. 3. Radiation pattern in the vertical (E) plane at 30 GHz.

In Fig. 3 the simulated radiation patterns in the vertical plane for both the CRA proposed here and that in [8] at the center frequency of 30 GHz are shown. As it can be seen, the two patterns are superimposed in the region of the main been, with almost no change in HPBW (3.3° against 3.6°). On the contrary, the SLL of the configuration considered here are lower than those of the antenna in [8], as shown also by the results in the fourth row of Tab. I, where the measured value of some of the quantities characterizing the behaviour of the two configurations are summarized.

Particularly noticeable is the increase in the gain, whose difference with respect to [8] in the considered frequency range is plotted in Fig. 4, that increases of more than 3.5 dB at the central frequency, and even more at the others. This is due to the different frequency behaviour of the gain for the two configurations, and in particular to the fact that for the one

TABLE I
MEASURED PERFORMANCES OF THE HERE PROPOSED CRA AND OF THE CONFIGURATION IN [8] AT 30 GHZ.

	Here proposed CRA	Configuration in [8]
Gain	33.27 dB	29.7 dB
Efficiency	47 %	22 %
1-dB BW	11 %	7 %
V-plane SLL	-17.7 dB	-15.1 dB
V-plane x-pol	–	-30 dB

considered here the gain decreases slowly moving from 30 GHz. As a consequence, the 1-dB bandwidth is wider, going from 7% to 11% (see third row in Tab. I), while the increase of the gain leads also to a higher efficiency, that grows up from 22% to almost 45% (second row in Tab. I). Finally, as expected, the designed CRA shows good cross-polarization features (fifth row in Tab. I).

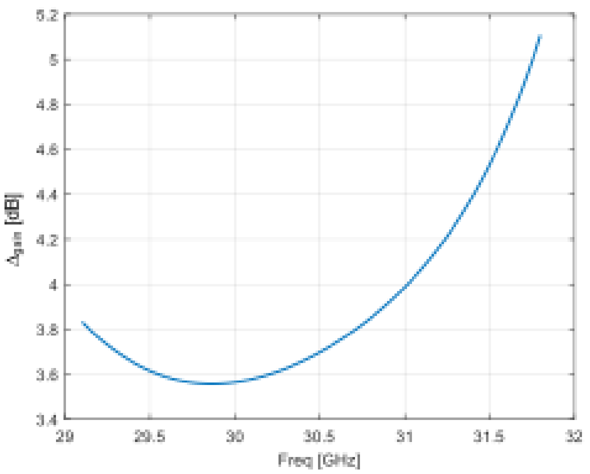

Fig. 4. Difference between the gain of the here proposed CRA and the configuration in [8] vs. frequency.

V. CONCLUSIONS

In this communication, some results on an improved Convex ReflectArray are shown: the enhanced antenna feature have been obtained mainly thanks to the use of an ad-hoc feed horn, realized with 3-D additive manufacturing. The radiation characteristics of the CRA are remarkably improved, both for what concerns the efficiency, the 1-dB bandwidth and the radiation pattern features (i.e SLL, cross polarization, HPBW). In conclusion is possible to state that this approach can be exploited when is not possible to act on the RA reflector itself, in order to improve the performances.

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