Design of a Circularly Polarized Microstrip Array Mounted on a Cylindrical Surface

M. V. T. Heckler [(1)], J. C. da S. Lacava [(2)*], and L. Cividanes [(3)]

(1) Institute of Communications and Navigation, DLR, Oberpfaffenhofen, D-82234, Wessling - Germany
(2) Antennas and Propagation Laboratory, ITA, 12228-900, S. J. Campos - SP - Brazil
(3) Brazilian Institute for Space Research, INPE, 12001-970, S. J. Campos - SP - Brazil

1. Introduction

Microstrip antennas are very well suited to conformal array applications [1]. Mounted on cylindrical surfaces, most of the developments emphasize the design of *N*-element wraparound arrays for omnidirectional radiation in the cylindrical roll planes [2]. The radiation characteristics for both linear and circular polarizations have been studied and reported by several authors [3-5]. Recently, the influence of the number of elements on the quality of the circular polarization has been investigated [6]. Following this subject, the present paper reports the design of a circularly polarized (CP) circumferential array for the *SONDA IV*, a Brazilian sounding rocket. Using an effective home made *CAD* tool (namely *Cylindrical*), the minimum number of radiating elements needed to obtain a radiation characteristic as close as possible to an isotropic pattern was determined. Then, constructive details were taken into account in order to finally define the total number of antennas. To validate our assumptions and the design procedure, a prototype of a sub-array of four CP microstrip patches was manufactured, and the tests results show very good agreement with the simulations.

2. Radiation Pattern of the Array Element

An efficient approach to analyze the radiation characteristics of cylindrical circumferential arrays of circularly polarized microstrip patches have been developed and reported in [6]. A nearly square radiator was used in that analysis because it can be modeled as a cavity with lateral magnetic walls in case of electrically thin substrates. This technique is not as rigorous and complex as full-wave model, but it does allow the derivation of useful design expressions, reducing the time required to achieve an optimized geometry [7]. To illustrate the potential of the developed technique, a circularly polarized antenna, printed on a substrate with $h = 3.048$ mm, $\varepsilon_r = 2.55$ and $\tan\delta = 0.0022$, conformed on a metallic cylinder with a 0.25 m radius, and operating at 2.25 GHz, was designed running the *CAD Cylindrical*. The radius was chosen to comply with *SONDA IV* sounding rocket, produced by the *Aerospace Technical Center*, in *São José dos Campos, Brazil*. Fig. 1 shows the antenna prototype mounted on the RF mockup of the *SONDA IV* second stage. Simulated and measured radiation patterns in the rocket roll plane are shown in Fig. 2. Very good agreement between experiments and simulations can be observed.

3. Radiation Characteristics of the Circumferential Array

For space vehicle applications, an isotropic radiation pattern is required in order to keep the telemetry channel reliable. This can be achieved disposing the elements uniformly around the circumference of the cylinder and driving them with the same current in amplitude and phase. After designing one CP radiating antenna, the minimum number of

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elements to obtain the isotropic radiation pattern with good axial ratio level in the roll plane was then determined. Following [7], this requirement can be realized running the *Cylindrical CAD* to calculate the array directivity for the CP case as a function of the number of patches. Fig. 3 presents the result of the simulation for the *SONDA IV* rocket. From this graphic we can clearly observe that seventeen elements are enough to obtain the required pattern. However, as the second stage has 1.57 m of perimeter, it is necessary to subdivide the array in a number of sub-arrays, in order to facilitate the design of the beam forming network. Therefore, the use of twenty four elements has been defined, once it can be composed by three sub-arrays with eight elements. Fig. 4 shows the predicted radiation pattern for the complete array plotted on the vertical plane.

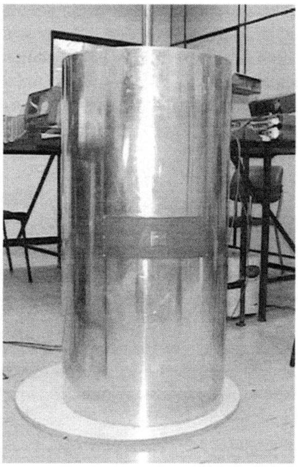
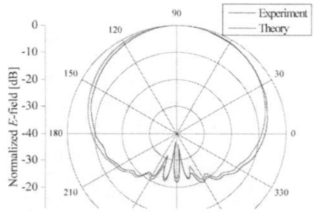
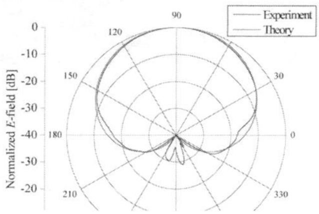


Fig. 1. CP antenna prototype mounted on the *SONDA IV* RF mockup.



(a) E plane: TM_{10} mode.



(b) H plane: TM_{01} mode.

Fig. 2. Simulated and measured results plotted in the roll plane of the mockup.

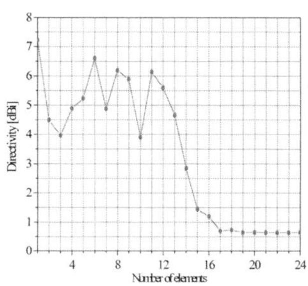


Fig. 3. Directivity versus number of elements for the mockup of Fig. 1.

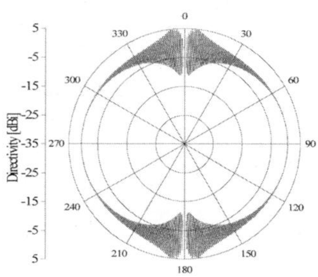


Fig. 4. Radiation pattern for an array of 24 elements (vertical plane).

3. Design of the Beam Forming Network

As the diameter of the second stage of the *SONDA IV* is 0.5 m and the telemetry frequency is 2.25 GHz, the radius under consideration is larger than one guided wavelength. Then, according to [5], a planar simulator can be used to design the antenna sub-array. However, it is not so easy to obtain any information about how the curvature can modify the planar design. For that reason, before designing the sub-array of eight elements, it was decided to study an array of four antennas. In this case, to facilitate the topology of the divider, corner-fed nearly square patches were used instead of the previous probe-fed elements. The simulations for this study were performed on the Ansoft Ensemble 8.0™ package. Fig. 5 shows a photo of the prototype and in Fig. 6 experimental and computed results for the planar configuration are presented. After that, the array was mounted on the same mockup shown in Fig. 1, and the input impedance and return loss were measured. The results, compared to planar experiments are shown in Figs. 7 and 8, respectively. It is possible to confirm that our strategy using analysis of planar structures to the design of the conformal array was successful, once the curvature seems to introduce only small variations on the final return loss of the array.

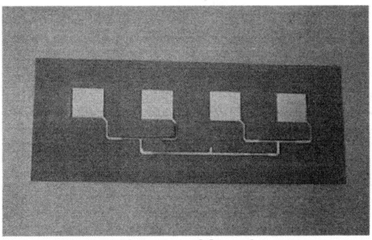


Fig.5. Sub-array of four elements.

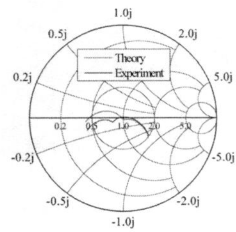


Fig. 6. Theory and experiment for planar array.

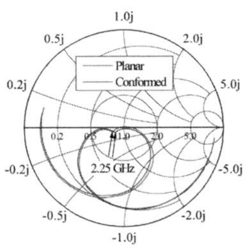


Fig. 7. Planar and conformed results.

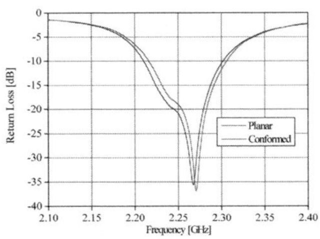


Fig. 8. Planar and conformed results.

Spinning-dipole radiation pattern for the four elements sub-array were also calculated. Fig. 9 presents the simulated results for the *SONDA IV* roll plane and the Fig. 10 shows the radiation pattern plotted on the vertical plane. It can be observed that very good performance was obtained with respect to the antenna axial ratio.

5. Conclusions

A procedure to design conformal arrays on cylinders with relatively large radii was presented in this paper. Initially, the definition on the minimum number of antennas to achieve an almost isotropic radiation pattern with good axial ratio level was determined.

This has been achieved by computing the directivity of the CP array using a technique based on the cavity model. Then, taking into account constructive details, the final number of antennas has been defined. Due to the radius used in the present case, the design of the feeding network was performed using planar analyses as an approximation. By measuring the return loss of the prototype for both planar and conformal cases, it becomes clear that our strategy was successful, once the influence of the curvature on this parameter was small and then one would expect the same behavior for a complete sub-array with eight elements. Our results show that good accuracy on the predictions can be achieved even without a rigorous analysis of the exact geometry, provided that the conditions stated in this work are satisfied. This can save time and costs during the design process.

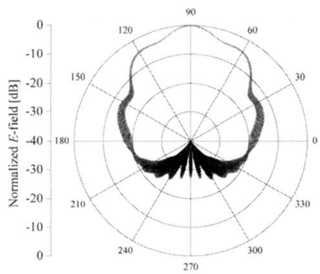


Fig. 9. Computed spinned radiation pattern (roll plane).

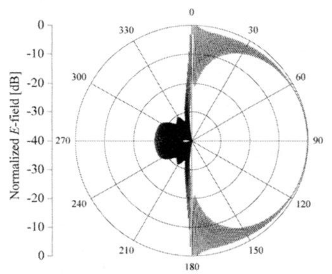


Fig. 10. Computed spinned radiation pattern (vertical plane).

Acknowledgments: This work was partially supported by *FAPESP*, Fundação de Amparo à Pesquisa do Estado de São Paulo, under Grants N° 01/00584-5 and N° 2002/14164-0, and by *CNPq*, Conselho Nacional de Desenvolvimento Científico e Tecnológico, under Grant N° 133267/2002-4. The authors would like to thank to Instituto de Fomento e Coordenação Industrial (IFI) to allow the measurements of the radiation patterns presented in this paper.

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