Analysis of Cylindrical Circumferential Array with Circular Polarization for Space Applications

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1. Introduction

Microstrip antennas have several attractive characteristics for space applications, such as lightweight, low profile and conformability. For space vehicle applications, an isotropic radiation pattern may be desired in order to establish a reliable telemetry link. Another important feature of such a link is the polarization of the ground and the embedded antennas. The use of circularly polarized (CP) antennas reduces the polarization mismatch between these antennas, increasing the link efficiency. The circumferential array analysis with such characteristics has been reported in the literature [1,2], but no comments are made on the influence of the number of elements on the quality of the circular polarization. By the aforementioned reasons, the purpose of this paper is to analyze CP microstrip antenna arrays conformed on cylindrical surfaces in order to achieve a suitable radiation pattern for telemetry of space vehicles.

2. Radiation of a slot in a metallic cylinder

We first start deriving the expressions to compute the fields radiated by a slot in a metallic cylinder, with infinite length, using the cylindrical wave equations in the spectral domain. Equations for both ρ and ϕ field components are coupled, while the equation for the z-component is decoupled from the others. This last equation has the form of a typical Bessel equation, so that it can be solved first. The z-component of the spectral fields can be written in terms of a *Hankel* function of 2nd kind because radiated fields outgoing from origin are desired:

$$E_z(\rho,p,k_z) = \mathbf{e}_z(p,k_z)H_p^{(2)}(k_{0\rho}\rho) \tag{1}$$

$$H_z(\rho,p,k_z) = \mathbf{h}_z(p,k_z)H_p^{(2)}(k_{0\rho}\rho) \tag{2}$$

where $k_{0\rho}$ is the free space wave number in the ρ-direction, p and k_z are spectral variables, $H_p^{(2)}(x)$ is the *Hankel* function of 2nd kind with order p, and $\mathbf{e}_z(p,k_z)$ and $\mathbf{h}_z(p,k_z)$ are functions to be determined taken into account the boundary conditions. The expression for the other field components can be derived writing them in terms of $E_z(\rho,p,k_z)$ and $H_z(\rho,p,k_z)$ [3,4]. These expressions are general for any slot shape.

3. Element Modeling and Design

The geometry of a rectangular probe-fed microstrip antenna conformed on a cylindrical structure is shown in Fig. 1. Considering that the substrate thickness is electrically thin, the cavity model [5] can be applied to this structure. Therefore, imposing the boundary conditions, the field between the metallic patch and the metallic cylinder is given by

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$$E_\rho = \sum_{m=0}^{+\infty}\sum_{n=0}^{+\infty} E_{0mn} \cos[m\pi(\phi - \phi_1)/2\theta_1]\cos[(n\pi z/2b)] \quad (3)$$

where

$$E_{0mn} = \frac{i\omega\mu_0 C d}{4ab\theta_1}\frac{\xi_m \xi_n}{k^2 - k_{mn}^2}\cos\left(\frac{m\pi}{2\theta_1}\phi'\right)\cos\left(\frac{n\pi}{2b}z'\right)\mathrm{sinc}\left(\frac{m\pi d}{4a\theta_1}\right) \quad (4)$$

ω is the angular frequency, C is the current density in the probe feed, d is the width of C, μ_0 is the magnetic permeability of the free space, k is the wave number in the substrate, k_{mn} is the reasonant wave number of each TM_{mn} mode, sinc (x) = $\sin(x)/x$ and $\xi_\tau = 1$ if $\tau = 0$ and $\xi_\tau = 2$ if $\tau \neq 0$. This expression is the key to model other antenna characteristics, such as input impedance and radiation patterns. Using (3) and adapting the procedure proposed by [5] to the cylindrical structure of Fig. 1, an expression for the synthesis of a *nearly square* CP microstrip antenna could be derived [4]:

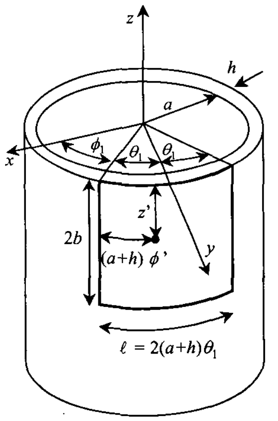

Fig. 1 – Geometry of the cylindrical conformed antenna.

$$\frac{\Delta b}{2b} \approx \frac{1}{2Q}\left(A + \frac{1}{A}\right) \quad (5)$$

where

$$A = \cos[\pi\phi'/(2\theta_1)]/\cos[\pi z'/(2b)] \quad (6)$$

Q is the quality factor and Δb is the increment in the length of one of the antenna dimensions. The cavity model can be also used to model the radiation characteristics of the element, which can serve as a basis to model array radiation patterns. The field computation can then be achieved by first replacing the element by a set of four slots disposed along its edges. Therefore, the field theory of section 2 can be applied for each of the four slots, with the boundary conditions imposed using (3). Unfortunately, the design and manufacturing parameters of this kind of antenna are critical. Without computational aid the design process can take a long time, with no guarantee of achieving the optimized antenna geometry. In this way, an efficient *C*omputer *A*ided *D*esign (*CAD*) package (named *Cylindrical*) to design and analyze rectangular probe-fed microstrip antennas conformed on cylindrical structures was developed [6]. Using this *CAD*, a circularly polarized antenna, printed on a substrate with h = 3.048 mm, ε_r = 2.55 and *tan* δ = 0.0022, conformed on a metallic cylinder with a 0.25 m radius, and operating at 2.25 GHz, was designed. A computed spinned radiation pattern can be seen in Fig. 2. In this case, an excellent figure of 0.15 dB for the antenna axial ratio was obtained. Experimental and computed input impedance are presented in Fig. 3. The radius was chosen to comply with *SONDA IV* sounding rocket, produced by the *Aerospace Technical Center*, in *São José dos Campos, Brazil.*

4. Conformal Circumferential Array

Using the field theory developed in section 2, calculations can be performed for a conformal array. Several geometries for such arrays are possible [4]. However, for space vehicle applications, an isotropic radiation pattern on the roll plane of the cylinder is required in order to keep the telemetry channel active. This can be achieved disposing the

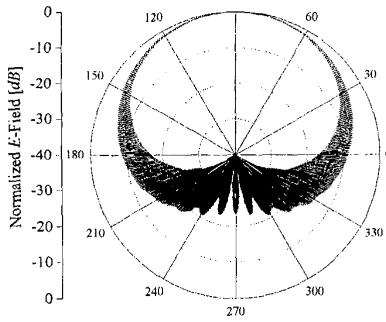

Fig. 2 – Spinned radiation pattern for a *nearly square* conformed antenna. (roll plane)

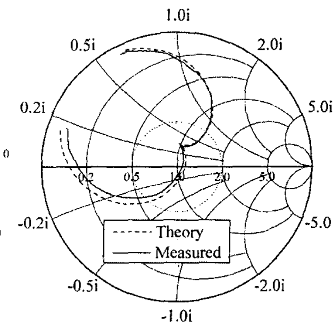

Fig. 3 – Prototype input impedance.

elements uniformly around the circumference of the cylinder and driving them with the same current in amplitude and phase (Fig. 4). When circular polarization is desired, it is important to determine correctly the minimum number of antennas needed to have low ripple in the radiation pattern and good axial ratio levels. Following the approach proposed in [7], the *Cylindrical CAD* achieves this requirements calculating the array directivity as a function of the number of patches. In order to exemplify, Fig. 5 presents the *CAD* computed spinned radiation pattern (roll plane) for an 8-element array. This picture shows the great ripple in the pattern and poor values of axial ratio around the circumference. Increasing the number of elements to 16 and 18, the maximum ripples are less than 2.5 *dB* and 0.4 *dB*, respectively. The radiation pattern for the last case is shown in Fig. 6. Using three sub arrays of 8 elements (24 elements), the computed radiation pattern is presented in Fig. 7. One can easily see that there is no ripple and the axial ratio level is very good.

5. Conclusions

Results obtained under the application of the cavity model in a conformal patch antenna were first presented. This technique allowed the derivation of useful expressions to design *nearly square* circularly polarized microstrip antennas. Initially, a single element conformed on a metallic cylinder with a 0.25 m radius was designed to operate at 2.25 GHz. Good agreement between measurements and *CAD* predictions were observed for radiation pattern [4] and input impedance. After that, a circumferential array was analyzed. It was shown that the number of elements to be placed around a cylindrical surface plays an important role in order to achieve radiation patterns with low ripple and good axial ratio in the roll plane of the cylinder. The cylinder radius of 0.25 m was chosen to comply with *SONDA IV*, a Brazilian sounding rocket. All simulations discussed in this paper were performed using the package *Cylindrical*.

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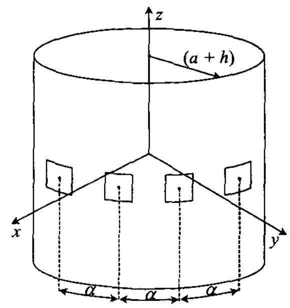

Fig. 4 – Conformal circumferential array geometry.

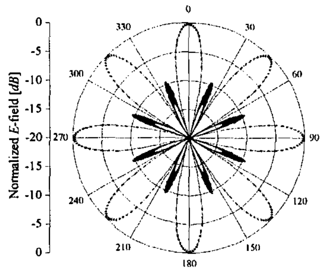

Fig. 5 – Spinned radiation pattern for an 8-antenna array uniformly spaced around the cylinder circumference. (roll plane)

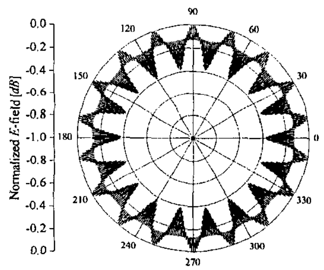

Fig. 6 – Spinned radiation pattern for an 18-antenna array uniformly spaced around the cylinder circumference. (roll plane)

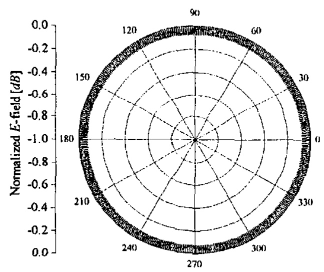

Fig. 7 – Spinned radiation pattern for a 24-antenna array uniformly spaced around the cylinder circumference. (roll plane)

References

[1] D. I. Wu, "Omnidirectional circularly-polarized conformal microstrip array for telemetry applications," *IEEE Antennas and Prop. Symposium Digest*, pp. 998-1011, June 1995.

[2] H. D. Weinschel, "A cylindrical array of circularly polarized microstrip antenna," *IEEE Antennas and Prop. Symposium Digest*, pp. 177-180, 1975.

[3] C. M. Silva, J. C. S. Lacava, and F. P. Richards, "Analysis of a conformal cylindrical microstrip antenna covered by a protection layer," *Proceedings of the SBMO/IEEE MTT-S International Mycrowave Symposium*, vol. 1, pp. 145-151, Jul. 1989.

[4] M. V. T. Heckler, Circularly polarized microstrip antenna arrays conformed on cylindrical surfaces, *MSc. Thesis*, Instituto Tecnológico de Aeronáutica, Brazil, 2003. (*in Portuguese*)

[5] W. F. Richards, Y. T. Lo, and D. D. Harrison, "An improved theory for microstrip antennas and applications," *IEEE Trans. Antennas Propagat.*, vol. AP-29, pp.38 – 46, Jan. 1981.

[6] M. V. T. Heckler, M. Bonadiman, R. Schildberg, L. Cividanes, and J. C. S. Lacava, "*CAD* package to design rectangular probe-fed microstrip antennas conformed on cylindrical structures," *Proceedings of the IMOC 2003*, Brazil, vol. 2, pp. 747-752, Sept. 2003.

[7] C. M. Silva, F. Lumini, J. C. S. Lacava, and F. P. Richards, "Analysis of cylindrical arrays of microstrip rectangular patches," *Electron. Lett.*, 1991, 27(9), pp. 778-780.