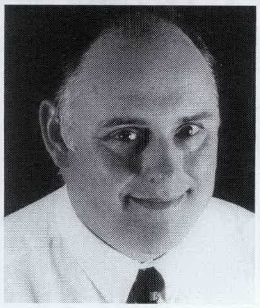

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Foreword by the Editor

This month's contribution addresses a CAD package for designing rectangular microstrip antennas conformed onto cylindrical structures: an important application of such antennas. The package uses the cavity model to rapidly design and analyze prototypes. The authors show that a full-wave FEM analysis indicated only small changes being required in the final dimensions. We thank the authors for their submission. Readers interested in obtaining the package should contact the authors directly.

We have also received correspondence regarding the August 2007 column. This appears in the Letters to the Editor section of this issue.

CYLINDRICAL: An Effective CAD Package for Designing Probe-Fed Rectangular Microstrip Antennas Conformed onto Cylindrical Structures

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Abstract

This paper presents a computer-aided design tool named *CYLINDRICAL*. The algorithm utilizes the cavity model to design and analyze linearly and circularly polarized probe-fed rectangular microstrip antennas conformed onto cylindrical structures. A brief description of the program is given. *CYLINDRICAL* was used to design a circularly polarized antenna to operate in the L1 band of GPS. Validation was further done with the Ansoft *HFSS* package. It was shown that the antenna dimensions given by the design algorithm of *CYLINDRICAL* needed to be only slightly changed in order to obtain an optimized circularly polarized radiator according to the *HFSS* software. The tool is also very suitable for teaching graduate courses on microstrip antennas.

Keywords: Conformal antennas; microstrip antennas; cavity model; circularly polarized microstrip antennas; design automation; cylindrical antennas

1. Introduction

The evolution of navigation technology and aircraft networks has made the cylindrical structure a very important focus of study and research. In several applications, there is a need for low-profile and flush installations in order not to significantly affect the aerodynamics of the vehicles. In addition, cylindrical antenna arrays have the potential for 360° coverage, with an omnidirectional pattern, with multiple beams, or with a narrow beam that can be steered over 360° [1]. Antenna for tracking GPS signals could be cited as a typical application. A microstrip patch antenna becomes a very useful and capable radiator for complying with all the requirements needed [2]. Unfortunately, the design of this kind of antenna may be time-consuming when circularly polarized (CP) antennas are desired [3-5]. Due to these drawbacks, an effective computer-aided design (CAD) package, named *CYLINDRICAL*, has been developed to design circularly polarized rectangular probe-fed microstrip antennas conformed onto cylindrical structures [3]. Its mathematical routines use the *FORTRAN 90* language, and the CAD interfaces are built in *Builder C++*. It provides user-friendly interfaces for the Microsoft *Windows* environment. It has a lot of facilities that can be used as an auxiliary tool in graduate courses on microstrip antennas. Therefore, the aim of this paper is to present an improved version of the software described in [3], which is now capable of designing and predicting the behavior of linearly and circularly polarized probe-fed rectangular microstrip antennas conformed onto cylindrical structures.

2. Overview of *CYLINDRICAL*

Nowadays, analysis of conformal microstrip radiators is restricted to CAD packages that are in general very expensive [6]. Low-cost alternative software can be developed by using the cavity model [7], a simple and successful method for designing and analyzing microstrip patches with canonical shapes. Although this method has the limitation that it obtains good results only for antennas with an electrically thin substrate, this choice is justified because useful equations for the design of microstrip antennas can be obtained. This is surely a characteristic well suited for CAD tools, which are in general much faster than software that applies rigorous full-wave methods.

The geometry of a rectangular microstrip patch conformed onto a cylindrical grounded substrate is shown in Figure 1. As is well known, this kind of antenna can radiate (or receive) linearly and circularly polarized waves [2]. However, to obtain the desired state of polarization, the patch dimensions and the probe position must be properly determined. This can be done by applying the expressions and the algorithm presented in [8]. An effective CAD package has been developed using these. Although this CAD program can handle both linearly and circularly polarized antennas, in this paper only the design of a GPS antenna is examined. Electrical parameters such as the input impedance (rectangular plot and Smith chart), axial ratio (AR), and radiation pattern are calculated and discussed.

3. Description of the Design Module

After starting *CYLINDRICAL*, the main interface (Figure 2) is shown. The current version contains two independent sections: the design and the analysis modules, which can be accessed through the pull-down menu `Element`. By selecting the `Design` option, the design interface (Figure 3) is shown. The inputs required to start the design procedure are the desired frequency; the cylinder radius, a; the probe radius, d; and the substrate data, such as the dielectric constant, ε_r, the loss tangent, $\tan\delta$, and the thickness, h. Also, the sense of rotation of the circular polarization must be set. The outputs are the two dimensions of the patch (ℓ and $2b$), and the probe position (ℓ' and z'). The probe position is designed in order to provide good impedance matching with a $50\,\Omega$ characteristic-impedance system, while keeping a good axial-ratio level.

To illustrate the design procedure, let us consider a rectangular patch antenna conformed onto a metallic cylinder of radius $a = 250\,\text{mm}$ and excited by a probe current of 0.5 mm radius. To receive GPS signals at the L1 frequency (1.57542 GHz), the radiator has to be right-hand circularly polarized (CP-Right). To comply with the GPS requirements, we have decided to use the Arlon CuClad™ 250 GX microwave laminate [9] for the antenna substrate. The main characteristics of this are $h = 3.048\,\text{mm}$, $\varepsilon_r = 2.55$, and $\tan\delta = 0.0022$.

The synthesis process is started by pressing the button `Design`. The computed final results are presented in the same interface. For the GPS antenna under consideration, the patch dimensions and the probe location were $\ell = 57.361\,\text{mm}$, $2b = 55.806\,\text{mm}$, $\ell' = 20.283\,\text{mm}$, and $z' = -20.229\,\text{mm}$, as shown in Figure 3. Finally, the button `Save` must be pressed to save the antenna's dimensions.

4. Description of the Analysis Module

The analysis section is dedicated to evaluating the characteristics of the designed antenna. To start this section, the

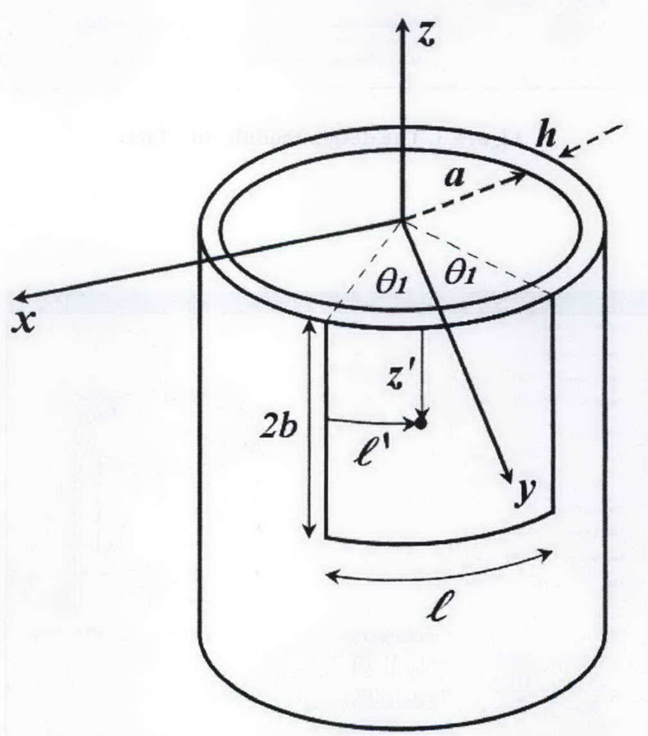

Figure 1. The geometry of a rectangular microstrip patch conformed onto a cylindrical grounded substrate.

Figure 2. The main interface of *CYLINDRICAL*.

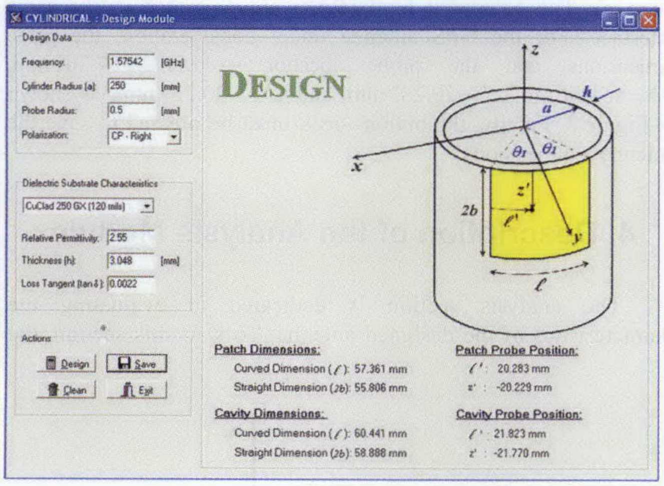

Figure 3. The design module interface.

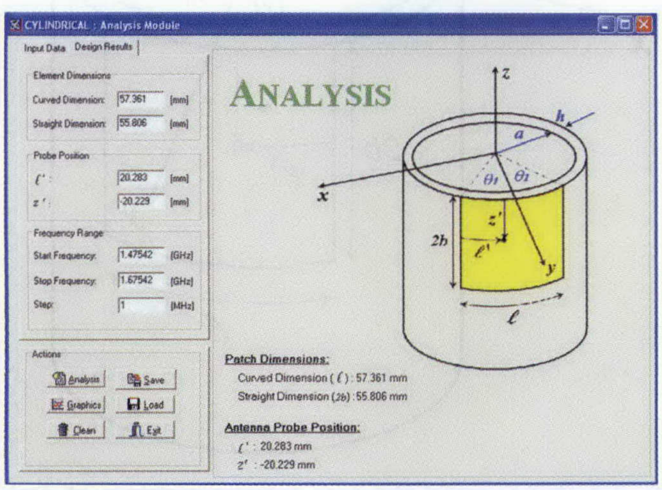

Figure 4. The analysis module interface.

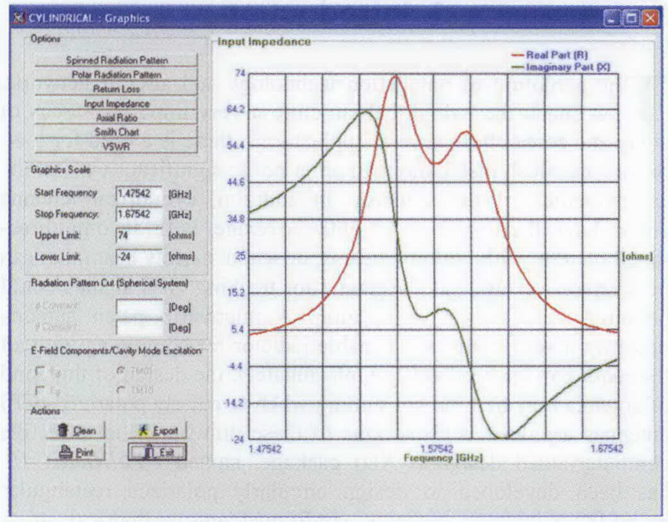

Figure 5. The input impedance for the GPS antenna.

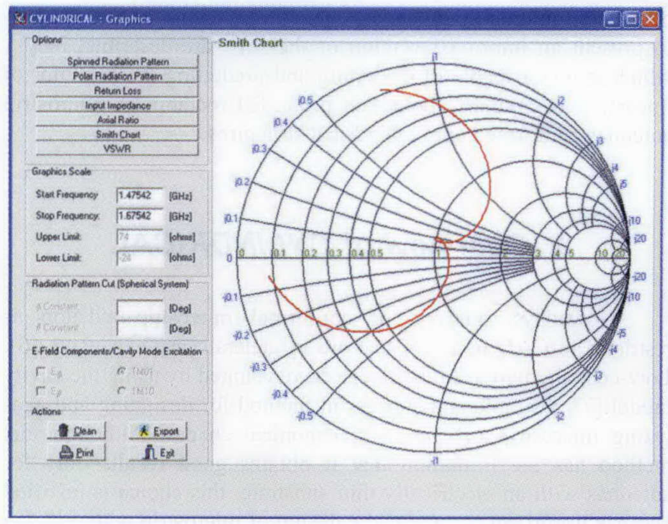

Figure 6. The input impedance on a Smith chart for the GPS antenna.

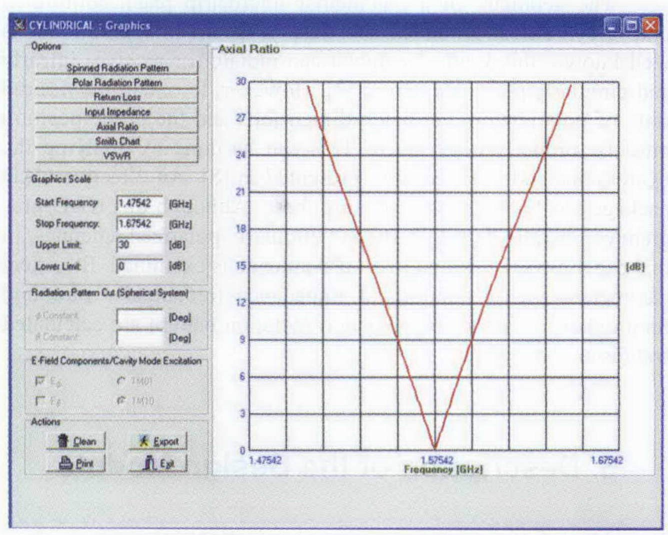

Figure 7. The axial ratio for the GPS antenna.

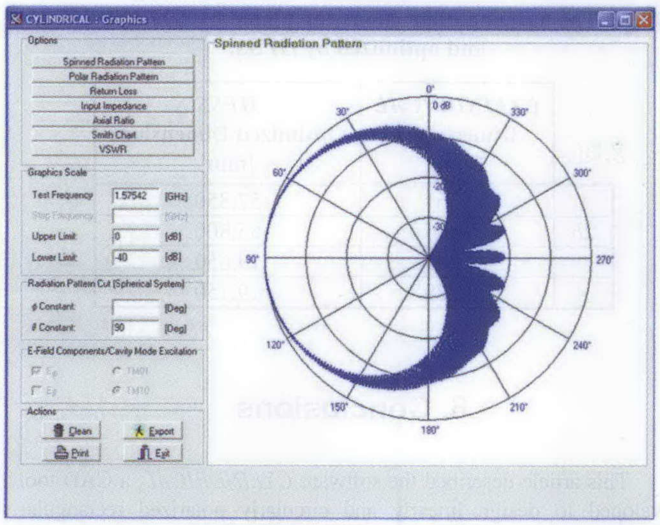

Figure 8. The spinning-dipole radiation pattern computed at the L1 frequency for the cylinder roll plane.

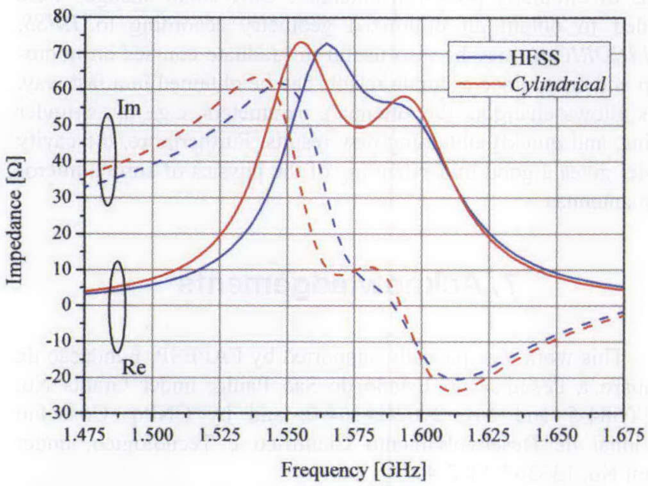

Figure 9. The *HFSS* and *CYLINDRICAL* results for the input impedance of the GPS antenna.

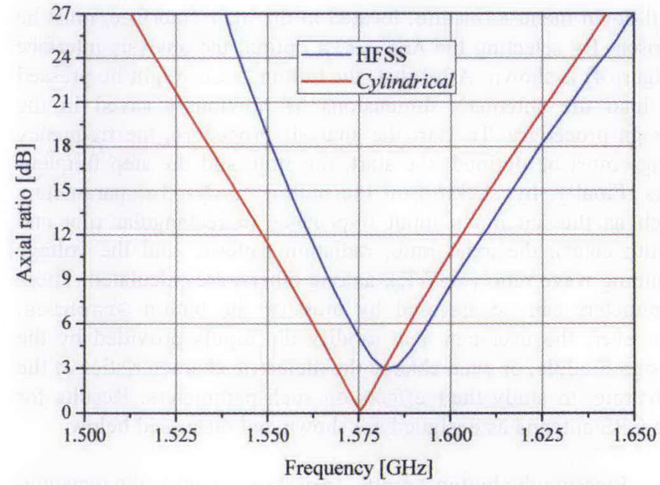

Figure 10. The *HFSS* and *CYLINDRICAL* results for the axial ratio of the GPS antenna.

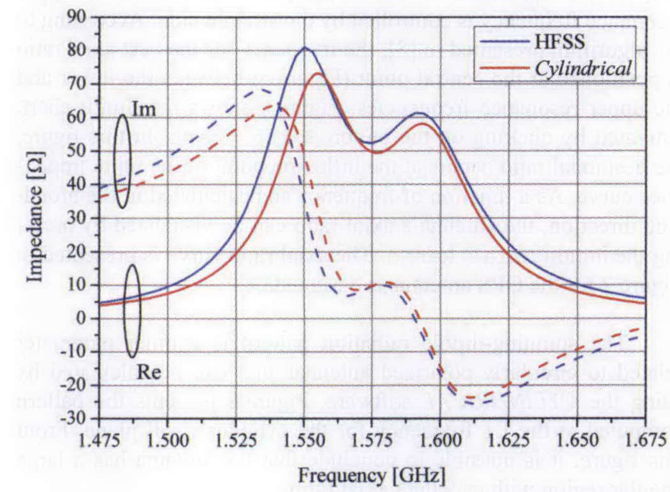

Figure 11. The *HFSS* and *CYLINDRICAL* results for the input impedance of the GPS antenna, calculated with the dimensions presented in Table 1.

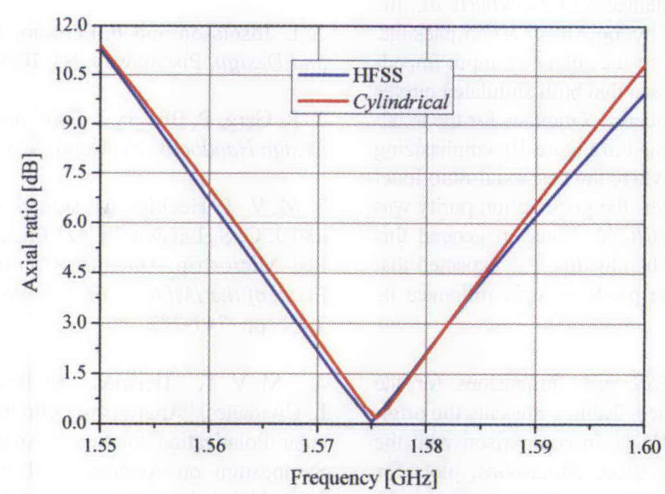

Figure 12. The *HFSS* and *CYLINDRICAL* results for the axial ratio of the GPS antenna, calculated with the dimensions presented in Table 1.

pull-down menu `Element`, located in the main interface, must be chosen. By selecting the `Analysis` option, the analysis interface (Figure 4) is shown. After that, the button `Load` might be pressed to load the antenna's dimensions as previously saved in the design procedure. To start the analysis procedure, the frequency range must be defined: the start, the stop, and the step frequencies. Finally, by clicking on the button `Analysis`, parameters such as the antenna's input impedance (a rectangular plot and Smith chart), the axial ratio, radiation patterns, and the voltage standing wave ratio (VSWR), among others, are calculated. These parameters can be assessed by pressing the button `Graphics`. However, the user can also modify the inputs provided by the design module, or even change the dielectric characteristics of the substrate, to study their effects on such parameters. Results for the GPS antenna as designed are shown and discussed below.

Pressing the button `Input Impedance` causes the rectangular chart (Figure 5) to be plotted. This presents the computed real and imaginary parts of the antenna's input impedance, as a combination of two orthogonal modes, TM_{01} and TM_{10}, required for the desired circularly polarized operation. The lower resonance frequency is controlled by the curved patch side, while the upper resonance frequency is controlled by the straight side. According to the algorithm presented in [8], the frequency for the best axial ratio is positioned at the central point (Figure 5) between the lower and the upper resonance frequencies. Figure 6 shows the Smith chart, activated by clicking on the button `Smith Chart`. In this figure, the best axial ratio occurs at the inflexion point of the input impedance curve. As a function of frequency and calculated in the broadside direction, the antenna's axial ratio can be visualized by pressing the button `Axial Ratio`. The axial ratio curve is presented in Figure 7 for the GPS antenna as designed.

The spinning-dipole radiation pattern is another parameter related to circularly polarized antennas that can be calculated by using the *CYLINDRICAL* software. Figure 8 presents the pattern computed at the L1 frequency for the cylinder's roll plane. From this figure, it is possible to conclude that the antenna has a large angular region with excellent axial ratio.

5. Comparison with *HFSS* Simulation

In order to validate the results obtained by *CYLINDRICAL*, the GPS antenna as designed was analyzed by the Ansoft *HFSS* package. Results for the real and imaginary parts of the antenna's input impedance are presented in Figure 9. One can see that both simulated curves were similar in shape, but shifted in frequency. Graphics for the axial-ratio parameter have the behavior presented in Figure 10, emphasizing that there was a shift for the frequency where the best axial-ratio level occurred, as observed before. Moreover, the polarization purity was poorer than that predicted by *CYLINDRICAL*. Since in general this kind of antenna presents a very narrow bandwidth, it is expected that small changes in the dimensions of the patch strongly influence its characteristics.

After optimizations done in *HFSS*, new dimensions for the circularly polarized antenna were obtained. Table 1 presents the original dimensions provided by *CYLINDRICAL* in comparison with the dimensions optimized in *HFSS*. Using these dimensions, plots for input impedance and axial ratio were drawn as shown in Figures 11 and 12. One can observe from these graphics that after small changes in the dimensions of the antenna designed by *CYLINDRICAL*, the predicted *HFSS* results complied with the GPS requirements.

Table 1. The antenna dimensions calculated by *CYLINDRICAL* and optimized by *HFSS*.

	CYLINDRICAL Dimensions [mm]	*HFSS* Optimized Dimensions [mm]
ℓ	57.361	57.850
$2b$	55.806	55.800
ℓ'	20.283	19.650
z'	20.229	19.150

6. Conclusions

This article described the software *CYLINDRICAL*, a CAD tool developed to design linearly and circularly polarized rectangular microstrip antennas conformed onto cylindrical structures. The software's operation was illustrated with the design of a circularly polarized antenna to operate in the L1 band of GPS. Results for the input impedance were compared with simulations obtained by Ansoft *HFSS*. *CYLINDRICAL* has proven to give good estimates for the dimensions of circularly polarized antennas. Only small changes were needed to obtain an optimized geometry according to *HFSS*. *CYLINDRICAL* may be also useful in graduate courses on microstrip antennas, since accurate results can be obtained in a fast way. This allows changing the antenna's parameters, e.g., the cylinder radius, and quickly obtaining new results. Furthermore, the cavity model gives a good understanding of the physics of simple microstrip antennas.

7. Acknowledgements

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