Compact Planar Two-Arm Compound Spiral Antenna for L-/X-Band Direction Finding Applications

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***Abstract*—This paper presents the design of an ultra-wideband planar two-arm compound spiral antenna composed of an equiangular spiral and an Archimedean spiral, which respectively improve the radiator performance at low and high frequencies. A metallic cavity filled with absorber material, used to make unidirectional the radiation pattern of the antenna, also allows the use of a resistive termination to improve antenna's performance at low frequencies. By using a Hecken approach, a microstrip to parallel-strip transition (balun) is designed to feed the spiral arms. In the range from L- to X-band, measured radiation patterns, axial ratio, and reflection coefficient attain good results. Finally, the application of the antenna in a direction finding system is described.**

***Keywords*—Archimedean spiral antenna; compound spiral antenna; direction finding; equiangular spiral antenna**

I. Introduction

Recently, the fast development of ultra-wideband (UWB) systems for commercial and military applications has highlighted the importance of UWB antennas. In this context, spiral antennas receive special attention owing to belonging to the class of frequency independent antennas. Ideally, parameters of these antennas, such as axial ratio, radiation pattern and input impedance remain unchanged over the band of operation [1].

Since this type of antenna is a balanced structure, a careful design of its feeder device is required. Generally, feed's source is a coaxial cable, i.e., an unbalanced device, forcing the use of a balun. This device, in addition to transforming an unbalanced topology into a balanced one, also provides impedance matching, required for proper operation of this antenna [2].

The unidirectional radiation pattern is required for some applications involving UWB systems. Thus, an usual solution to accomplish this, without compromising other features, is to use a metallic cavity filled with a microwave absorber material backed on one side of the spiral structure to reduce backward radiation. Usually, the distance between antenna and cavity bottom is approximately one-quarter guided wavelength at the center frequency of the operating band to improve antenna's gain [1].

This paper proposes the design of an unidirectional radiation compound spiral antenna with a backed cavity and fed with a tapered balun, which operates from 1 to 11 GHz. Radiation performances are simulated through full-wave electromagnetic simulation software ANSYS Electronics Desktop 2017 – HFSS®. A specific antenna structure together with its parameters are given and the experimental results are discussed. From these, an analysis confirms that the designed antenna is UWB compatible, keeping all its features including unidirectional radiation.

Lastly, a theoretical operation of the designed antenna in a Direction Finding (DF) system is described for the previously mentioned band. The approach employed in this analysis consists of using two squinted antennas to compare amplitudes of the signals received by them, and afterwards estimate the angle of arrival (AoA) of the incoming radio waves [3]. The results reveal that the designed antenna is suitable for application in DF systems based on amplitude comparison.

II. Theoretical Model

A. Parameters of the Compound Spiral Antenna

The proposed two-arm compound spiral antenna, designed by combining a typical equiangular spiral antenna with an Archimedean spiral line, is depicted in Fig. 1. The antenna is printed on a Rogers CuClad 250GX substrate ($\epsilon_r = 2.5,\ \tan\delta = 0.0018$) with 0.762 mm of thickness and 80 mm of diameter. As observed in Fig. 1, the inner region and outer region of the spiral are composed of an Archimedean and equiangular spiral, respectively [4]. As depicted in Fig. 1 the numbers of turns of spirals are $N_{Arc} = 7.2$ and $N_{Equ} = 6$, imposing internal (r_1) and external (r_2) radius values of $r_1 = 0.55\ mm$ and $r_2 = 37.95\ mm$. Both arms are terminated by a resistor of 130 Ω connected to the metallic cavity wall [1].

The unidirectional radiation pattern is obtained through the lossy metallic cavity backing the spiral antenna, as visualized in Fig. 1. To ensure a good UWB-like performance, two absorber material layers (ECCOSORB LS-22) were added inside the cavity, as illustrated in Fig. 1. The absorber layers thicknesses used are 3.175 mm and 18.7 mm, which are standard off-the-shelf values.

B. Balun Configuration

As presented in Fig. 2, a tapered balun is used in this design. The microstrip (MS) line turns gradually into parallel-strip (PS) line, thus performing the conversion of non-balanced to balanced feed. The approach uses the Hecken taper to define the shapes of balun's top and bottom lines, to achieve a good continuity between the two boundaries (MS and PS lines), which leads to a low reflection coefficient [2]. The substrate used was Rogers RT/duroid 5880 ($\epsilon_r = 2.2,\ \tan\delta = 0.0009$) with a 0.508 mm of thickness and length (L) of 74.95 mm.

This research was supported under scholarships from CAPES and CNPq, Brazil.

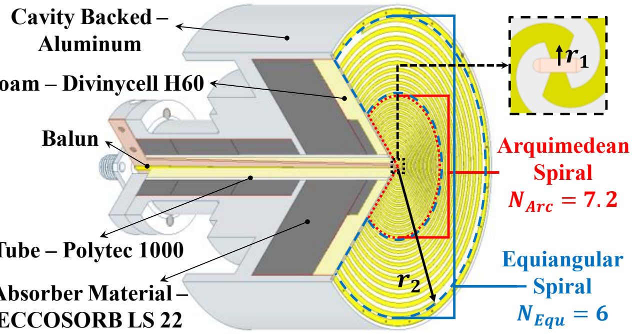

Fig.1. Geometry of the proposed compound spiral antenna simulated in HFSS.

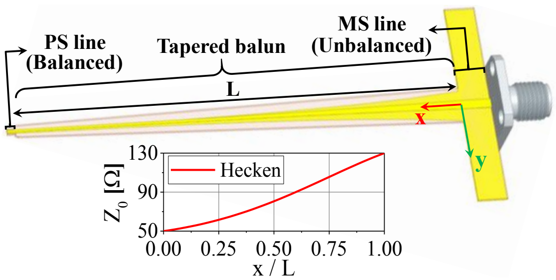

Fig. 2. Geometry of the proposed balun and its impedance profile.

III. Prototype and Experimental Results

A prototype photo is presented in Fig. 3a. Prototype measured reflection coefficient magnitude and broadside axial ratio (AR) are both depicted in Fig. 3b. It can be observed from Fig. 3b that the antenna presents a good impedance matching ($|\Gamma| < -9.5\ dB$) and low axial ratio ($AR < 3\ dB$) over all targeted frequency range (L- to X-band). Radiation patterns measured at low and high frequencies in *yz*-plane (Fig. 3a) are shown in Fig. 4.

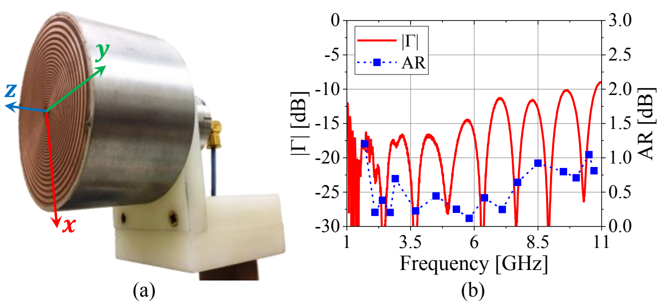

Fig. 3. (a) Prototype side view; (b) Measured reflection coefficient magnitude and broadside axial ratio.

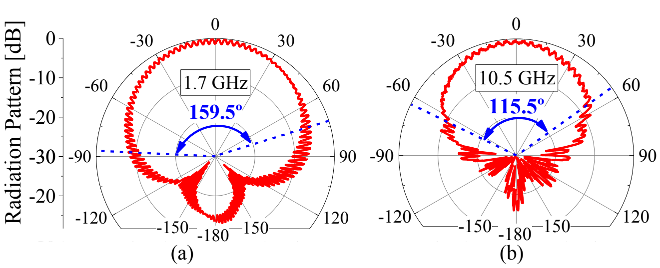

Fig. 4. Prototype's radiation patterns in *yz*-plane: (a) 1.7 GHz; (b) 10.5 GHz.

The preceding results confirm the expected unidirectional radiation pattern and also a low axial ratio ($AR < 3\ dB$) over a wide angular aperture – 159.5° (Fig. 4a) and 115.5° (Fig. 4b).

Another suitable feature that can be extracted from the symmetry of the radiation patterns is the small beam squint exhibited by the antenna. This is a result of the good balanced feed provided by the balun. These findings can also be noticed at intermediate frequencies as well as in other constant-phi planes.

IV. Direction Finding Performance

The described antenna can be used together with an identical twin in an Azimuth amplitude-only DF system as the one discussed in [3]. The main goals of such system are to achieve an RMS error smaller than 3° and to obtain a high DF function slope within the largest possible field of view (FOV) in Azimuth. Evidenced by simulations, it has been shown that squinting the antennas 40° off boresight meets this goal, as depicted in Fig. 5.

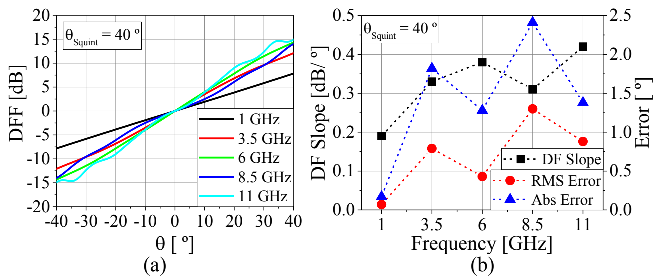

Fig. 5. Results of the antenna simulated in HFSS with squint of 40°. (a) DFF; (b) DF Slope, RMS Error and Absolute Error.

In Fig. 5a the simulated direction finding function (DFF) is plotted in 2.5-GHz steps. As observed, the DFF is almost a straight line within the unambiguous FOV of 70° for all analyzed frequencies. Also, it is noticeable that at the lowest frequency the antenna is less directive (Fig. 4a), increasing the FOV (Fig. 5a), but simultaneously decreasing DF slope (Fig. 5b). Finally, as seen in Fig. 5b, the main goal was achieved, since RMS error was smaller than 1.5° over all band of operation and the biggest absolute error was smaller than 2.5°. These results confirm that the DF system is able to estimate AoA of electromagnetic signals with good accuracy.

Final Comments

In this paper, a two-arm compound spiral antenna for L-/X-band direction finding applications was presented. The measured reflection coefficient magnitude, axial ratio, and radiation patterns in the frequency range of operation present a good performance, as predicted during the design phase. The proposed antenna was shown to be a good candidate for DF systems based on amplitude comparison, due to FOV obtained value of 70° with an RMS error smaller than 1.5°.

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