UWB Differentially-fed Circular Monopole Antenna with Stable Radiation Pattern

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***Abstract*—A small UWB circular monopole antenna with a differential feed is presented in this paper, as a solution to increase the stability of the radiation pattern of a single-fed circular monopole antenna. A detailed characteristic modes analysis is presented in order to support the selection of the feeding mechanism. Simulated active-S parameter is shown for the proposed antenna, showing a good matching for the UWB frequency range. Normalized surface current distributions are presented, and 3D radiation patterns are compared to a reference monopole. The antenna structure shows more stable and omnidirectional radiation patterns over the studied frequency range compared to a same sized single-fed reference monopole.**

***Index Terms*— Differentially-fed Antenna, Planar Monopole Antenna, Radiation Pattern Stability, Ultrawideband (UWB) Antenna, Small Antenna.**

I. INTRODUCTION

During the last decade, planar monopole antennas have shown great interest for UWB applications, since they present very attractive properties such us low profile, large impedance bandwidth, omnidirectional radiation pattern, low cost and easy construction [1].

Extensive investigations considering different shape geometries (square, rectangular, triangular, circular, elliptical, and so on) and/or feeding mechanism (double–fed, stepped or asymmetrical fed) have been carried out during these years, using 3D or 2D (coplanar) configuration for the monopole mounting [1]-[3].

Moreover, other similar antennas have been proposed latterly for UWB applications. These are printed wide slot antennas, which consist of a wide slot with some geometrical shape, etched in a finite ground plane and fed with a microstrip of coplanar waveguide (CPW) microstrip line terminated in a shaped stub [4]-[6]. Many designs have been proposed with different shapes geometries, showing very good behavior for UWB applications. Some experimental design guidelines have also been proposed for this kind of antennas [4].

Recently, some differentially driven printed wide-slot antennas have been reported, which provide UWB performance using a differential feeding mechanism, which eases antenna integration with differential wireless communications systems, providing better radiation pattern stability [7]-[9].

This paper presents a differentially excited monopole antenna with two antenna feeding ports, for UWB applications. The antenna is based on that presented in [10], which covered lower frequencies and where a detailed parametric study was made in order to investigate the influence of different geometrical parameters on the antenna performance.

The objective of the paper is to provide a design which increases the stability of the radiation pattern of a circular planar monopole (which usually presents a single port). An analysis based on characteristic modes (CM) will be performed, in order to support the selection of the feeding mechanism.

II. ANTENNA STRUCTURE

Fig. 1 presents the geometry of the proposed antenna with the coordinate system. As can be observed, the antenna consists of a circular planar monopole with two microstrip feeding lines inserted at the top and bottom of the planar structure. Small rectangular ground planes are inserted under the two feeding lines. The width of feeding lines is 2 mm, which is not exactly 50 Ω as the mutual coupling affects to the active impedance matching.

The antenna uses an air dielectric substrate ($\varepsilon_r = 1$) of thickness 0.6 mm. The antenna is fed by two 50 Ω discrete ports with the same amplitude but opposite phase, in order to create a differentially-driven antenna. Total dimensions for the proposed antenna are shown in Table I.

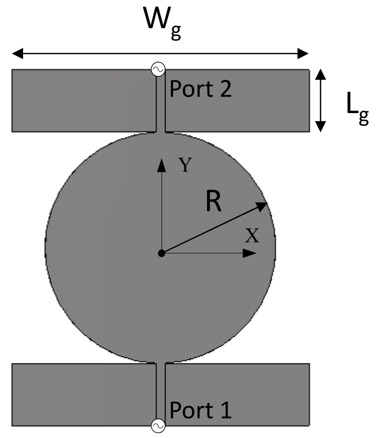


Fig. 1. Geometry of the proposed antenna with coordinate system.

TABLE I. DIMENSIONS OF THE DIFFERENTIALLY-DRIVEN CIRCULAR MONOPOLE

Parameter	W_g*(mm)*	L_g*(mm)*	*R (mm)*
Value	26	5,4	10

By means of the feeding configuration, vertical current distribution is reinforced in the structure. This method allows more stable radiation pattern than other current distributions, which may disturb the radiation pattern and polarization properties. In the next section a characteristic mode (CM) analysis will be performed in order to understand the physical radiating behavior of the antenna.

III. CHARACTERISTIC MODES ANALYSIS

In this section, the Theory of Characteristic Modes will be applied to study the radiating behavior of the proposed antenna.

A. *Characteristic Modes of a Circular Plate*

In Fig. 2, the current distribution of the first six CM of a circular plate of radius R=10 mm are shown. Characteristic angle variation with frequency is shown in Fig. 3 for the same modes.

As observed, eigenvector J_0 presents an inductive behaviour due to its current forming a closed loop over the plate. Eigenvectors J_1 and J_1' are degenerated modes presenting horizontal and vertical currents, while higher order modes J_2, J_2' and J_3 present increasing nulls along the perimeter of the plate.

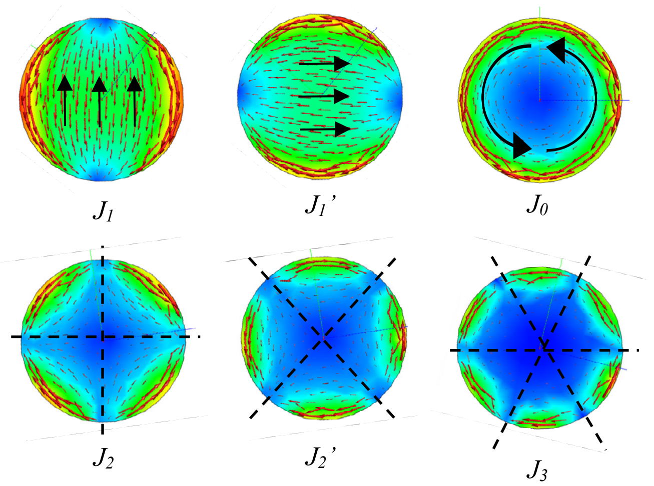


Fig. 2. Surface current distribution of the first six CM for a circular plate of radius R=10 mm. Black arrows represent the direction of the current flow, whereas dashed lines denote nulls in the current distribution.

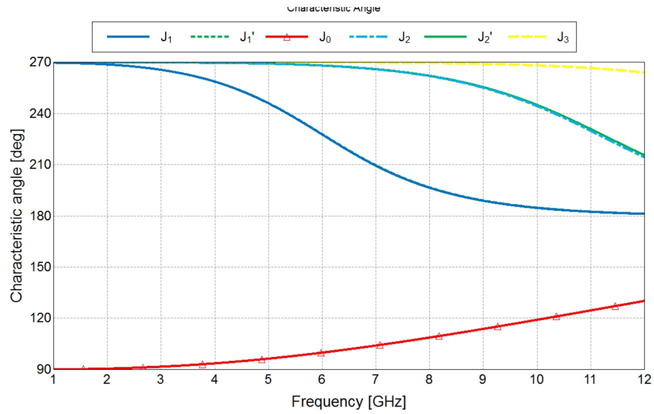


Fig. 3. Characteristic angle versus frequency for a circular plate of R=10 mm.

As presented recently in [11], a modal parameter can be used to assess the stability with frequency of the radiation pattern of each CM. This parameter, called Modal Pattern Stability Factor (*MPSF*), shows that mode J_1 of a circular plate exhibits a radiation pattern with increased stability when compared to other geometries such as square, or square with truncated corners, for vertical polarization [11].

Therefore, the aim is to excite mode J_1 in the circular plate in order to exhibit increased stability in the radiation pattern. With that purpose, two ports located at the top and bottom of the circular plate are used with 180º phase shift (differential feeding), in order to force excitation of mode J_1 and prevent the excitation of other modes.

B. *Characteristic Modes of a Circular Plate with Two Ground Planes*

In order to differentially excite the circular plate at two points, two microstrip ports are used, as shown in Fig.1. In this section, a new CM analysis will be performed for the whole structure (circular plate with two rectangular plates acting as ground planes).

Fig. 4 shows the current distribution for the first nine CM of the differentially-fed antenna. Fig. 5 presents the characteristic angle variation with frequency associated to previous modes and, as observed, the number of CM within the analyzed frequency range increases with respect to those shown in Fig. 3 due to the combination of the CM of the circular plate with those of the ground planes. Moreover, as observed in Fig. 5, most of the modes decrease their resonant frequency due to the presence of the rectangular ground planes.

CM are independent of the excitation. Thus, if a differential feeding mechanism is used at the two ports, then modes with vertical current distribution at the circular plate will be excited. Therefore, it is expected that only modes J_1 and J_7 will be excited in the structure when using a differential feeding excitation.

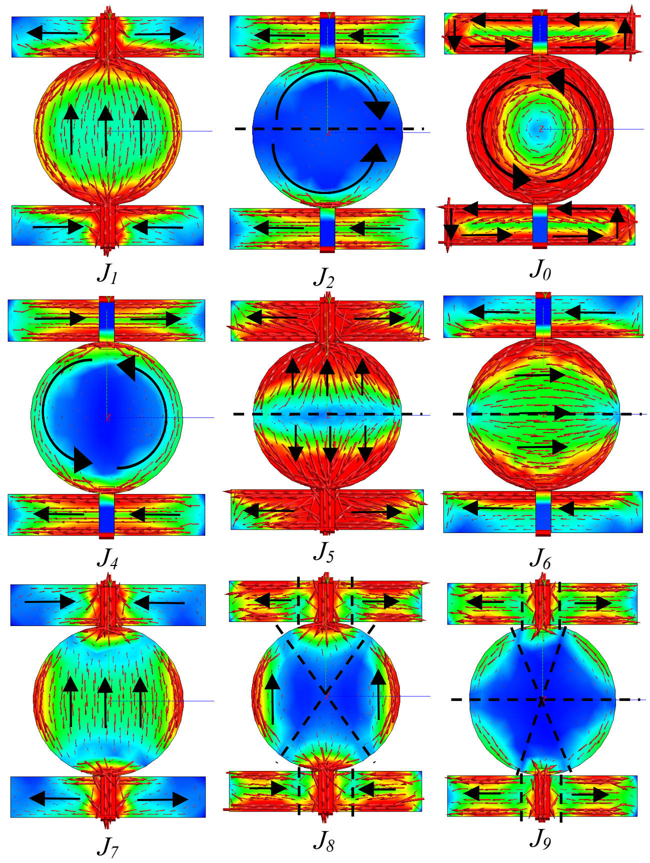


Fig. 4. Surface current distribution of the first nine CM of the proposed antenna. Black arrows represent the direction of the current flow, whereas dashed lines denote nulls in the current distribution.

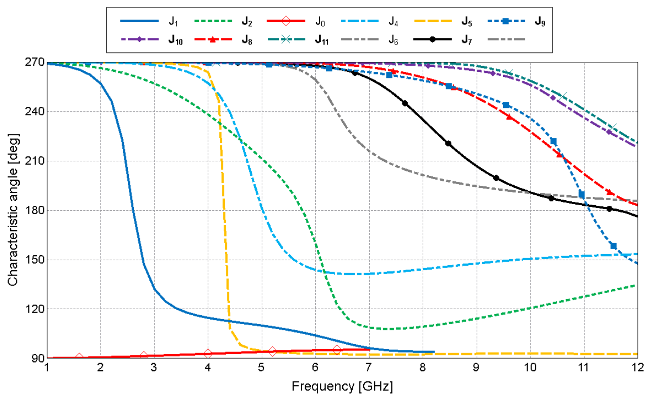


Fig. 5. Characteristic angle versus frequency for the first nine CM of the antenna proposed in Fig.1.

C. Excitation of Characteristic Modes in the Proposed Structure

Fig. 6 illustrates the contribution of each mode to the total power radiated by the antenna when using the differential feeding configuration. As observed, differential feeding facilitates the excitation of modes exhibiting vertical current distribution. Thus, mode J_1 is excited up to 7 GHz, whereas mode J_7 is excited from 7 GHz on. A small contribution of mode J_8 is also present at higher frequencies.

Fig. 7 shows the radiated far field associated to modes J_1 and J_7 at different frequencies within the operating band. As observed, modal radiated far field varies over the frequency range, being the total radiated field a linear combination of these modal fields.

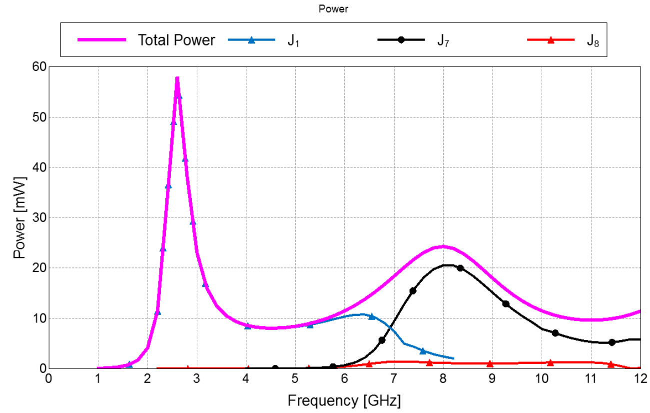


Fig. 6. Contribution of CM to the total radiated power of the antenna shown in Fig. 1.

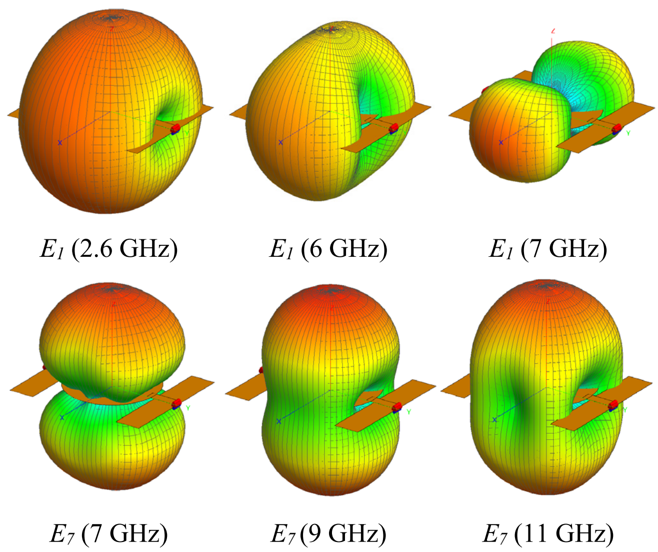


Fig. 7. Modal radiation pattern (E_m) associated to modes J_1 and J_7 at different frequencies.

IV. RESULTS

In this section, the simulated results of the studied antenna structure are presented. First, the S-parameters and Active S-parameters, defined as S_{11} - S_{12}, are given. Then, the surface current distributions in XY-cut and 3D radiation patterns are presented and compared to a monopole structure with a single feed. CST Microwave Studio 2015 was used in the simulations.

A. *Simulated S-Parameters and Active S-Parameters*

Fig. 8 presents the simulated S-parameters and Active S-parameters or Differential S-parameters, as defined in [9]. Since the antenna structure is symmetrical, S-parameters of Port 2 are the same as Port 1.

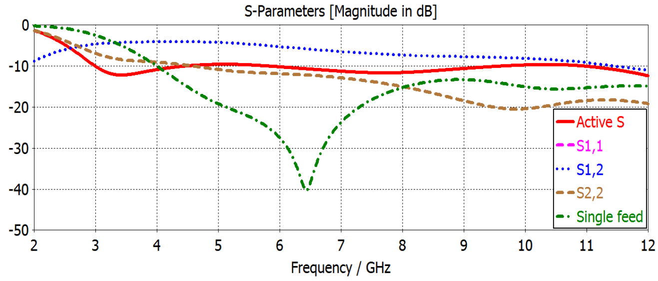


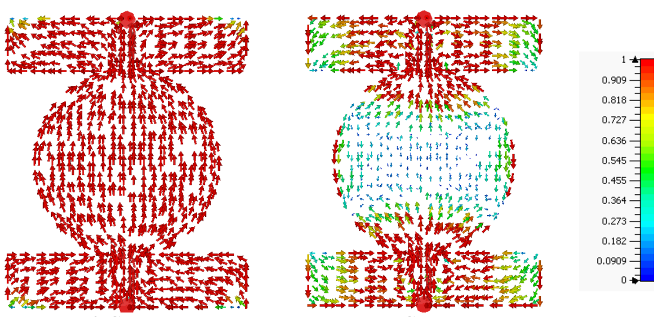
Fig. 8. Simulated Active S-parameter and S-parameters of the UWB antenna.

As it can be observed, Active S-parameters presents -10 dB reflection coefficient bandwidth from 3 GHz to more than 12 GHz, covering then UWB frequency range. As it can be noticed, the S_{11} and S_{22} have the same performance, since the structure is symmetrical. As expected, the S_{12} (equal to S_{21}) is very high between the ports, but when the ports are differentially fed, the mutual coupling between the ports is interesting.

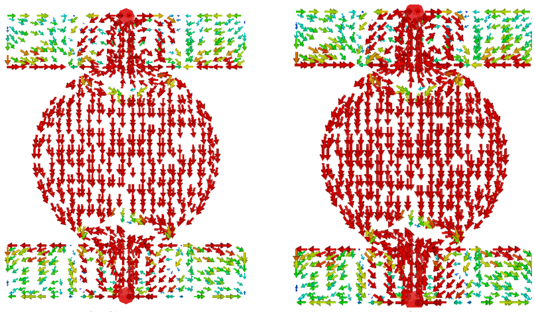
In Fig. 8 it can also be seen a curve for the single-feeding case. The curve represents the same antenna structure as that presented in Fig. 1 and with the same dimensions, but with only one rectangular ground plane and feeding line. In this case, the antenna only has one port, Port 1, and, thus, it is a typical circular monopole antenna. The single-fed monopole is a reference case to the differentially driven one, and as it can be observed, the benefit for differentially fed monopole is additional bandwidth, as well as a significant increase in the stability of the radiation pattern, as it will be seen in next section.

B. *Simulated Surface Current Distributions and Radiation Patterns*

In this section, the simulated surface current distributions and radiation patterns are presented. Fig. 9 presents the normalized surface current distributions of the studied differentially fed antenna at 3, 5, 9 and 11 GHz. As it can be observed, even higher order modes are woken, the excitation only excites radiating modes which are vertically polarized.



3 GHz 5 GHz



9 GHz 11 GHz

Fig. 9. Normalized total current distribution on the antenna shown in Fig. 1.

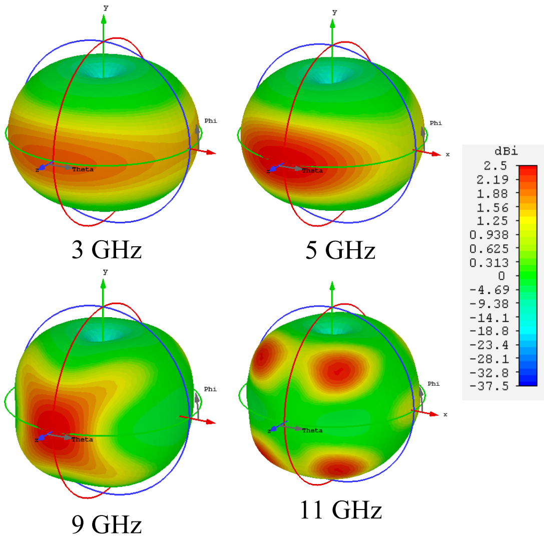


Fig. 10. Simulated 3D radiation patterns of the differentially-fed antenna shown in Fig. 1.

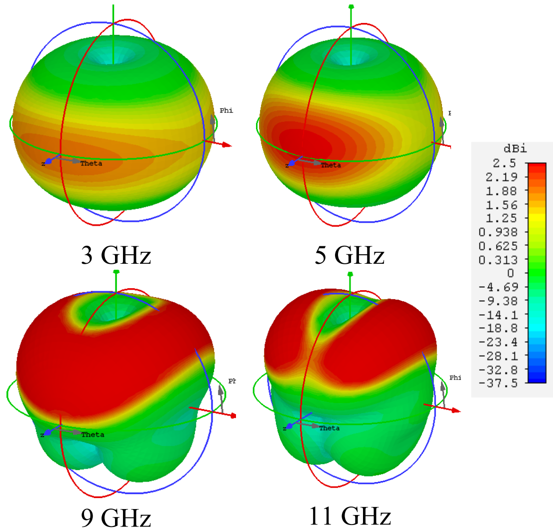


Fig. 11. Simulated 3D radiation patterns of a single-fed circular planar monopole antenna.

Fig. 10 presents the 3D radiation patterns of the differentially driven antenna studied in this paper for different frequencies within the operating frequency range.

For the sake of comparison, Fig. 11 presents the radiation patterns of the single-fed circular monopole antenna described in Section IV.A. As it can be observed, the differentially driven antenna has more stable, symmetrical, and omni-directional radiation pattern over the studied operating bandwidth, compared to the single-fed reference monopole. Since a monopole is not a symmetrical structure, it has more directivity to the Y direction. The maximum gain varies between 2 and 5 dBi, depending on frequency. But for example in the direction of X, the gain varies only by 1 dB over the frequency range.

V. CONCLUSIONS

This paper presented simulation results for a UWB differentially driven monopole antenna using air dielectric substrate. A characteristic mode analysis has been performed in order to explain the radiating behavior of the antenna and support the use of the differential feeding to increase pattern stability. Then, it is shown that by using differential feeding, the radiation pattern is more stable and omnidirectional compared to a single fed monopole. By using differential feed, the vertical radiating modes can be excited to obtain very large bandwidth.

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