Design of Microstrip Monopoles for Broadband Systems Using an Iterative Wave Formulation

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***Abstract*—This paper presents the analysis of microstrip monopoles for applications in ultra wideband systems (UWB). Antenna structures using circular and semi annular ring patches are considered. The antennas are printed on a FR4 dielectric substrate and present truncated ground planes with a small cut beneath the microstrip line feeder to improve the antenna impedance matching. Results for return loss, resonant frequency, and impedance bandwidth are calculated using an iterative full-wave formulation based on the concept of electromagnetic waves (WCIP Method) and simulated using Ansoft HFSS software. Prototypes are fabricated and measured for validation purpose. Agreement is observed between WCIP calculated, HFSS simulated and measured results, confirming the WCIP method accuracy. The performance of the developed antennas are suitable for UWB and broadband systems.**

***Index Terms*—microstrip antenna, microstrip monopole, ultrawide band, UWB, iterative method, WCIP.**

I. INTRODUCTION

The development of modern wireless communication systems has required the development of compact circuits, such as printed circuits [1], [2], including microstrip antennas, to perform a large number of service applications with higher transmission and reception rates. Usually, a microstrip antenna is composed of a conducting patch printed on a dielectric substrate which is mounted on a ground plane. Usual formats of the microstrip conducting patches are rectangles, circles, regular polygons and complex geometries as fractals or quasi-fractals.

Recently, a special attention has been given to the development of UWB antennas, for applications in the range from 3.1 to 10.6 GHz [3], [4]. UWB devices and circuits require large bandwidths, which causes their emission to spread the spectrum overlapping with various radio services.

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This work presents a study of microstrip monopoles with circular and semi annular ring patch geometries with truncated ground planes for UWB applications. Numerical results are calculated using WCIP method and simulated through Ansoft HFSS software.

The WCIP method is a full-wave iterative formulation based on the process of reflection and transmission of waves on the circuit interface. Lately, the WCIP method has been widely used for designing and characterizing several planar circuits, as microstrip antennas [5], filters [6] and frequency selective surfaces [7], [8].

Results for the return loss versus frequency, resonant frequency, and impedance bandwidth are calculated using WCIP method and simulated through HFSS software. Prototypes were fabricated for the purpose of experimental validation and good agreement between calculated, simulated, and measured results is verified.

II. ANTENNA DESIGN

The microstrip antenna geometries investigated in this work are shown in Fig. 1.

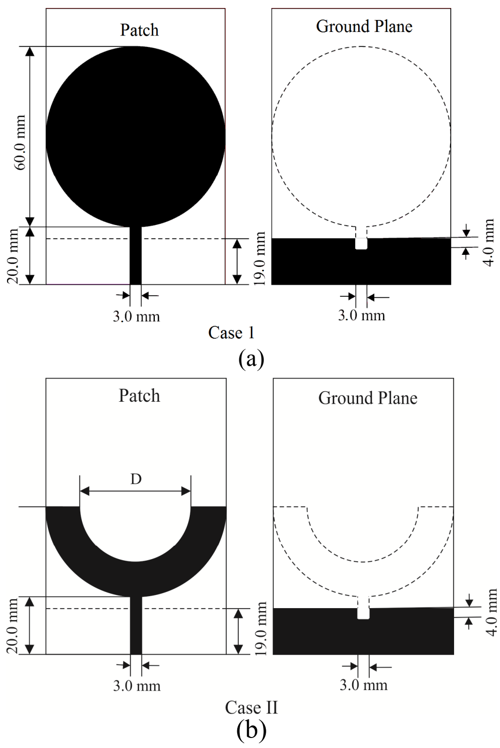

Fig. 1. Analyzed microstrip antenna geometries with (a) circular patch and (b) semi annular ring patch.

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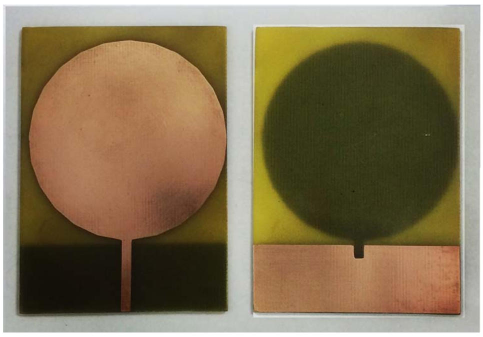
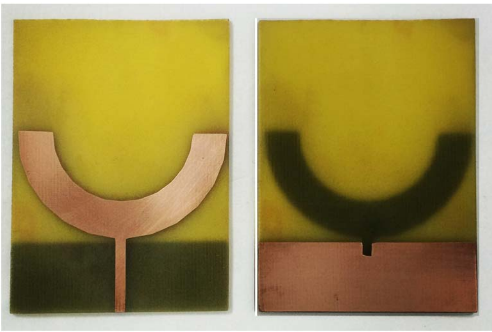
Fig. 1(a) shows the reference antenna, which consists of an antenna with a circular patch with radius of 30 mm and a truncated ground plane with a small rectangle cut beneath the microstrip line antenna feeder.

Fig. 1(b) shows the semi annular ring antenna geometry. It is formed removing the upper half of the circular patch (Fig. 1(a)) and then removing a semicircular slot at the antenna patch, constituting a semi annular ring patch antenna. The antenna is printed on a FR4 dielectric substrate with relative permittivity $\varepsilon_r = 4.4$ and thickness $h = 1.57$ mm. The antenna dimensions are shown in Fig. 1. The patch is fed by a 50 Ω microstrip line. Fig. 2 shows the fabricated antennas prototypes used for experimental characterization.

Fig. 2 shows the antennas prototypes used in the experimental characterization.



(a)



(b)

Fig. 2. Microstrip antennas prototypes with: (a) circular patch and (b) semi annular ring patch.

III. WCIP Formulation

Wave concept iterative procedure (WCIP) is an iterative numerical technique used in planar microwave circuit analyss [5]-[9]. It is based on the ratio of transmission and reflection of incident, $\vec{A}_i$, and reflected, $\vec{B}_i$, electromagnetic waves at the circuit interface that is being analyzed. These equations are given in (1) and (2).

$$\vec{B}_i = \hat{S}\vec{A}_i + \vec{A}_0 \quad (1)$$

$$\vec{A}_i = \hat{\Gamma}\vec{B}_i \quad (2)$$

Equations (1) and (2) represent the basic equations of the WCIP formulation. Equation (1) represents the interface circuit effect on the relationship between $\vec{A}_i$ and $\vec{B}_i$ waves. The scattering operator $\hat{S}$ takes into account the boundary condition in each region of the circuit interface [8]. It is defined by imposing the electromagnetic field continuity conditions at different media: conductors, dielectrics, loads and sources.

Equation (2) represents the influence of the media around the analyzed interface circuit. The reflection operator $\hat{\Gamma}$ is defined in the modal domain and takes into account the propagation conditions of the media around the circuit is interface.

The iterative process of the WCIP method is defined by the transformation between spatial and modal domains. Equations (1) and (2) are calculated at each iteration step until convergence is reached. Transformation between spatial and modal domains for the field components is done using the Fourier transform.

IV. Results And Discussion

Firstly, a parametric analysis of the antenna was done to investigate the effect of the parameter function D (shown in Fig. 1(b)) on the antenna frequency behavior. It has been observed that parameter D has presented a little influence in the antenna bandwidth, but affects the least value of the return loss (s_{11}) parameter in the investigated frequency range, as shown in Fig. 3. For the antenna shown in Fig. 1(b), the optimized value for D is 20 mm, which improves the antenna input impedance matching.

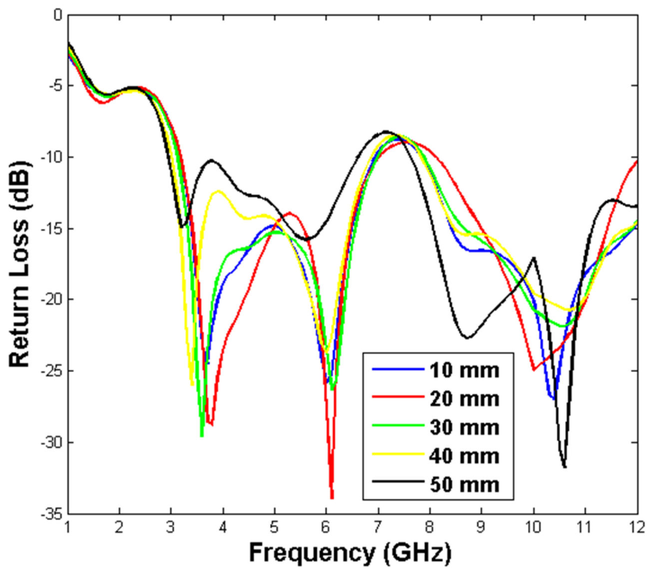
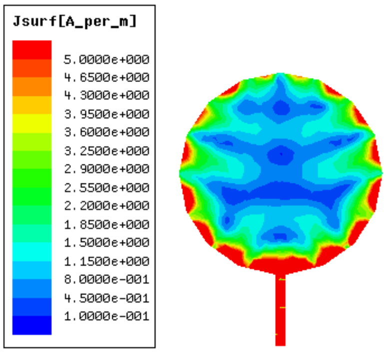
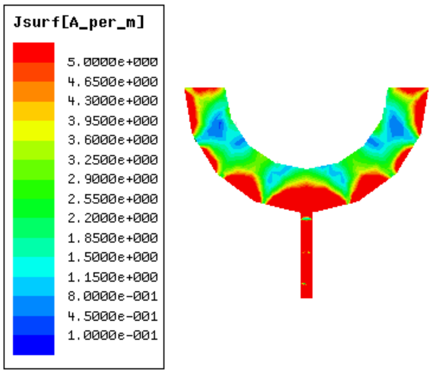


Fig. 3. Return loss simulation and measurements results for the antenna shown in Fig. 1(b), for different values of D (in mm).

Fig. 4 shows results for the surface current densities for the antennas shown in Fig. 1. Observe that higher current densities are concentrated at the edges of the circular patch and semi annular ring patch. Therefore, changes made at the central region of the antenna patch have little influence on the behavior of the antenna frequency response. This shows the low dependence of the return loss on the antenna dimension D. In addition, it has been observed that the antenna frequency response is affected only for higher values of D, about 50 mm.



(a)



(b)

Fig. 4. Surface current densities on the patches of the monopoles microsprip antennas shown in Fig. 1.

Fig. 5 shows the simulation results for the antennas in Fig. 1. For the circular patch antenna in Fig. 1(a), a dual band frequency response is observed. The first one ranges from 2 to 2.7 GHz and the second one from 3.6 to 12 GHz. For the semi annular ring patch antenna in Fig. 1(b), a dual band frequency response is observed. The first one ranges from 3.1 to 6.8 GHz and the second one from 7.9 to 14 GHz. Therefore, these antennas are good candidates for UWB systems and for some frequency bands used on satellites, as C and X bands. In all cases, a -10 dB s_{11} reference level was used.

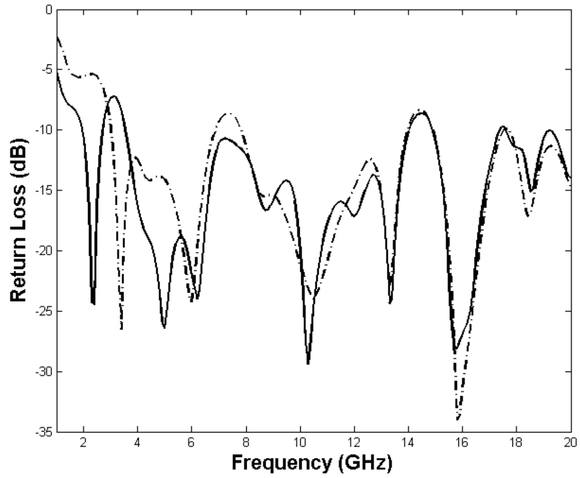


Fig. 5. Simulation return loss results for the circular patch (——) and semi annular ring patch (–·–·–) antennas.

Fig. 6 shows a comparison between measurements and simulation results for the antennas in Fig. 1. At the first resonant frequency for the antenna shown in Fig. 1(a) is 2.5 GHz for WCIP simulation; 2.4 GHz according to HFSS simulation, and 2.31 GHz according to the measurements. The corresponding simulated and measured bandwidths are 0.70 GHz (WCIP), 0.70 GHz (HFSS), and 0.63 GHz (measured). For the second resonant frequency, the antenna presented ultrawide band performance, with the following bandwidths results: 8.4 GHz (HFSS), 8.2 GHz (WCIP) and 8.5 GHz (measured); which are in good agreement.

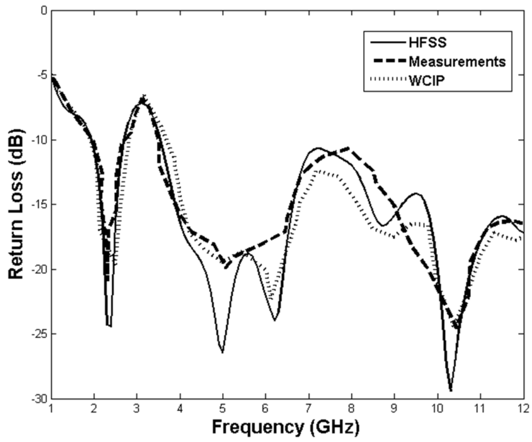


Fig. 6. Simulation (WCIP and HFSS) and measured return loss results for the circular patch antenna.

Fig. 7 shows simulation and measurements results for the monopole antenna configuration shown in Fig. 1(b). In this case, the antenna presented a dual band frequency response performance, operating in two different frequency bands within the whole UWB band.

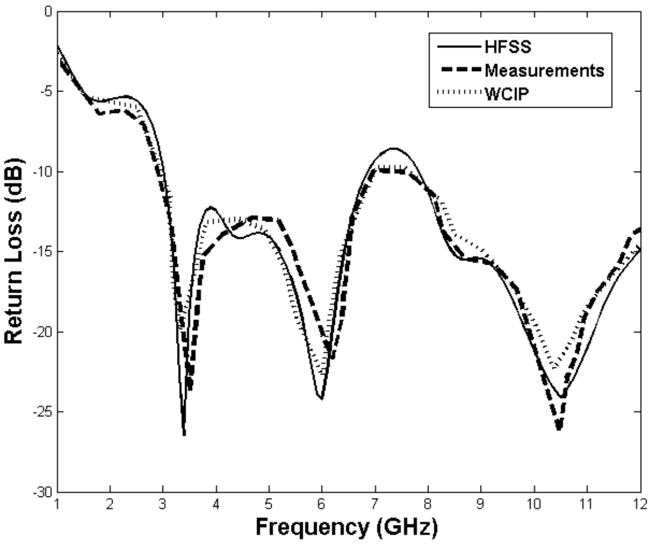


Fig. 7. Simulation (WCIP and HFSS) and measured return loss results for the semi annular ring patch antenna.

As shown in Fig. 7, the antenna presents a dual band response in the considered frequency range. At the first resonance, bandwidths simulated and measured results are 4 GHz (using WCIP), 3.8 GHz (through HFSS software), and 3.1 GHz (measured); which are in agreement. At the second resonance, bandwidths simulated and measured results are 4.4 GHz (using WCIP), 4.1 GHz (through HFSS software), and 4.4 GHz (measured); which are in agreement.

Tables I and II summarize the frequency responses for antennas shown in Figs. 1(a) and 1(b), respectively.

TABLE I. RESONANT BANDS FOR THE MONOPOLE MICROSTRIP ANTENNA WITH CIRCULAR PATCH

	Antenna Frequency Ranges	
	1rst Resonance Band (GHz)	**2nd Resonance Band (GHz)**
HFSS	2.0 to 2.70	3.6 to 14
Measurements	2.0 to 2.63	3.5 to 14
WCIP	2.1 to 2.80	3.8 to 14

TABLE II. RESONANT BANDS FOR THE MONOPOLE MICROSTRIP ANTENNA WITH SEMI ANNULAR RING PATCH

	Antenna Frequency Ranges	
	1rst Resonance Band (GHz)	**2nd Resonance Band (GHz)**
HFSS	3.0 to 6.8	7.9 to 14
Measurements	2.9 to 7.0	7.6 to 14
WCIP	3.0 to 7.0	7.6 to 14

V. CONCLUSION

A numerical characterization of monopoles microstrip antennas with circular and semi annular ring patches was presented and discussed. The analysis was performed using the WCIP method. The use of the truncated ground planes resulted in broadband characteristics for the investigated antennas geometries. The insertion of slots and changes in the patch structure provided notches at particular frequency ranges, isolating the antennas resonance bands. Simulation results (through HFSS software) and measurements results were compared to the WCIP method results showing good agreement.

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