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A Modified Ultra Wide Band Antenna With Metamaterial Patterns for Telecommunications Systems

***Abstract**. In this work, an ultra wide band antenna is modified with periodic structures in order to improve its performance, in terms of gain, bandwidth and resonance. Basically, three topologies are used (Jerusalem cross pair, fractal and tripolar array).The main idea is improve its performance without increase its dimensions which could compromise their application in telecommunications systems especially mobile devices.*

Streszczenie.** W artykule zaprezentowano projekt ultra szerokopasmowej anteny z periodyczną strukturą w celu optymalizacji wzmocnienia, pasma I rezonansu. Testowano trzy topologie – para krzyży Jeruzalem, struktura fraktalna i układ trzybiegunowy. **Zmodyfikowana antena szerokopasmowa z wzorem z metamateriału w zastosowaniu do telekomunikacji

Keywords: antennas. UWB. metamaterial. telecommunications systems.
Słowa kluczowe: antena szerokopasmowa,.telekomunikacja, metamateriał

Introduction

The planar antennas are a great advance in microelectronics, due to its easy fabrication, compact dimensions and low costs. However, these structures have some characteristics that limit their use in some applications. Known for its small size, easy installation, among other advantages, the planar antennas have low gain and a narrow bandwidth. Patch antennas are typically narrow band, with a bandwidth around 2% [1]. Even though the efforts and researches, the maximum improve is achieved with multilayer substrates [2].

The main purpose of introducing the metamaterials on the structure of a planar antenna is to refine these limitations by producing effects on the bandwidth, increasing the gain or creating regions of rejection. The metamaterials have properties such as negative refraction, and when inserted into the substrate, near the structure of a planar antenna, it can get results that optimize the characteristics of these devices.

Actually, metamaterial is a macroscopic composite of periodic or non-periodic structure, whose function is due to both the cellular architecture and the chemical composition [3]. Therefore, the behavior of a material, in the presence of an electric field, is determined by the macroscopic parameters, permittivity ε and permeability μ. Several metamaterial structures have been investigated along the last years. In particular, ones those are capable to provide artificial magnetic responses and electric walls.

The artificial magnetic conductors can be obtained when a plane wave focus on the capacitive gap, while the artificial electric conductor is obtained through the opposite way.

In fact, the metamaterial pattern is applied to physical devices aiming to obtain specific responses. In [4] a CSRR structure is employed to a UWB antenna in order to provide a rejection characteristic in a desired frequency. On the other hand, in [5] metamaterial structures are applied to an UHF antenna and a better gain is obtained, while in [6] the periodic structures are applied to the septum of a GTEM – Gigahertz Transverse Electromagnetic chamber, expecting a shift on the resonance frequencies.

In this context, to improve the performance in terms of gain, bandwidth and resonance, of a know UWB antenna for telecommunications applications, three different topologies were employed. It is worth mentioning that the performance of the antenna is improved maintaining the same dimensions, thus, do not compromising its applications in telecommunications applications. The CST Studio design tool, which is based on Finite Integration Technique (FIT), was employed for the design and analysis of the proposed structures. Experimental results are compared to the simulated ones.

UWB Patch Antenna

Planar antennas, by its nature, show some advantages when compared to the conventional microwave antennas. The main advantages are related to their design, they are light, thin and can easily take sizes suited to mobile devices. Furthermore, it does not require complex in their manufacture, resulting in a low cost antenna. The planar antenna can be easily implemented in integrated circuits and microwave power lines so as impedance matching can be manufactured simultaneously with the antenna structure [2].

The UWB - Ultra Wideband antenna, has as main characteristic the possibility of high data transmission rate. So, it can attend several applications, such as radar, military, commercial, medical systems and in mobile communications devices. To transmit high data rates, a wide bandwidth is essential to avoid interference in the transmission, but the bandwidth is a limiting factor of planar antennas. In this context, a circular shape of UWB antenna was modified with metamaterial patterns in order to overcome the limitation of its bandwidth, resonance and gain.

The UWB antenna was built in Rogers RO4003 substrate with εr = 3.55 and thickness of 0.81 mm. The copper layer has 0.035 mm of thickness. The dimensions of the fabricated UWB antenna are shown in Fig.1. The ground plane has a hole with height of 1 mm and width of 4 mm, symmetrically located.

Metamaterial Pattern

The electrical and magnetic properties of materials in relation to the electromagnetic field are characterized by the constitutive parameters permittivity (ε) and magnetic permeability (μ), respectively. Together, these two parameters determine the response of a material in the presence of an electromagnetic radiation [7]. In common materials found in nature, both parameters assume positive values. However, in metamaterials both ε as μ are negative and thus take a class called DNG (Double Negative). Therefore, the metamaterial technology is represented by periodic structures that are implemented with different shapes and sizes in order to attend several applications.

The fractal topology is one of the most known metamaterial pattern. Its unitary cell has the H format as its main characteristic, and have four levels of branching, being the fractal pattern generated by a main line, as can be seen in Fig. 2(a). The main advantages of fractal cell are its sub-wavelength properties, simple architecture and its wide application. The sub-wavelength allows the system to have a smaller size when compared with the wavelength along all resonance directions. Thus, the cell can behave as a compact reflector.

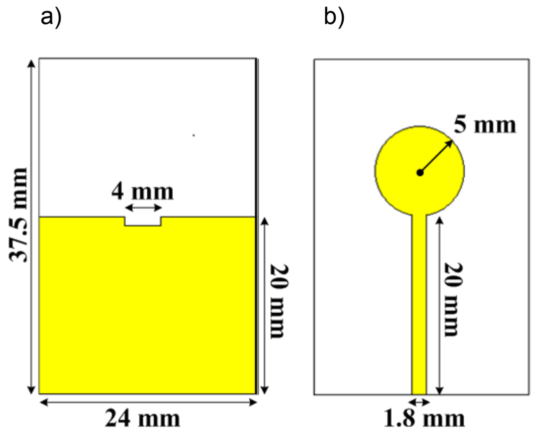

Fig. 1. Circular UWB antenna: a) bottom side; b) top side.

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On the other hand, the JCP pattern consists of periodic structures where its unit cells are based on the concept of a pair of crossed wires in a cross shape as shown in Fig.2(b). Thus, such structures are applied in strategic positions in order to act in devices that operate in the microwave and optical bands. This configuration shows modes of electric and magnetic resonance with negative permittivity and permeability, and thus negative refraction as expected metamaterials [8]. This pattern consists of sets of pairs of Jerusalem crosses coupled, so that, due such symmetry these structures show an isotropic response for any incident wave.

Thus, for any orientation of the incident magnetic field, an induced loop current comes near the displacement current at the external arms, because the perpendicular component of the field in relation to the area between the central arms of the crosses of Jerusalem. Although the JCP unitary cell be symmetrical, the surface current in the two conductors is asymmetrical [8], thus generating a current loop that can be represented by an equivalent magnetic dipole. With this magnetic moment is expected a negative resonance effect , which indeed proves the artificial behavior of such structure.

The tripolar array, Fig. 2(c), is generally developed for mobile applications which require small and thin structures . The set of tripolars is arranged in two layers, so that its grouping is modeled in the hexagonal shape. The symmetry of the tripolar provides an isotropic response to any incident wave, and it can be expected that this transmission property, in somehow, be preserved when the incident wave is tilted away from the normal incidence [8]. In this work, the dimensions of the adopted unitary cells are presented in [7-8].

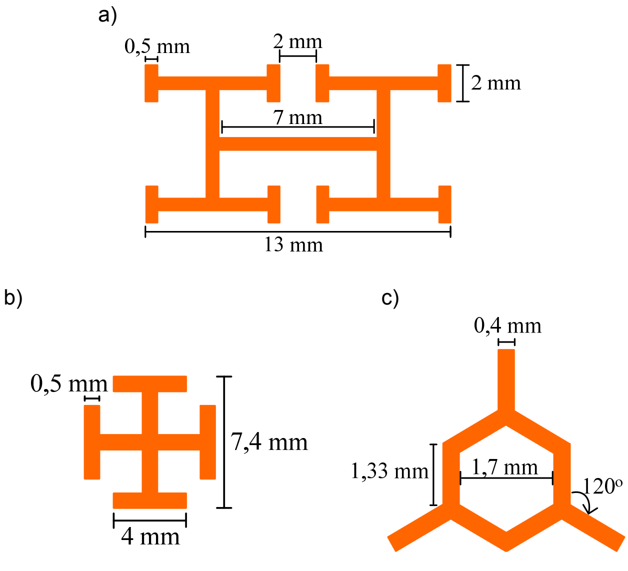

Fig. 2. a) unitary fractal cell; b) unitary JCP cell; c) tripolar array.

Results

The fractal cell was applied in two ways in the UWB antenna, being added to the substrate surface with the same metal thickness, and forming a cavity in the ground plane. In this first configuration, the fractals cells are positioned close to the UWB antenna. Both configurations can be seen in Fig. 3. Comparing the results of the S11 parameter of the conventional UWB antenna and with the configuration where the fractal cells are placed at the top of the antenna, we can see a transfer of the highest frequency resonance from 7 GHz to 10 GHz, Fig. 4, and thus the creation of a rejection band in the range 3-8 GHz.

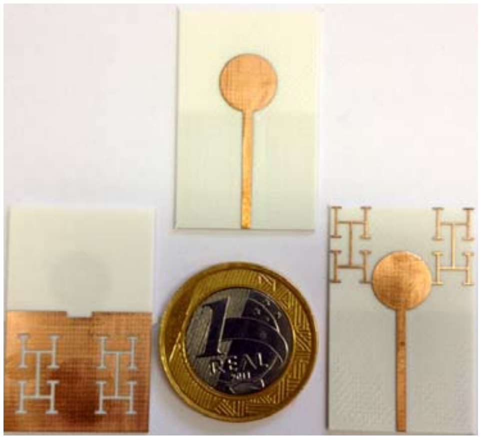

Fig. 3. Fractal cells applied to the UWB antenna in two different configurations - Fractal cells at the ground plane and fractal cells at the top of the antenna.

Figure 5 shows the UWB antenna with fractal cells positioned 2 mm from the side edges of the substrate and 4 mm from the upper edge of the ground plane forming a cavity. This configuration generated a rejection band until 7 GHz and the resonance was shifted to 13 GHz.

The JCP metamaterial structure was applied to the UWB antenna exactly at the center of the antenna circle in order to make a cavity with the same metal thickness. This setting increased the gain in two frequencies, 5.1 GHz and 10.6 GHz and created a region of rejection between 7 and 8.6 GHz, as can be seen in Fig. 6.

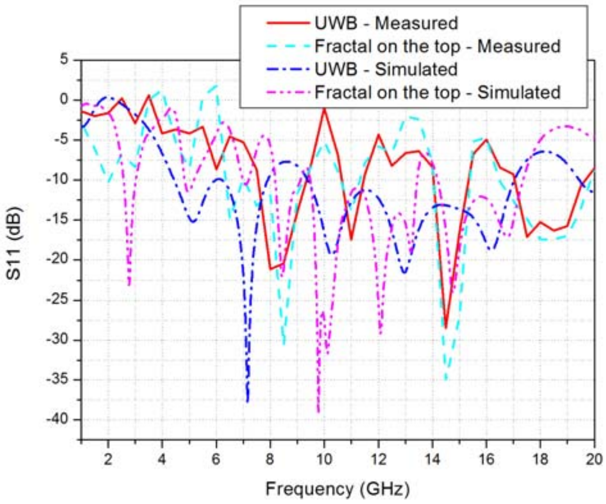

Fig. 4. S11 comparison for the UWB with and without fractal cells at the top.

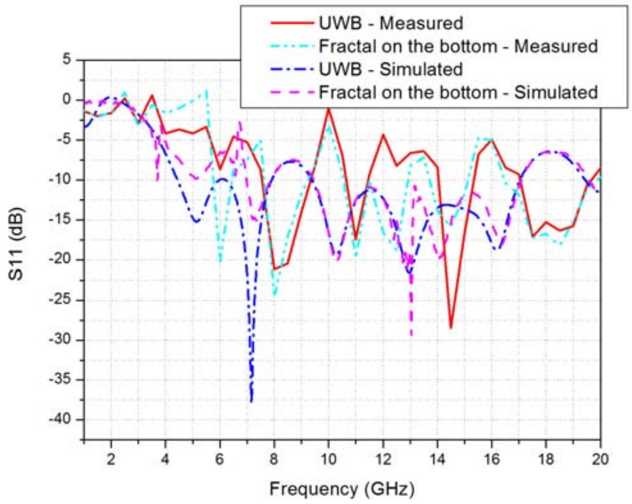

Fig. 5. S11 comparison for the UWB with and without fractal cells at the bottom (ground plane).

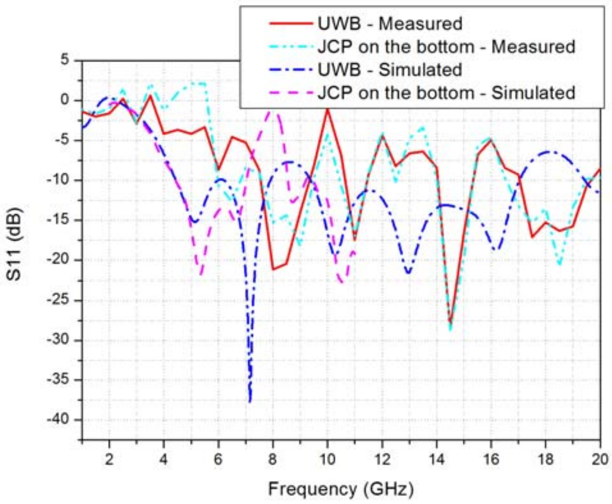

Fig.6. S11 comparison for the UWB with and without JCP cell at the top.

The tripolar array was applied in two ways, at the top and bottom of the UWB antenna as can be seen in Fig. 7. At the top, the tripolar array was arranged to form two lines located 1 mm diameter from the antenna. By the other side, when it was applied at the bottom, the tripolar array was placed along the ground plane in order to create cavities.

The first topology with tripolar array at the top (Fig.8) generated a shift on the S11 parameter, and increased the bandwidth in some frequencies, compared with the behavior of the non metamaterial antenna. The bandwidth has increased by 0.8 GHz, in the 8 to 17 GHz frequency range.

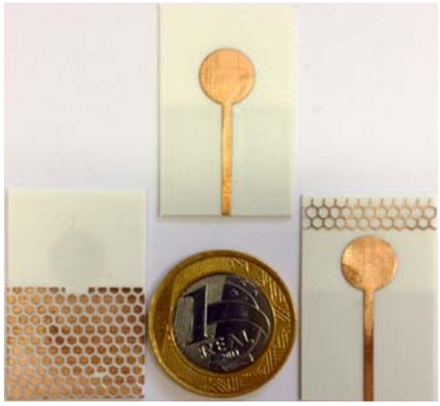

Fig. 7. tripolar array applied to the UWB antenna in two different configurations - tripolar array at the ground plane and at the top of the antenna.

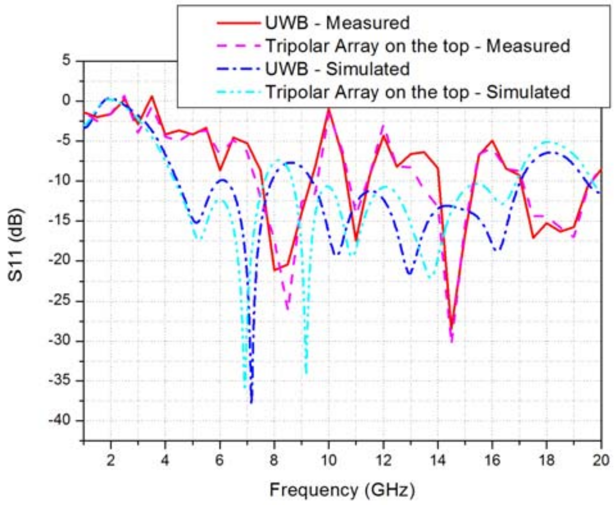

Fig. 8. S11 comparison for the UWB with and without tripolar array at the top.

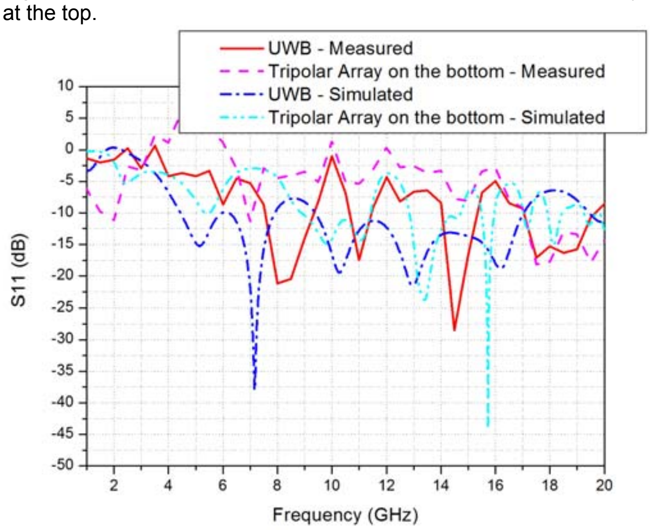

Figure 9: S11 comparison for the UWB with and without tripolar array at the bottom (ground plane).

When the tripolar array is applied to the ground plane, it can observe a rejection band from 1 to 10 GHz, and the shifted of the main resonance to approximately 11.4 GHz, as shown in Fig. 9. To organize in a clearer way, the main obtained results were organized in Table I.

Table 1. The influence of metamaterial patterns applied to the UWB antenna.

	S11 (dB)	Best Resonance (dB)	Bandwidth (GHz)
Original UWB	7	-38	7.5
Fractal at the top	10	-39	3.9
Fractal at the bottom	13	-30	7.5
JCP cell	5	-25	7.1
Tripolar array at the top	6.7	-34	8.3
Tripolar array at the bottom	11.3	-30	4.5

Conclusions

Periodic structures are widely used in order to provide different behavior on devices that operate in high frequencies. Some of them, are capable to change the constitutive parameters ε and μ, so that, the incident wave can assume a different behavior. As soon as the constitutive parameters are not positive anymore, this materials are known as metamaterials.

In this work, an ultra wide band antenna was improved in terms of gain and bandwidth with the metamaterial technology. This could be achieved without any change on the dimensions of the antenna, which represents economy in terms of material, and do not compromise their application in telecommunications systems, especially in mobile devices. Both bandwidth and gain were improved with the use of the metamaterial patterns.

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