The Metamaterial Technology Applied to Planar Antennas

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Abstract— In this work, metamaterials structures are applied to electromagnetic devices in order to improve its performance, in terms of gain, bandwidth and resonance. Basically, three topologies are used (fractal, Jerusalem cross pair and tripole array), in two different planar antennas: Yagi-Uda and Quasi-Yagi. The obtained results show the expected changes on the behavior of the analyzed devices, in order to prove the metamaterial efficiency in high frequencies applications.

1. INTRODUCTION

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 [1]. 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 [2] 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 [3] metamaterial structures are applied to an UHF antenna and a better gain is obtained, while in [4] the periodic is 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 planar antennas, four different topologies are employed.

2. METAMATERIAL TECHNOLOGY

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 [5]. 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. 1(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.

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. 1(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 [6]. 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 [3], thus generating

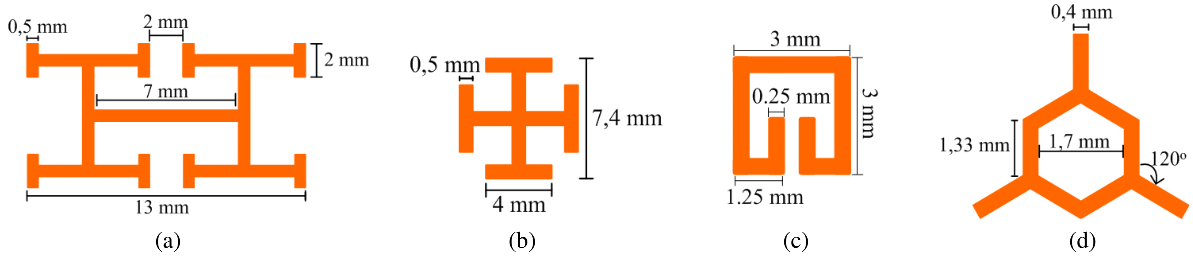


Figure 1: (a) Unitary fractal cell, (b) unitary JCP cell, (c) unitary CLL cell, (d) tripole array.

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 CLL structure can be defined as a simplification of the SRR (*Split Ring Ressonator*), where its main characteristics is it behaviors as magnetic or electric conductor, depending on the direction of the incident wave. When the incident wave achieves its unitary cell at the gap, its response assumes an artificial magnetic conductor behavior, while at the opposite side an artificial electric conductor is observed. This phenomenon occurs due the gap at the front size of the unitary cell act as a capacitor, while in the back size, distributed inductance and resistance are present. It's shape and dimensions are shown in Fig. 1(c).

The tripole array, Fig. 1(c), is generally developed for mobile applications which require small and thin structures. The set of tripoles is arranged in two layers, so that its grouping is modeled in the hexagonal shape. The symmetry of the tripole 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 [5]. In this work, the dimensions of the adopted unitary cells are presented in [3, 4].

3. PATCH ANTENNAS

The planar Yagi-Uda antenna shows good characteristics as high gain and simple shape. In Fig. 2(a) is shown the Yagi-Uda antenna designed in this work, with seven elements and a feed line. The antenna consists of a rectangular drive, four directors and two reflectors placed near the feed line [7].

The driver is the radiating element and is connected to the feed line. On the other hand, the reflectors and directors, play the role of parasite elements, due they are not connected to the feed line, allowing the improvement of gain. The antenna was designed over the 5880 Rogers Duroid, with dielectric constant around 2.2 and 1.5 mm of thickness.

The metamaterials topologies, CLL and JCP were applied making holes on the four reflectors of the Yagi-Uda antenna, as seen in Fig. 2(b) and Fig. 2(c). Both implementation changed the resonance frequency for 10.5 GHz and increased the gain on this frequency, but the first with CLL cells, Fig. 3(a), presented a better result than the second with JCP cells, Fig. 3(b).

The second analyzed antenna was the Quasi-Yagi — QY, which is widely used in microwave systems. Its geometry has the advantages of planar antennas and the main characteristics of the

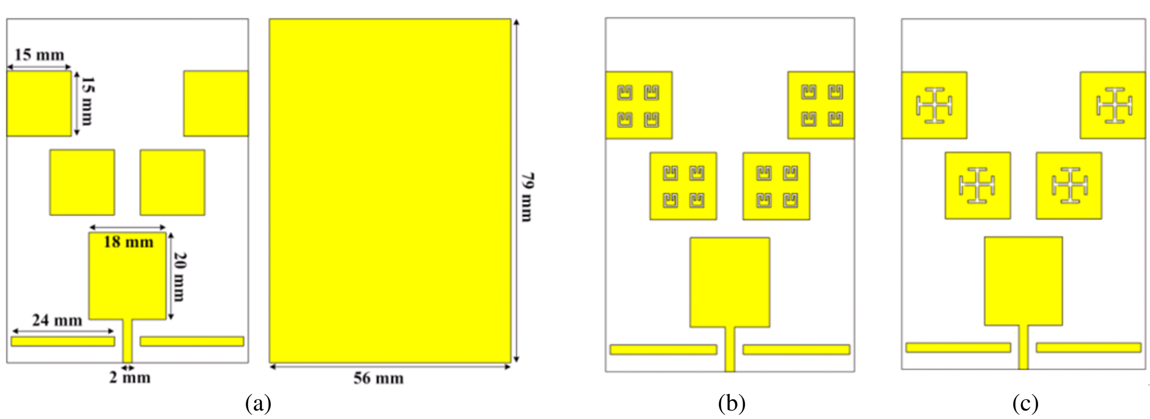


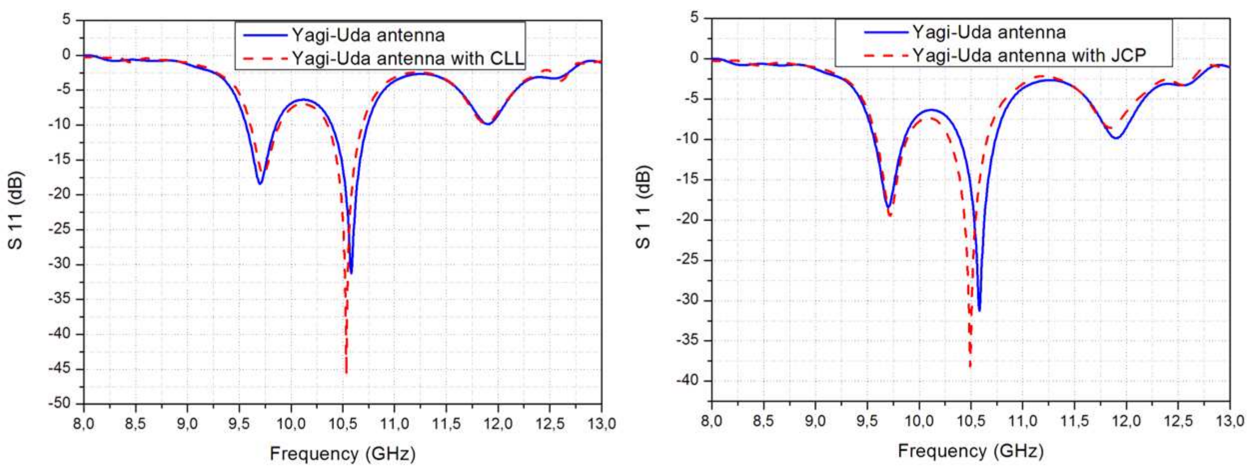
Figure 2: (a) Yagi-Uda dimensions. (b) Yagi-Uda with CLL cells. (c) Yagi-Uda with JCP cells.

Yagi-Uda as drivers. Furthermore, the QY antenna has a truncated ground plane which acts as a reflector, making it unnecessary the use of a separate dipole. Generally, the QY is built on substrates with $\varepsilon_r \geq 4$, in order to reduce its overall size, making it smaller than half wavelength. The analyzed antenna was built on a glass substrate with $\varepsilon_r = 4.82$ and a thickness of 0.8 mm. In Fig. 2(a) is shown the QY dimensions.

In the QY antenna, the JCP pattern was applied on the top of the substrate with the same thickness of the antenna, Fig. 2(b). The cells are placed on the upper side of the antenna, in arrays composed by four cell, which are located at 4.7 mm from the lateral border and 4.35 mm from the upper border. From Fig. 3(a), the resonance in 5.6 GHz and 9.6 GHz, was improved, around 25 dB and 10 dB, respectively. On the other hand, the fractal pattern was applied to the QY antenna on the ground plane, Fig. 2(b). The periodic structures were placed at 7.5 mm from the lateral border and 3.8 mm to the upper border. This configuration results on a wide rejected band, from 0 to 8 GHz, with resonance only in 8.3 GHz, as can be seen in Fig. 3(a).

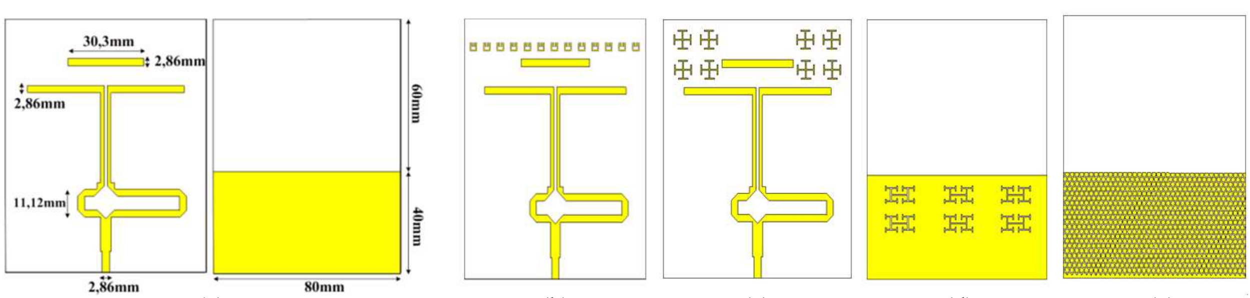
The tripole array was applied to the antenna throughout all ground plane, as can be seen in Fig. 2(c). In Fig. 3(c), it can be observed resonances in 3.4 GHz, 4.7 GHz, 7.5 GHz and 8 GHz, and a shift from 6.5 GHz to approximately 5.8 GHz. It also can be observed a rejected band from 8.1 GHz to 10 GHz.

Therefore, it is clearly the influence of the metamaterial structures on the behavior of the QY antenna. Various configurations were performed, but no contributions on the antenna performance were found. Furthermore, each pattern, and its positioning, can improve or not the gain, bandwidth and resonance and even create a rejected band.



(a) (b)

Figure 3: (a) S_{11} parameter of Yagi-Uda antenna with CLL pattern. (b) S_{11} parameter of Yagi-Uda antenna with JCP pattern.



(a) (b) (c) (d) (e)

Figure 4: (a) QY dimensions; (b) QY with CLL cells on the top; (c) QY with JCP cells on the top; (d) QY with fractal cells on the ground plane; (e) QY with tripole array on the ground plane.

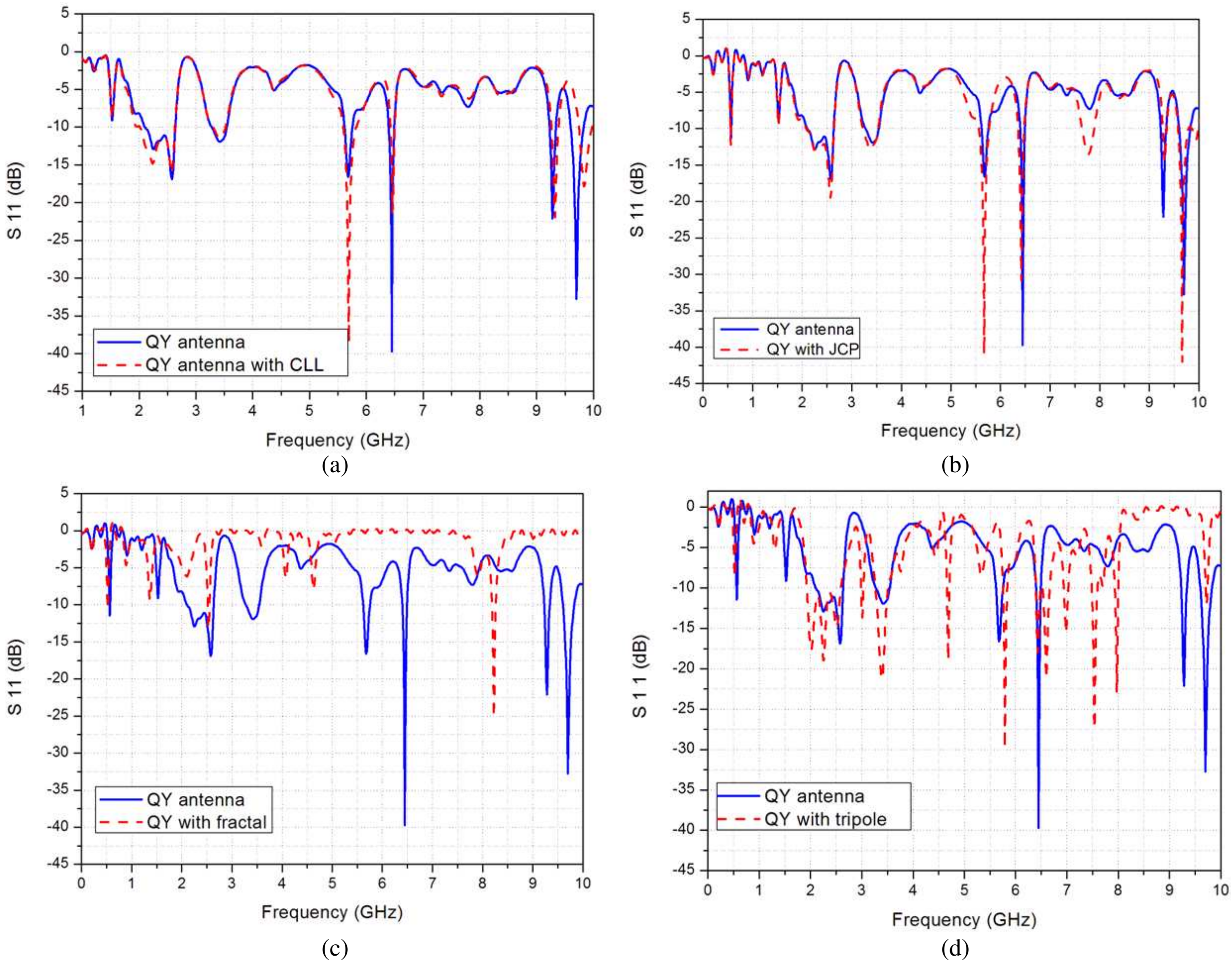


Figure 5: (a) S_{11} parameter of QY antenna with CLL pattern; (b) S_{11} parameter of QY antenna with JCP pattern; (c) S_{11} parameter of QY antenna with fractal pattern; (d) S_{11} parameter of QY antenna with tripole array.

4. 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 four metamaterial structures, fractal, CLL, JCP and tripole array, were applied in planar antennas. The S_{11} parameter was analyzed for all structures, where it was clearly observed the appearance of new resonant frequencies, bands of rejection and gain increasing.

ACKNOWLEDGMENT

The authors would like to thank CAPES for the partial financial support.

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