Study of Microstrip Antenna Behavior with Metamaterial Substrate of SRR Type Combined with TW

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Abstract: This work aims to characterize microstrip antennas working on microwave band, especially their behavior in frequency band from 6 GHz to 16 GHz, when they are on metamaterial substrate. These microstrip antennas allow their structure miniaturization, which is important to the equipment that uses those antennas. The main characteristic of the metamaterials shows special features of permissiveness and permeability, which are not found in natural state materials, whose main effect is the refraction negative index. Due to these characteristics, the application is allowed in several electromagnetism and optical means.

Key-Words: Antenna, metamaterial, microstrip, SRR, substrate, TW.

1 Introduction

Due to the increasing of media, some influences of new signal transmission equipment, especially the antennas, have to be analyzed in order to follow the development. Therefore, there is a technological advance in the analysis of even smaller structures to be adapted to the new wireless media systems, as well as the use of artificial substrates, called metamaterials, which have new specific features of electromagnetic propagation.

The metamaterials present an emergent and promising research area that states to bring up important scientific advances in several areas. Some studies delimit the metamaterials to artificially structured periodic media in which the periodicity is much smaller than the electrical wavelength. This concept of metamerials is directly related to the artificial dielectric work made on microwave frequencies [1].

The comprised features in metamaterials were initially proposed by Victor Veselago [2]. The metamaterials or anisotropic materials are developed through electromagnetic or optical features, which possess artificial structures that are not found in nature and also can be determined, by two constitutive parameters called electrical permissiveness (ε) and magnetic permeability (μ). These parameters designate the material response when an electromagnetic wave spreads through itself.

2 Antenna Modeling With Metamaterial Substrate

The methodology which has been used in this work was based on the modeling of two microstrip antennas, for a resonance frequency of 10 GHz, being one as a reference (pattern) antenna and another with metamaterial substrate.

2.1 Pattern Antenna Project

The pattern antenna project was developed through the parameters of the rectangular microstrip patch antenna, which has a complete grounding plan and microstrip line power, as in Fig. 1, in which is based on the transmission line method theory, that means, operation frequency of 10 GHz, substrate thickness of 2.5 mm, relative permissiveness of 4.4 and loss tangent tan δ = 0.02, as the antenna dimensions on Table 1.

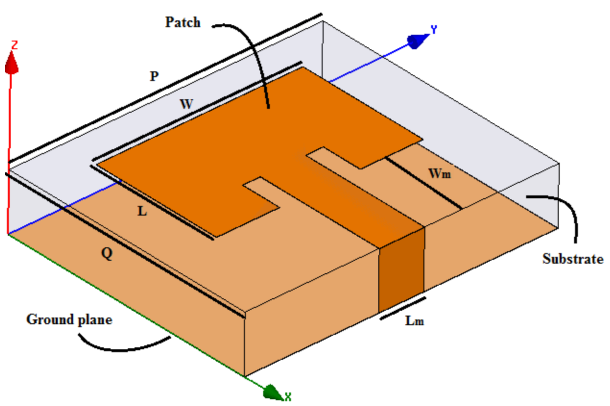

Fig. 1 - Microstrip antenna pattern to 10 GHz.

Table 1: Dimension of the Antennas to 10 GHz

Dimensions (mm)	W	L	W_m	L_m	P	Q
	9.12	5.87	4.0	2.0	13.85	11.50

According to [3] the antenna dimensions were calculated through (1) to (6).
The width W of the radiator element is given by (1).

$$W = \frac{1}{2 f_r \sqrt{\mu_0 \varepsilon_0}} \sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{v_0}{2 f_r} \sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

The effective dielectric constant of the antenna is determined by (2).

$$\varepsilon_{ref} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left(1 + 12 \frac{h}{W}\right)^{-1/2} \tag{2}$$

After determining the W value, the length extension generated by edge fields is determined in (3).

$$\frac{\Delta L}{h} = 0.412 \frac{(\varepsilon_{ref} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{ref} - 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{3}$$

The true antenna length is given by (4).

$$L = \frac{1}{2 f_r \sqrt{\varepsilon_{ref}} \sqrt{\mu_0 \varepsilon_0}} - 2\Delta L \tag{4}$$

The effective antenna length is finally calculated in (5).

$$L_{ef} = L + 2\Delta L \tag{5}$$

The resonance frequency is shown by (6) for the dominant mode TM_{010}.

$$(f_r)_{010} = \frac{v_0}{2L\sqrt{\varepsilon_r}} \tag{6}$$

2.2 Split Ring Resonator (SRR)

Split Ring Resonator (SRR) is an artificial structure that is used to achieve the metamaterial properties [4], exerted in this work for a new substrate formation, in which the SRR is a pair of concentric annular rings with openings in opposite ends and both rings are placed so that each opening is situated on the opposite side of the another one.

The SRR acts like small magnetic dipoles, which increases the material magnetic response by using a bigger amount of rings. When the SRR is smaller than the wavelength, about a tenth of the wavelength, the circuit is considered LC, in which L is the ring self-inductance and C is the slit capacitance [5]. The physical dimensions used in the ring geometry are: external ring's length and width are expressed as 'a', internal ring's length and width are expressed as 'b', each ring slit is represented as 'g' and the rings' thickness as 'e', as it may be seen on Fig. 2.

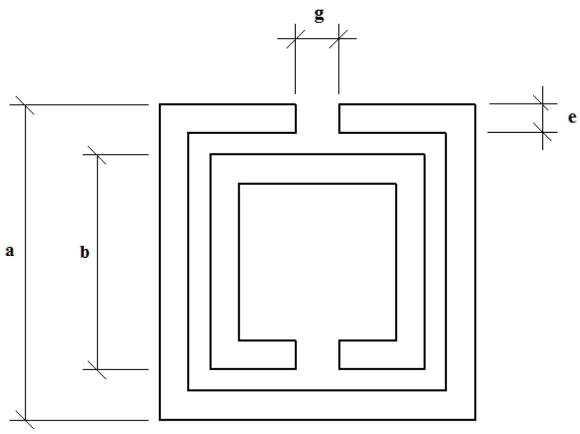

Fig. 2 – Dimensions of physical geometry of SRR.

2.3 Metamaterial Structure

Based on the idea of [2] about the behavior of flat waves spreading in materials that have negative permissiveness and permeability simultaneously, the unitary structure model proposed in [6], has demonstrated the existence of the means with both negative electromagnetic properties.

The substrate structure is made by five small glass fiber blocks (FR4) and they are placed perpendicularly to the grounding plan, the square resonator elements are distributed at the front part of the blocks and have the following dimensions: R and r are the external and internal ring width, Q and q the external and internal ring length and also TW (Thin Wire) which is inserted at the back part, as in Fig. 3.

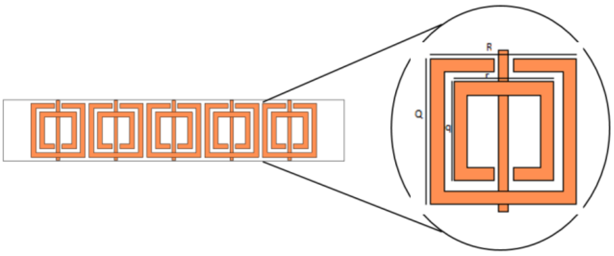

Fig. 3 - Substrate Structure with SRR.

The project dimensions analyzed are presented on Fig. 4. The SRR and the thick wire of metallic material (copper) are placed at the front and back part of the block, respectively, having thickness of 0.25 mm. The copper thickness, used in the ring geometry and the thick wire, was of 0.017 mm. The thick wire is 0.14 mm wide. The SRR external and internal rings are squared and inverted, the external one has 2.2 x 2.2 mm² and the internal one has 1.5 x 1.5 mm², both rings' thickness are 0.2 mm wide. The gap in which ring has 0.3 mm and the distance between them is 0.15 mm.

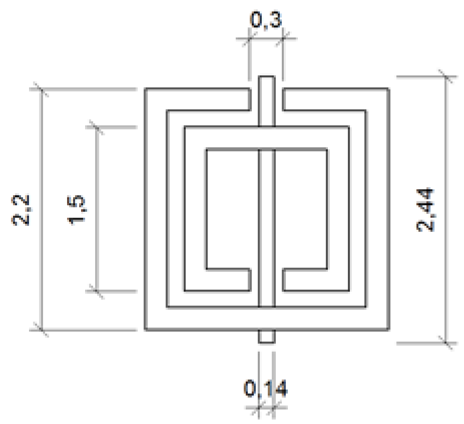

Fig. 4 - SRR and TW Dimensions.

2.4 Proposed Antenna Project

The microstrip antenna with metamaterial substrate of SRR rectangular type combined with TW consists of a project from a pattern antenna with operation to 10 GHz.

The geometry of the antenna project with metamaterial substrate, presented on Fig. 5, has the following dimensions: grounding plan of 13.85 (P) x 11.5 (Q) mm² and substrate thickness of 2.5 mm, rectangular patch has (W) 9.12 mm of length and (L) 5.87 mm of width, connected to a microstrip line that is 2.0 mm wide and 4.0 mm long to an impedance of 50 Ω, besides the inset feed of 1.8 mm. the same way that each block, composed by five resonators and thick wires placed perpendicularly to the grounding plan, possess one another a periodicity of 2.5 mm, the resonators of a single block also possess a periodicity of 2.35 mm.

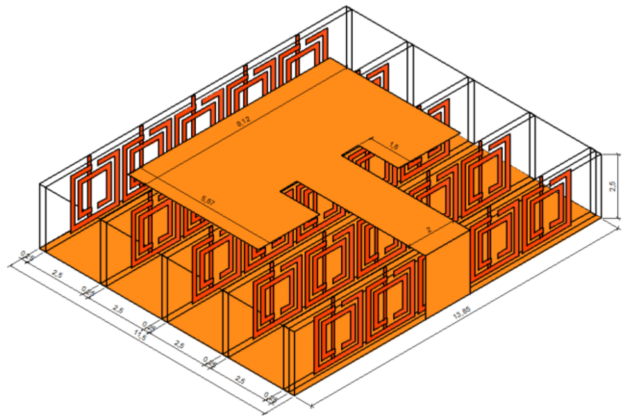

Fig. 5 - Microstrip antenna dimensions with metamaterial substrate.

3 Results

In order to compare results, a simulation has been made with a conventional antenna with glass fiber substrate (FR-4) which has dielectric constant ε_r = 4.4 and with metamaterial substrate to the same resonance frequency of 10 GHz. About the electromagnetic aspect, the Fig. 6 shows a comparison of return loss between both antennas, for a frequency band of 6 – 16 GHz.

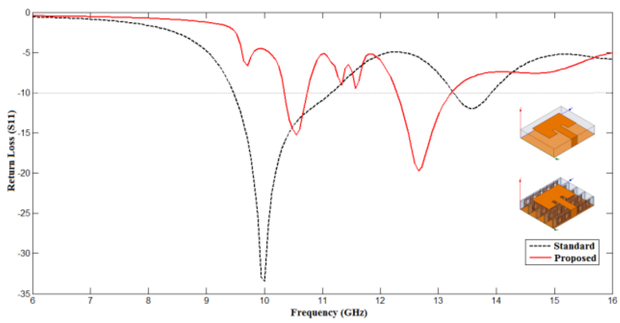

Fig. 6 - Comparison of return loss between the pattern microstrip antenna and the one with metamaterial substrate.

It is possible to verify in the first resonant mode between the antennas that there was an increase on the parameter values S11 of about 18.2 dB, besides the frequency displacement from the metamaterial antenna, which is due to the change in electromagnetic parameters of permissiveness and permeability of the material used in the substrate, as well as the match haziness of the antenna impedance as metamaterial substrate, which result has already been expected due to the looping current loss in the unitary cell turns, and the capacitive loss by using a thicker substrate. However, for the second resonant mode the antenna with metamaterial substrate presented a decrease on the parameter values S11 of about 7.77 dB in relation to the pattern antenna, besides de increase in width band for the second resonant mode.

So, the antenna with metamaterial in its substrate shows a dual band behavior for an observed frequency band (6 - 16 GHz), which allows the antenna to work in two frequency bands in some applications. In this context, a variation has been made in some parameters of the structure in the substrate, varying the thick wire dimensions and the resonator gaps in order to verify the microstrip antenna behavior after that.

3.1 Thick Wire Variation

This section presents the results for the width variation of the thick wire inserted in the substrate, by the opposite ring side. The variation of the wire width dimension begins in 0.14 mm and ends in 0.74 mm at the step of 0.2 mm. The alterations in the width dimensions of the thick wire reflects directly on the plasma frequency and on the permissiveness behavior. The plasma frequency represents the frequency limit for the permissiveness to present negative behavior. On Fig. 7 is shown an analysis of the return loss responses in related to the width variation of the thick wire, for a behavioral analysis on the frequency band from 8 to 14 GHz.

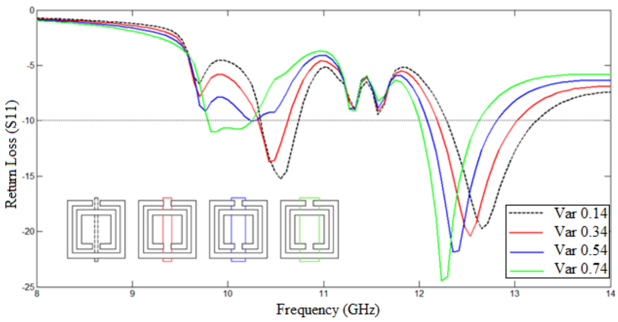

Fig. 7 - Return loss response for the thick wire variation.

It is possible to observe a dual band in the moment that the antenna is simulated and two distinct resonant modes are represented. For these resonant modes, it is verified that the frequency displaces as the wire width is altered, in which the first mode shows significant changes referred to return loss, verifying that the variation of 0.4 mm of the wire (Var 0.14 to Var 0.54) shall not resonate at -10 dB, for the project frequency of 10 GHz, the behavior analysis of the second mode makes this variation to decrease the band width regarding to the return loss in the antenna with metamaterial substrate. This is because for the electromagnetic wave, the wire that was initially thick becomes a sheet, reflecting the wave back to the ring, compromising and altering the ring's behavior, responsible for the permeability response. However, such distortions did not compromise the obtaining of a media with negative refraction index.

3.2 Gap Variation

The magnetic permeability response and the ring capacitance are interfered by the gap variation in the SRR structure. Thereby, gap variation has been made in order to analyze the antenna parameter behavior in the alteration of the capacitive response

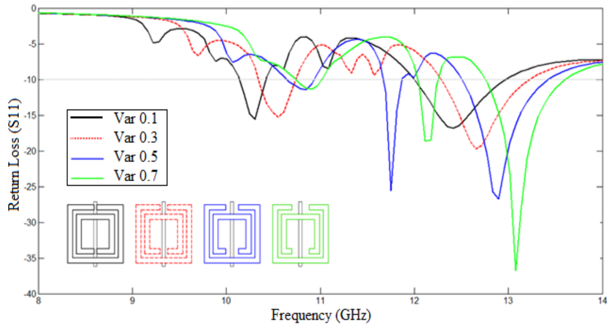

Fig. 8 - Return loss response for the ring gap variations.

According to the Fig. 8, it is possible to see that, besides the dual band posture, the gap variation from 0.1 mm to 0.7 mm at the step of 0.2 mm, has resulted in a displacement of the first resonant mode to increasing frequency values, as well as, from the variation 0.5 mm (Var 0.5), the appearing of more than one resonant mode in addition to the two existing ones, which means a tri band posture for the variations from 0.5 mm to 0.7 mm.

4 Conclusion

Therefore, the antenna's behavior with metamaterial in the substrate, for an operation frequency of 10 GHz, in function of its geometric structure variation of thick wire, which implied the result of an antenna with dual band posture, being possible to apply on distinct and specific frequencies (resonating under -10 dB) on the band between 8 and 14 GHz, as well as the resonator gap variations, which implied on a dual band and also a tri one according to the dimensions of the variation.

So, in this work it has been analyzed a composed array of unitary cells disposed periodically, characterizing a metamaterial substrate for the microstrip antenna, and verified the behavior through numerical simulations made with the aid of computational tools.

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