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A miniaturized rectangular microstrip patch antenna with negative permeability unit cell metamaterial for the band 2.45 GHz

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Abstract. This work presents a miniaturized rectangular patch Antenna with negative permeability metamaterial unit cell etched on the ground plane of a conventional patch antenna operating at 3.3 GHz. The new compact metamaterial (MTM) antenna is resonating at 2.45 GHz. It is 44,82% smaller than a conventional rectangular patch antenna resonating at 2.45 GHz and has a bandwidth of 183.3 MHz, a reflection coefficient of -45,36 dB and a gain of 1.37dB, the materials used for the conception are FR-4 dielectric as a substrate, its permittivity is 4.4 and cooper annulled as metal for radiating element and the ground plan, the simulation of the antenna was done with CST solver.

1 Introduction

Nowadays, Compact telecom equipment such as smart phones, tablets,…wireless routers requires miniaturized antennas witch resonate at the appropriate frequency of the targeted telecom technology (2G,3G , … WiFi, RFID) and responding properly to the other performances of the antenna (gain, bandwidth…) Referring to literature in antenna design, there are several miniaturization approaches that was applied by researchers to patch antennas to reduce their size for conforming them to the body of the compact devices. Among these miniaturization techniques [1,2]: Material Loading, Reshaping Antenna Geometry (use of fractal structures, Adding Truncation: Slots, Notches, and Cuts), Shorting and Folding, Modification of the ground Plane and the use of metamaterials. In this paper, we aim to reduce a conventional microstrip patch by using the miniaturization metamaterial method.

Before presenting in detail our metamaterial antenna design, we give first a brief definition of metamaterials, their applications and we also provide a look about some works reported in literature which present a miniaturized antenna with the metamaterial approach.

Metamaterial is a word composed from Meta & Material in which "Meta" means beyond normal, it is an artificial designed material that shows specific electromagnetic properties not found in nature. The size of the unit cell that compose the metamaterial structure is much smaller than the guided wavelength [3]. 1968 is the year in which Veselago [4] reported the

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theory study of materials with negative permittivity and permeability. From that time, metamaterial research has known an empty period until 1999 when J.Pendry demonstrated the existence of negative permittivity medium using a network of thin metallic wires separated by air and the existence of negative permeability medium using a structure composed by split ring resonators (SRRs) [5,6]. The first realization of a metamaterials was done by Dr. Smith in 2000 [7,8], it is a (DNG) double negative permeability and permittivity metamaterial, it was achieved by combining the network of vertical metal wires and the periodic array of split ring resonators (SRR) already demonstrated by J.Pendry. Because of their abnormal properties, Metamaterials were introduced in many branches of research to study their impact, they were applied in sensors, cloaking device, absorber ...and Antenna design [9]. In this last area of research, metamaterials are widely used to improve gain and efficiency, enhance directivity, increase bandwidth, create multiband antenna and antennas miniaturization the subject of this paper [10,14].

In the following, we present some works from literature in which their authors demonstrated that metamaterials present an effective technique for reducing the size of an antenna and improving their other characteristics [15, 20]. In [15], the author reduced the antenna with 43% by using two metamaterial (MTM) unit cells as superstrate above the patch antenna. In [16], the author uses in the vicinity of a half loop antenna two double negative permittivity and permeability metamaterial unit cells, he shifted the resonance frequency by 20%. In [17], The researcher proposed a miniaturized microstrip patch antenna loaded on a ring shape metamaterial, he achieved a reduction of 68%. In [18], the author presented a rectangular miniaturized patch antenna loaded by six permeability negative unit cells metamaterial which are made of a spiral and three wires printed on both sides of a dielectric, the reduction achieved was about 40% and 30%. In [19], the author miniaturized a square patch antenna by using concentric complementary split ring resonator (CSRR) structures in between the patch and ground plane, he reduced the normal patch antenna by 25%. In [20], The MTM antenna designed by the author is 64% smaller than the conventional patch antenna, that results was achieved by etching circular split ring resonator in the ground plane of the circular patch antenna.

2 Antenna design methodology

2.1 Design of the conventional patch Antenna

2.1.1 Calculating the length and width of the patch

Basing on the TLM (Transmission Line Model) founded in [21], the resonant frequency (fr) of the patch antenna depicted in Fig.1, is approximated by the equation (1)

$$f_r = \frac{c}{2W\sqrt{\frac{\varepsilon r+1}{2}}} \qquad (1)$$

c = 3.10e8ms-1, speed of the light.
εr =4.4 the relative permittivity of the dielectric.
W: the width of the patch.

Our studied conventional patch antenna resonating at 3.3 GHz, we design this antenna with FR-4 dielectric as substrate, from equation (1), the width of the patch is W= 27.64 mm.

To calculate the length of the patch (L), the below formulas are followed by substituting W, εr, fr, and h, the thickness of the substrate, by their values.

$$\varepsilon reff = \frac{\varepsilon r + 1}{2} + \frac{\varepsilon r - 1}{2} \times \left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \qquad (2)$$

$$Leff = \frac{\lambda}{2\sqrt{\varepsilon reff}} \qquad (3)$$

$$\lambda = \frac{c}{fr} \qquad (4)$$

$$\frac{\Delta L}{h} = 0.412 \times \frac{(\varepsilon reff + 0.3) \times (\frac{W}{h} + 0.264)}{(\varepsilon reff - 0.258) \times (\frac{W}{h} + 0.8)} \qquad (5)$$

$$Leff = L + 2 \times \Delta L \qquad (6)$$

The obtained length of the patch is L= 21.22 mm

2.1.2 Calculating the width of the feeding microstrip line.

The rectangular patch microstrip antennas have several feeding techniques, such as the microstrip line (with and without inset), coaxial probe, proximity coupling, and CPW. Referring to the comparison between those feeding techniques done in [22], microstrip line is the most suitable for this work even its low bandwidth it is simple to design, directional and offers high gain.

Basing on the on the Eq. (7) [23] ,the width of the microstrip line that has an impedance of 50 Ω is 3.083

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_r}\left(\frac{W}{h} + 1.393 + 0.667\,ln\left(\frac{W}{h} + 1.44\right)\right)} \qquad (7)$$

With Z0: The characteristic impedance of the microstrip line.
Wf: The width of the microstrip line.
h: The high of the substrate

To verify the previous theoretical study, the conventional microstip patch antenna with microstrip line feeding was simulated with CST. The antenna is printed on a substrate EPOXY FR4 with relative permittivity εr = 4.4, thang loss equal to 0.025 and a thickness of 1.6 mm. The other parameters (Fig.1) are: antx = 27.64mm, anty = 21.22mm, sbx = antx, sby = 2*anty, trx=3.083mm

Fig.2 presents the S11 of the conventional patch antenna, The simulated resonance frequency is 3.216 GHz (red curve), it is lower than the resonance frequency given by TLM 3.3GHz, CST and other commercial software based on a full wave method like: Finite Element

Method (FEM), Finite Integral Technique (FIT), and the Method of the Moment (MoM) are more accurate compared to the TLM method.

Hence, the design is optimized to have 3.3 GHz as the resonance frequency with the full wave method used in CST, the new dimensions of the patch are: antx = 26.95 mm and anty = 20.67 mm. Fig.2 shows the S11 of the optimized antenna.

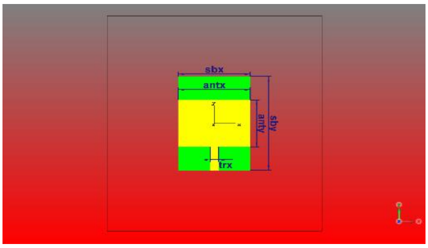

Fig. 1. Top view of The conventional patch antenna

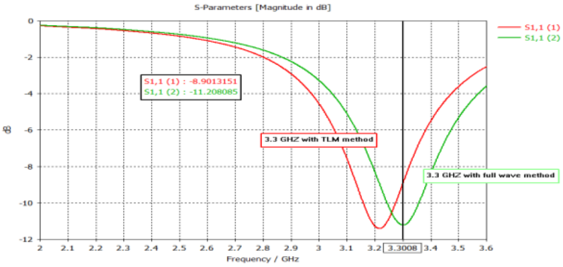

Fig. 2. S11 of the conventional patch with TLM and full wave method

2.2 Design of the Meta-material Antenna

As shown in Fig.3, on the ground plane of the previous conventional patch antenna we print a negative permeability metamaterial unit cell, Fig.4, its center has a distance X1 from the center of the patch antenna, the Table 1 below sums up the parameter's values of the new MTM antenna. A parametric study about the distance X1, Fig.5, was done to define the right position of the parasite element that results the suitable conclusion, we notice that at X1=5.52 mm, the MTM antenna resonating at the frequency 2.45 GHz and has a bandwidth of 183.3 MHz, (2.3604 to 2.5437 GHz).

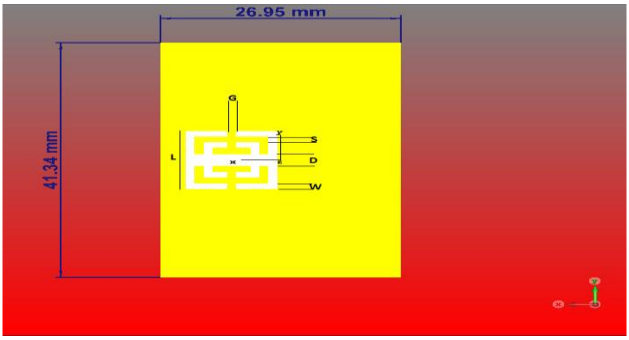

Fig. 3. Back view of The MTM patch antenna

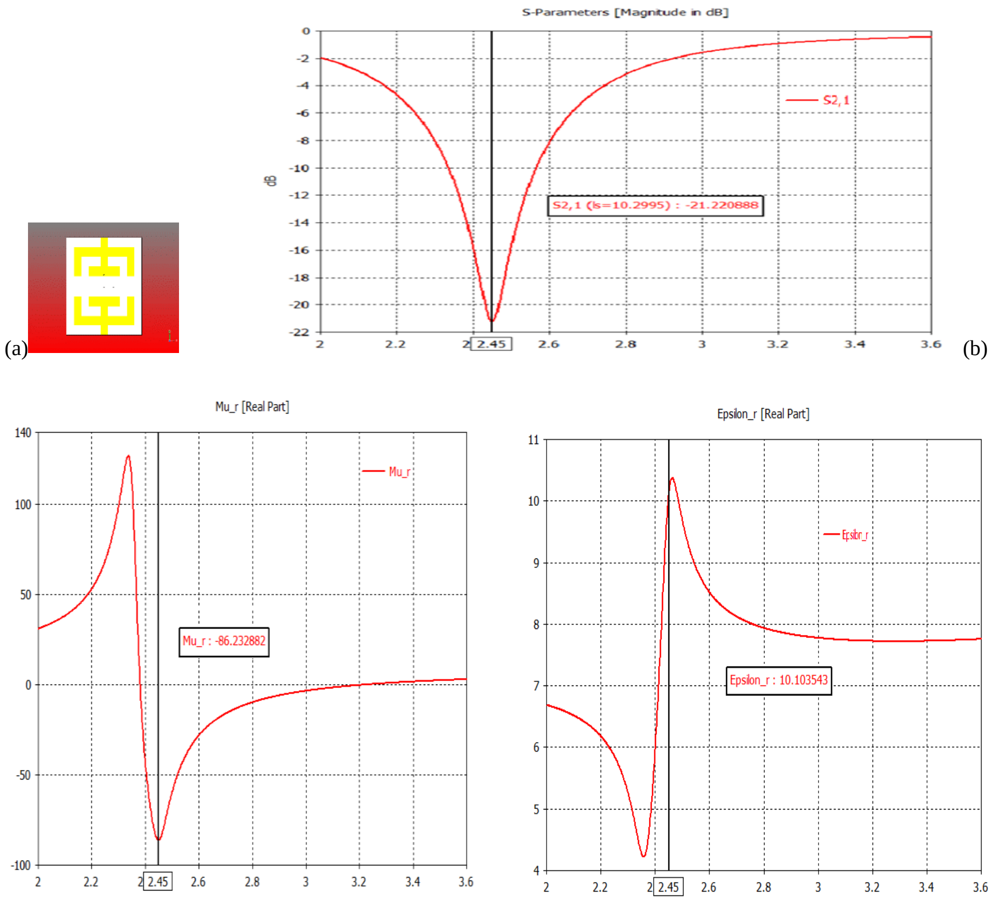

Fig. 4. The unit cell ant its behavouir at its resonance frequency 2.45GHz , (a) : The metamaterial unit cell ,(b) : S21 of the unit cell (c) : the permiabilitty and (d) the , permitivity of the unit cell.

Table 1. The parameters values of the new MTM antenna.

MTM antenna Parameters values			
Parameters	**Value in (mm)**	**Parameters**	**Value in (mm)**
sbx	26.95	G	0.5
sby	41.34	W	0.5
antx	26.95	S	0.5
anty	20.67	L	9.7
trx	3.083	D	1

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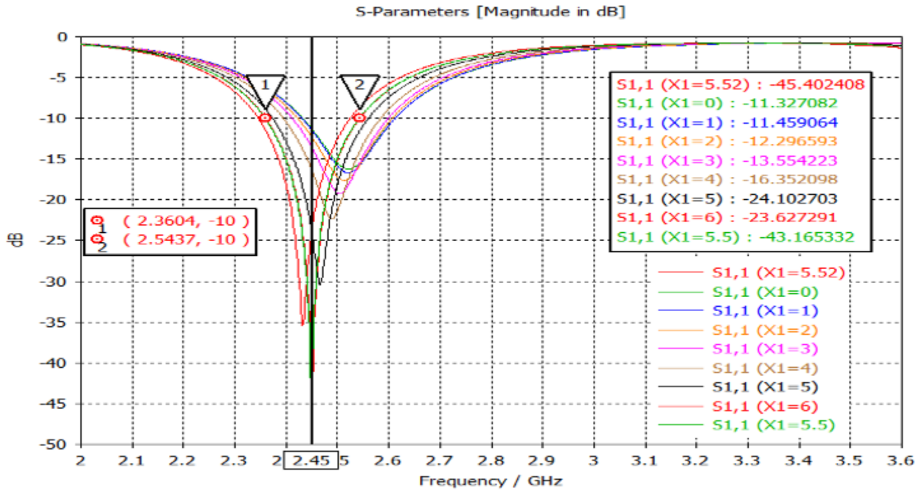

Fig. 5. S11 Parametric study about X1 of the MTM antenna.

3 Simulation results and discussion

The Fig.6, gives a comparison between the reflection coefficient S11 of the 3.3 GHz conventional patch antenna (before we have etched on its ground the metamaterial unit cell) and the resulting MTM antenna (after etching the unit cell on the ground plan), as shown in the figure, the resonance frequency of the normal antenna was shifted from 3.3 to 2.45 GHz.

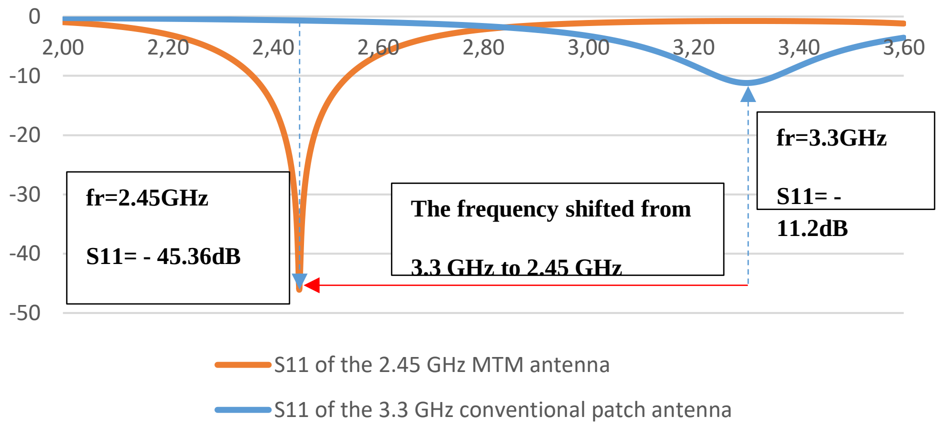

Fig. 6. Reflection coefficient S11 of The MTM antenna and Conventional antenna.

Fig.7: illustrate that the radiation patterns of the miniaturized MTM antenna at 2.45 GHz is almost omnidirectional.

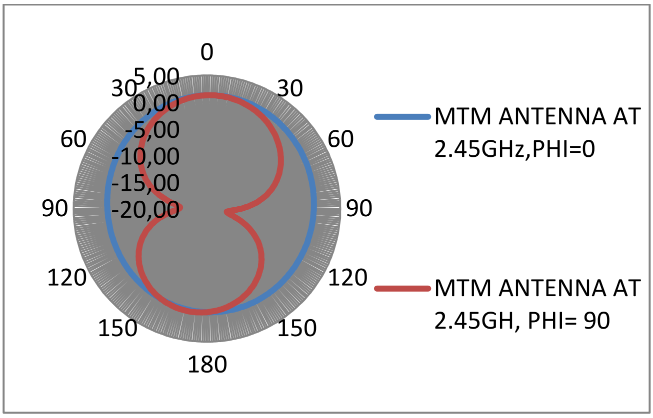

Fig. 7. Radiation patterns of the MTM antenna at 2.45 GHz:(a) Phi=0 and Phi=90

Fig.8 shows the gain variation of the MTM antenna, it varies from 1.283 dB to 1.277dB in the band (2.3604 to 2.5437) GHz and has a maximum 1.3674 dB at 2.45 GHz.

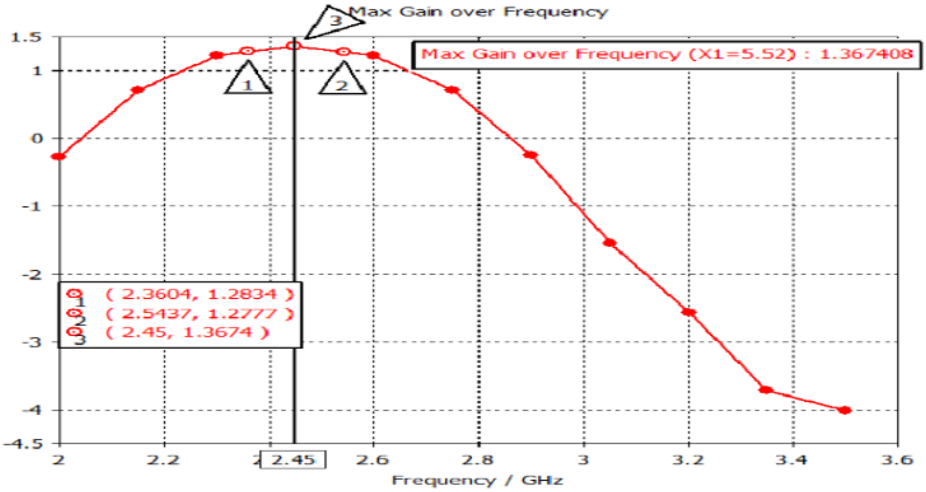

Fig. 8. Gain variation of the MTM antenna

Following the same steps to calculate and simulate the conventional patch 3.3 GHz, we define the dimensions of the 2.45 GHz conventional patch, The Table 2 sums up the dimensions of the conventional patch and MTM antennas which both resonate at 2.45GHz. The New conceived MTM antenna is 44,82% smaller than the 2.45 GHz conventional patch antenna.

Table 2. Conventional & MTM 2.45 GHz antenna dimensions.

Antenna dimensions	
Antenna type	**Volume in mm^3**
2.45 GHz Conventional patch	36.13 x55.88x1.6
2.45 GHz MTM antenna	26.95x41.34x1.6

4 Conclusion

In this work we have proven by simulation that etching the negative permeability metamaterial unit cell on the ground plane of the conventional patch antenna leads to reduce the size of the antenna, this demonstration is explained by the noticed shifting resonance frequency from 3.3 GHz to 2.45 GHz of the conventional antenna. The achieved reduction is about 44,82% if we compare the dimensions of the conventional patch antenna and the MTM antenna which resonate at the same frequency 2.45 GHz. The next step for this work is to fabricate a prototype of the proposed antenna and do measurement to confirm the simulation results.

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