A New Design of 5G Planar Antenna based on metamaterials with a high gain using array antenna

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Abstract. In this paper, a symmetrical monolayer metamaterial superstrate is placed on a microstrip patch antenna resonant at 3.5 GHz. MTM metamaterial based CSRR Complementary Split Ring Resonators, constituting two rectangular rings is opposite splits on both ends, which are printed on Rogers RT 5880 type substrate with relative permittivity of 2.2, tangential loss of 0.0009, and a thickness of 0.508mm. This resonator is capable of exhibiting an ε-negative permittivity. Moving an MTM superstrate loaded with a 2 × 3 grating on a single radiating element, provides a gain increase from 4.66 dBi to 5.67 dBi was found at its operating frequency, and the radiation pattern was directional and stable over the entire frequency band. For a 4×1 antenna array loaded with MTM, the gain reaches about 9.84 dBi. the proposed antenna is suitable for 5G mobile applications.

Keywords: metamaterial, CSRR, superstrate, 5G, antenna array

1 Introduction

Metamaterials (MTM) play a very important role in wireless communication systems by improving the gain of the antenna's performance, the radiation pattern. There are several enhancement techniques, using them. For example in work [1] a technique is used to improve antenna gain and bandwidth by combining triangular and rectangular patches with two types of metamaterial structure, which includes two complementary split ring resonators (CSRR), printed on the top layer, and 3×3 MTM slots on the bottom layer. A gain increased from 6.84dB to 12.8dB by adopting a MIMO antenna array configuration [2]. Another technique for improving performance of the proposed antenna, due to metasurfaces (MS), consisting of CSRR, and used as a ground plane [3]. In [4-5] a decoupling element is realized by the combination of the EBG and the SRR. A complementary split ring resonator placed between the antenna array elements exhibits better isolation [6-8]. Adding a superstrate consisting of SRR printed on both sides of a dielectric plate on a microstrip patch antenna (MPA), improves antenna gain and radiation efficiency [9]. MTM cells loaded with D-SSRRP double-layer symmetry single ring resonator pairs are inserted around the conventional patch antenna, improving the gain and directivity of the antenna [10]. In [11], a technique for improving antenna gain by 4 dB, with widening its bandwidth from 2.9% to 4.98%, by placing left-handed metamaterial (LHM) structure above the patch antenna.

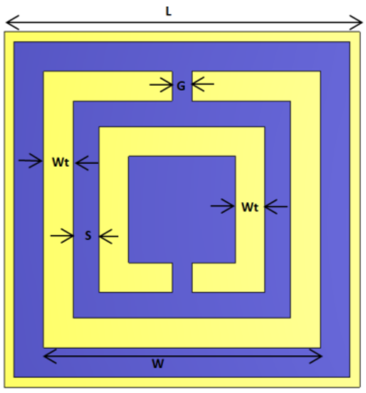
In this paper a rectangular patch antenna inspired by metamaterials operating at 3.5GHz. In the first section, we will present a complementary split ring resonator, sized in this work to obtain a ε-negative permittivity at the same resonant frequency as that of the conventional antenna, with a presentation of reflection coefficient and transmission in dB, and the variations of the effective permittivity's real and imagined parts, determined by the parameter S. The second section discusses the application of metamaterial for the reference antenna, by moving a dielectric layer containing CSRRs above the patch antenna, to see its influence on gain improvement for a single element, and for an antenna array also. The simulation of these structures is carried out with the CST Microwave Studio software.

2 Geometry of metamaterial unit cell and its performance characteristics

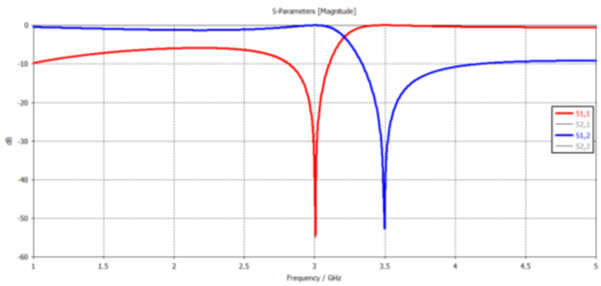
The rectangular dielectric rings constituting the CSRR are printed on an Rogers RT 5880 type substrate with a relative permittivity ε= 2.2, a loss tangent tan(δ)=0.0009, and a height of 0.508 mm. Figure 1(a) shows the geometry of the proposed complementary split ring resonator with dimension 9mm×9mm. Figure 1(b) shows a resonance peak at 3.5 GHz and a transmission of -52 dB as a result of frequency analysis of parameters S11 and S12 (reflection and transmission coefficients). In table 1, the resonator's geometric parameters are presented.

Table 1. The optimized parameters of the CSRR.

Parameter	**mm**
L	9
W	7
Wt	0.75
G	0.5
S	0.65



(a) CSRR



(b) Reflection coefficient

Fig. 1. (a) Representation and parameters of a square CSRR cell unit. (b) S Parameters in dB.

The suggested metamaterial unit cell's permittivity (ε) and permeability (μ) are calculated using the method (Nicolson-Ross-Weir (NRW)) [12-13]. Ziolkowski offered an approximation [14], which we illustrate below. [15]

The transmission (T) and reflection coefficient (r) are calculated as follows:

$$T=\frac{S_{11}+S_{22}-\Gamma}{1-(S_{11}+S_{22})\Gamma} \quad (1)$$

$$\Gamma=X\pm\sqrt{X^2-1} \quad (2)$$

Where $$X=\frac{S_{11}^2-S_{21}^2+1}{2S_{11}} \quad (3)$$

The permeability (μ) is given by

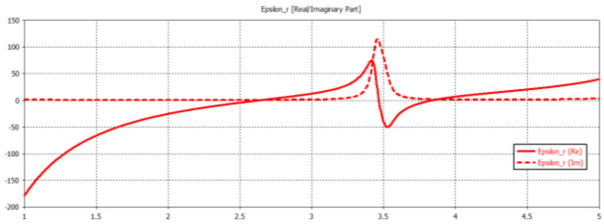
$$\mu=\frac{1+\Gamma}{\Lambda(1-\Gamma)\sqrt{\frac{1}{\lambda_0^2}-\frac{1}{\lambda_c^2}}} \quad (4)$$

Where $$\frac{1}{A^2}=\left(\frac{\varepsilon_\rho*\mu_\rho}{\lambda_0^2}-\frac{1}{\lambda_\chi^2}\right)=-\left(\frac{1}{2\pi\Lambda}\lambda\nu\left(\frac{1}{T}\right)\right)^2 \quad (5)$$

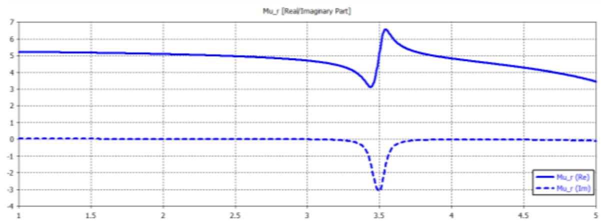
The permittivity (ε) is given by

$$\varepsilon=\frac{\lambda_0^2}{\mu_r}\left(\frac{1}{\lambda_c^2}-\left(\frac{1}{2\pi L}\ln\left(\frac{1}{T}\right)\right)^2\right) \quad (6)$$

The variations of the real and imaginary parts of the effective permittivity (ε), and effective permeability (μ) of the resonator's are depicted in Figure 2, and were calculated using the parameters S. It was obtained that the designed resonator presents a permittivity ε-negative at 3.5GHz.



(a) Permittivity (ε)



(b) Permeability (μ)

Fig. 2. (a) Effective permittivity's real and imaginary parts. (b) Effective permeability's real and imaginary parts.

3 Design of a planar antenna based on metamaterials

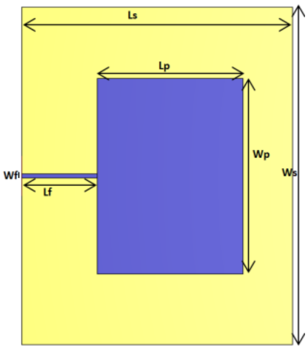
3.1 A single radiating element integrated with a metamaterial-inspired superstrate.

Initially, we chose a printed antenna of rectangular shape fed by microstrip line resonating at 3.5GHz. The rectangular patch of size 19.44 mm × 26.08 mm in PEC of thickness t, printed on an FR4 type substrate with a relative permittivity ε= 4.4, a loss tangent tan(δ)=0.025, a height of 1.6 mm, and a size of 36 mm x 45 mm. The final optimized parameters of the rectangular antenna are shown in Table 2.

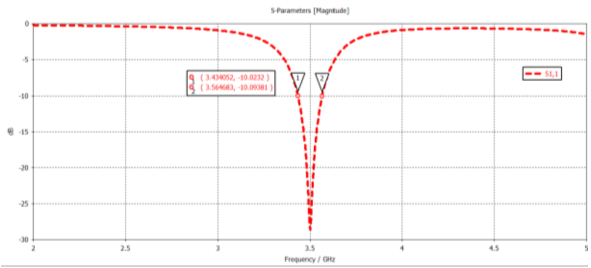
Table 2: The optimized parameters of the conventional patch antenna

Parameter	**mm**	**Parameter**	**mm**
Ls	45	Wp	26.08
Ws	36	H	1.6
Lp	19.44	Wf	0.35

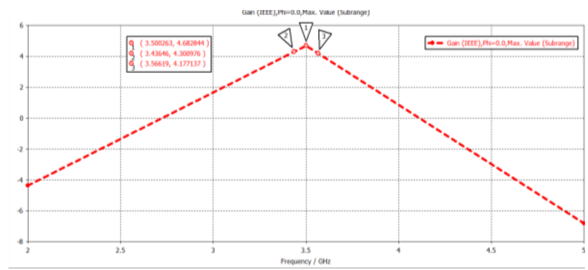
The geometry of this antenna is given in Fig. 3(a). The patch antenna has a good input impedance match at 3.5GHz with a reflection coefficient of -28dB, a frequency band of 190MHz, and a gain of 4.68dBi. The patch antenna is simulated using a finite integration-based electromagnetic solver (FIT).



(a)



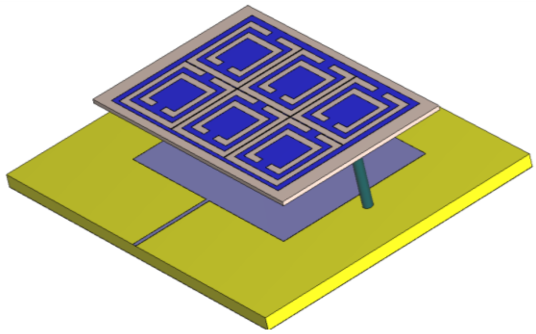
(b)



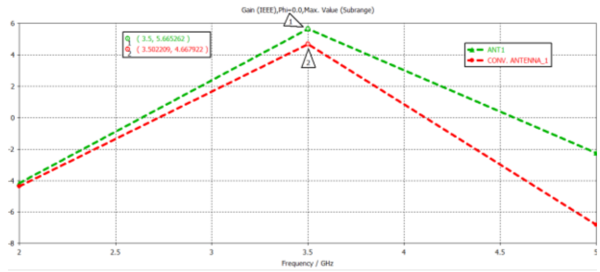
(c)

Fig. 3. (a) Basic antenna geometry, (b) reflection coefficient as a function of frequency, (c) gain as a function of frequency

To improve the gain of the antenna, the same previous antenna is used, and a two-dimensional periodic structure of the complementary split resonators is applied, printed on a Rogers's type superstrate with a size of 19.3 mm × 28.8 mm, and placed 5.092 mm above the patch. Figure 4 (a) shows the geometry of the rectangular antenna embedded with a metamaterial-inspired superstrate. A network of 2×3 metamaterial unit cells is printed on the superstrate. The distance between the resonators is x=0.1mm. The addition of proposed metamaterial superstrate above the previous patch improves the gain from 4.68dBi to 5.68dBi of the proposed antenna compared to the conventional antenna without MTMs as shown in Figure 4(b). This is because the addition of MTM superstrate suppresses surface waves due to its ε-negative characteristics and therefore results in a significant improvement in gain.



(a)



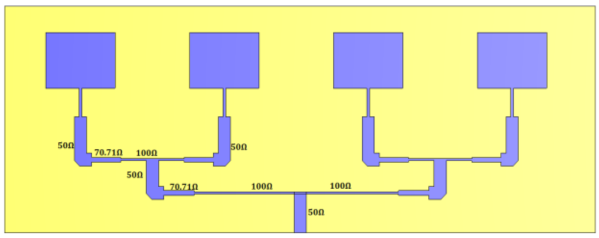
(b)

Fig. 4. (a) The geometry of the antenna with MTM, (b) the gain of the single patch microstrip antenna with and without MTM.

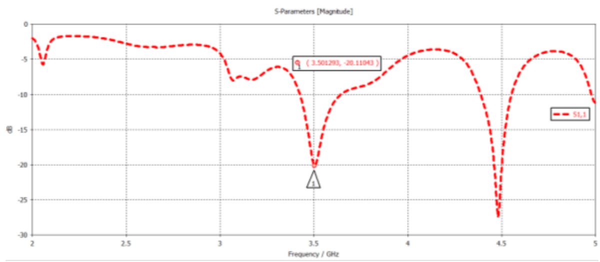
3.2 Design of a 1×4 antenna array integrated with a metamaterial-inspired superstrate.

To further improve the antenna gain, a 1×4 antenna array is designed as can be seen in Figure 5(a). The distance between the radiating elements is $\frac{\lambda}{2}$.

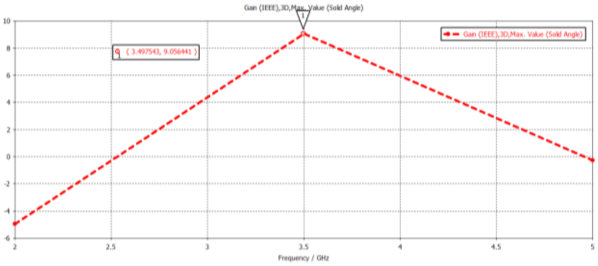
Figure 5 (b) shows that the 1*4 antenna array exhibits a good reflection coefficient match at 3.5 GHz of -17dBi, generating a second frequency band at 4.4 GHz, with a significant improvement in gain at 3.5GHz which reaches 9dBi (Figure 5(c)).



(a)



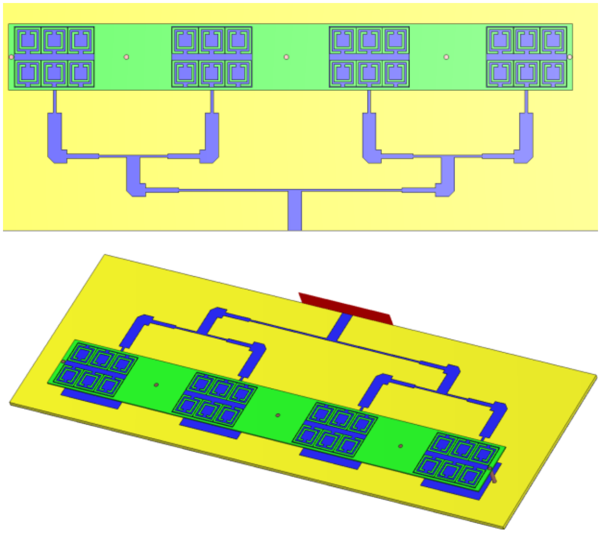
(b)



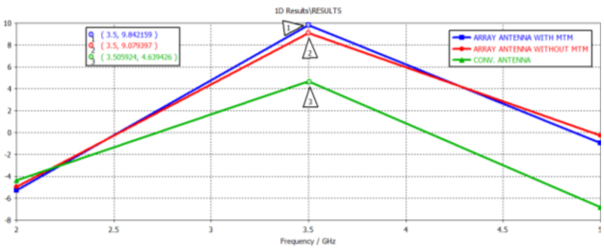
(c)

Fig. 5. (a) 1×4 antenna array, (b) reflection coefficient as a function of frequency, (c) gain as a function of frequency

Figure 6(a) shows the 4×1 antenna array, adding the preceding metamaterial superstrate above each radiating element. There is an improvement in the gain of the proposed antenna compared to the standard antenna that can be seen in Figure 6 (b).



(a) Top and 3D view



(b)

Fig. 6. (a) The 1×4 antenna array with MTM, (b) The gain of a single basic radiating element, the gain of an antenna array without MTM, and with MTM

Table 3 presents a comparison of the proposed antenna with other antennas published in the literature in terms of gain.

Table 3: Comparison between the proposed antenna and some published antennas

Ref no.	size (mm^3)	Freq. (GHz)	Band. (MHz)	Gain (dB)
11	117×127×41.6	2.4	4.98%	4.22
15	61.2×61.2×4.8	2.4	48	7.94
16	137 × 77 × 3	5.8	1.78 10^3	9.2
17	20.1× 183× 1.6	2.41 3.61	5.72% 7.3%	7.48 2.383
Pr.	79.22×222×6.6	3.5	170	9.84

4 Conclusion

In this work, we validated a novel antenna structure inspired by metamaterials suitable for 5G applications that resonates at 3.5 GHz. By moving a dielectric layer containing CSRRs above the conventional antenna, the gain is reached to the value of 5.66dBi for a single radiating element, and 9.84dBi for a 4×1 antenna array. This structure was verified by a series of optimizations utilizing the electromagnetic solver's Random technique. This proposed antenna is certified for 5G mobile applications. In the same time as perspectives, we are thinking about associating some components like varactor diodes in order to have a reconfigurable antenna that can be suitable for many standards of communication

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