Microstrip Patch Antenna Covered With Left Handed Metamaterial

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Abstract **─** We present gain characteristics of microstrip patch antennas covered with metamaterial substrate composed of split-ring resonators (SRRs) and metallic strip. To determine the performance of the SRR-metallic strip mounted on microstrip patch antenna, the metamaterial has been proposed as an effective medium with extracted constitutive parameters. Simulation results are supported by experimental measurements. The experimental results confirm that the metamaterial covered patch antenna improves gain by an amount of -5.68 dB (60.3%) as well as radiation pattern (-8 dB to +20 dB) at WLAN communication.

Index Terms - Effective parameters, FDTD, gain, patch antenna, metamaterial, and split ring resonator.

I. INTRODUCTION

Microstrip patch antenna is one of the most commonly used antenna in portable communication devices due to compact, conformal, low cost, and ease of fabrication properties. Although, it offers many advantages as mentioned, it has some disadvantages, which result from conductor and dielectric losses. Beside this, gain reduction and poor directionality are also observed in this antenna due to surface waves [1]. Conductor and dielectric losses can be minimized by using better conducting metal and low loss dielectric substrate, but these choices result in higher fabrication cost. Gain, bandwidth enhancement, miniaturization, and broadband directionality can be provided by using metamaterial structures [2-6]. Metamaterials are manmade structures designed to have properties that may not be found in nature. These structures have both negative effective permittivity and permeability at the same frequency range. It causes negative effective refractive index in the structure [7]. These properties of metamaterial provide novel application opportunities to several disciplines, such as microwave and optical cloacking, focusing of images, and sensing of biological and chemical substances.

Metamaterials have also many application areas for novel antenna systems [8-11]. One of the applications of metamaterials is miniaturization of the microstrip antennas with different types of artificial materials. The conventional way to reduce the antenna size is to use high permittivity substrate. This approach reduces the wavelength of the signal in the substrate [12]. But, this design results in more energy consumption due to high permittivity, since it decreases the bandwidth of the antenna impedance. One another way is to remove the substrate to minimize the effective dielectric constant. This application restricts the wave to travel in the substrate, hence, improving the gain of the patch antenna has been possible [13, 14]. However, the maximum gain enhancement does not exceed 2 dB with all these techniques and the directionality also does not change too much. Hence, many different solutions are proposed to overcome these problems, such as utilization of metamaterials with patch antenna [15-18].

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This article describes a novel way to enhance both the gain and directionality of patch antenna used for WLAN application. Split ring resonators (SRR) for negative permeability and metal strip for negative permittivity are used to improve both gain and directionality of patch antenna. The effective permittivity of strip and permeability of SRR are evaluated by both finite element method (FEM) based high frequency structure simulator (HFSS) and finite difference time domain method (FDTD) based computer simulation technique (CST). The dimensions of the inclusions are optimized to realize negative values of the constitutive parameters at the operating frequency of antenna. The SRRs and metal strips are fabricated with optimum dimensions to provide negative constitutive parameters at 2.4 GHz. The fabricated metamaterial is mounted on microstrip patch antenna to observe the effects on it. The measurement results are in good agreement with simulated values. It has been noticed that the metamaterial considerably enhances the gain of the patch antenna.

II. METAMATERIAL DESIGN AND CONSTITUTIVE PARAMETERS

Figure 1 illustrates the front and back side of metamaterial structure, which consists of both circular split ring resonator (SRR) and metallic strip (MS). The combination structure is designed on two sides of 10 mm × 10 mm × 1.6 mm FR4-epoxy (ε = 4.4, μ = 1, and dielectric loss tangent δε = 0.02). While the SRR produce magnetic material-like responses and exhibit negative permittivity the MS acts as strong dielectric and exhibits negative permeability [19].

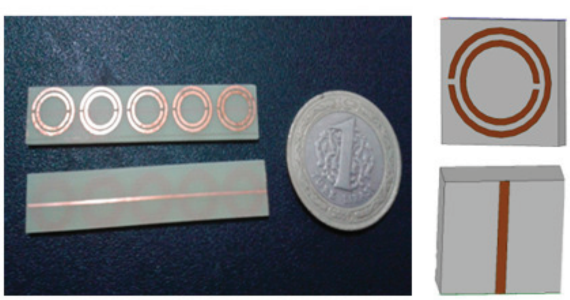


Fig. 1. Front and back view of metamaterial.

All the dimensions of the SRR and MS are optimized by HFSS to achieve negative permittivity and permeability at 2.4 GHz. The TEM wave is applied to the metamaterial. E field is applied paralel to the MS and H field is applied normal to the plane of SRR. It means that the system is a direction dependent. The periodicity of one unit cell with SRR-MS is obtained by assigning perfectly electric conductor-PEC (side normal to E field) or perfectly magnetic conductor- PMC (side normal to H field) to the sides of the unit cell. The constitutive parameters are evaluated from scattering parameters (S_{11} and S_{21}) by using Nicolson Ross Weir (NRW) approximation [20, 21],

$$z = \sqrt{\frac{(1+S11)^2 - S21^2}{(1-S11)^2 - S21^2}} \tag{1}$$

$$n = \frac{j}{kod} \ln\left(\frac{S21}{1 - S11\frac{z-1}{1+z}}\right) , \tag{2}$$

$$\varepsilon_{eff} = n/z \; ; \; \mu_{eff} = n.z \tag{3}$$

where z, d, and k_0 represent impedance, thickness of the metamaterial and free space wave number, respectively. The effective permittivity, permeability and refractive index are denoted by ε_{eff}, μ_{eff}, and n, respectively. The simulations are realized up to 6 GHz. All of the electromagnetic constitutive parameters are negative at 2.4 GHz. Hence, this structure can be used as negative refractive index metamaterial with patch antenna operating at this frequency as shown in Fig. 2.

Microstrip patch antenna is fabricated to operate at frequency range in which permittivity and permeability of metamaterial utilized with this antenna are negative. In this study, the frequency of 2.4 GHz is chosen for the operating frequency of microstrip patch antenna of which specifications are shown in Table I.

Table I: Dimensions of patch antenna on FR4 laminate.

Parameter	**Magnitude**	**Unit**
Operating frequency	2.4	GHz
Patch length(L)	59	mm
Patch Width(W)	42.4	mm
Laminate length (Lg)	75	mm
Feed	coaxial	-
Laminate Thickness	1.6	mm

The microstrip patch antenna is fabricated on an FR4 substrate (ε = 4.4, μ = 1, and dielectric loss tangent δε = 0.02).

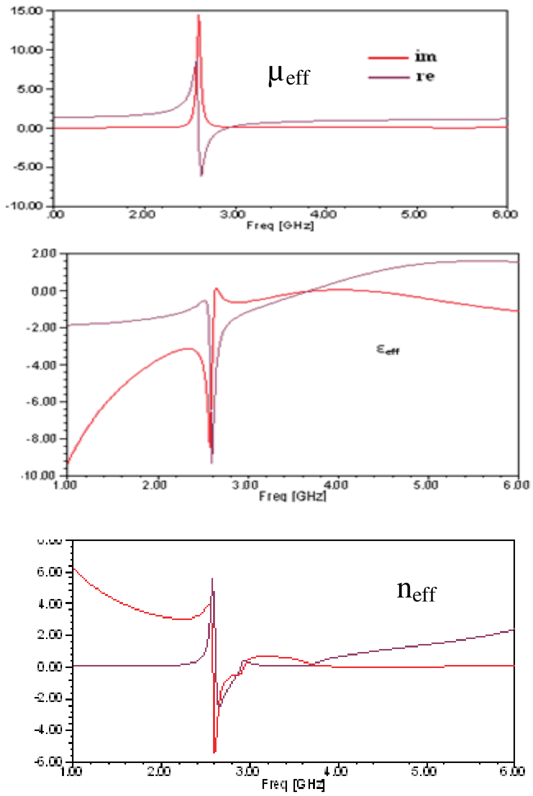
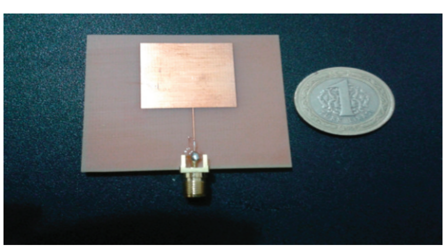


Fig. 2. Effective parameters of metamaterial.

The evaluated results are obtained by HFSS and CST simulators and measured results of microstrip patch antenna without metamaterial are shown in Fig. 3. Return loss measurement is realized by using ENA series network analyzer (E5071B). While return loss (gain value), S_{11} value, of patch antenna is -13.68 dB in HFSS and -16.64 dB in CST, measured value is only -9.42 dB. The difference between measured and simulated values of antenna results from measurement mistakes and fabrication process.



S_{11}	HFSS	CST	Measurement
Patch Antenna	-13.68dB	-16.64 dB	-9.42 dB

Fig. 3. Microstrip patch antenna without metamaterial and return losses in dB.

Effect of the metamaterial to return loss of the microstrip patch antenna is investigated by placing metamaterial on it. The SRR-MS structure is fabricated to obtain negative constitutive parameters at 2.4 GHz and it is periodically mounted on microstrip antenna as shown in Fig. 4.

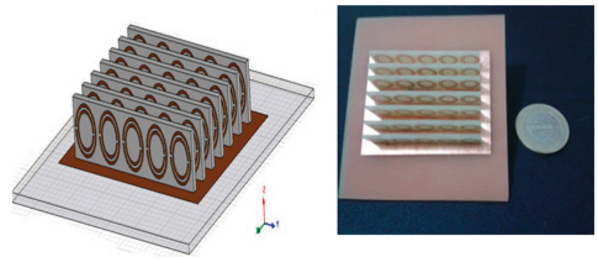


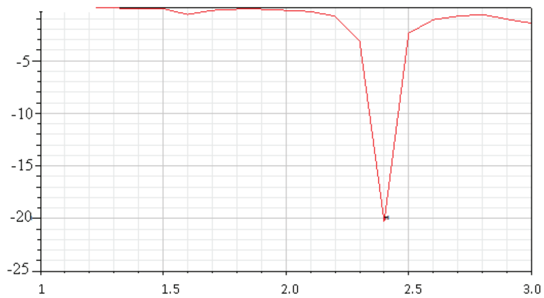
Fig. 4. Fabrication of patch antenna-metamaterial system.

The direction of the metamaterial is important to improve gain of the patch antenna, since the metamaterial has anisotropic behavior. Therefore, they are mounted such that the center of SRR are parallel to H field and MT is parallel to E field direction of the antenna. The distance between the periodically arranged metamaterials is 2 mm. The simulated and measured results of microstrip patch antenna covered with metamaterial are shown in Fig. 5.

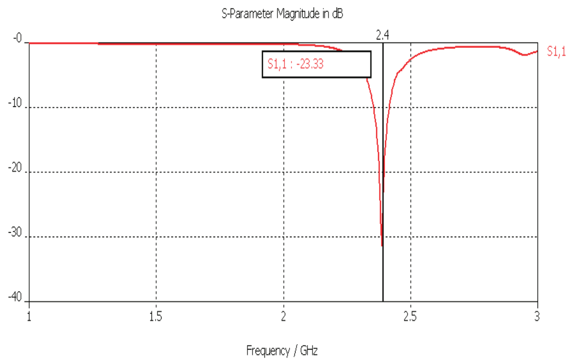
While the return loss decreases down to -20.27 dB in HFSS simulation and -23.33 dB in CST simulation, it is observed -15.1 dB in measurement at 2.4 GHz. This means 60.3% enhancement of the antenna gain (return loss) with respect to antenna without metamaterial. The enhancement results of antenna with and without metamaterial is indicated in Table II. Good gain improvement (return loss) is obtained for all of HFSS-CST and measurement results. Although, measured return loss (S_{11}) of the patch antenna with metamaterial indicates several modes at different frequencies as shown in Fig. 5 (c), but these modes are not sufficient to mention about new extra radiation frequencies. Since the return losses of these extra modes are higher than -10 dB.

Table II: Comparison of simulation and measurement results of return loss (S_{11}).

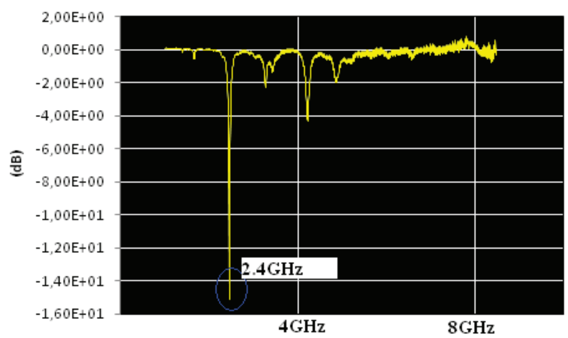
	HFSS	CST	Measurement
W/O MTM	-13.6812 dB	-16.64 dB	-9.42 dB
with MTM	-20.2712 dB	-23.33 dB	-15.1 dB
Gain	-6.59 dB	-6.69 dB	-5.68 dB



(a)



(b)



(c)

Fig. 5. (a) HFSS simulation, (b) CST simulation, (c) and measurement results of patch antenna with metamaterial.

It is well known that the radiation pattern of the antenna with and without metamaterial give exact idea about the gain of the antenna system, since the return loss (S_{11}) is not enough alone to decide the antenna performance. The radiation patterns of the patch antenna with and without metamaterial are evaluated by HFSS as shown in Figs. 6 and 7. The radiation patterns of H plane are simulated at every 30^0 between $0^0/180^0$. Although, the maximum radiation gain of the antenna without metamaterial is -8 dB (Fig. 7), it reaches up to +20 dB for antenna with metamaterial (Fig. 6). These exhibits that metamaterial not only provide minimization of return loss (S_{11} value) but also give chance to enhancement of the antenna gain.

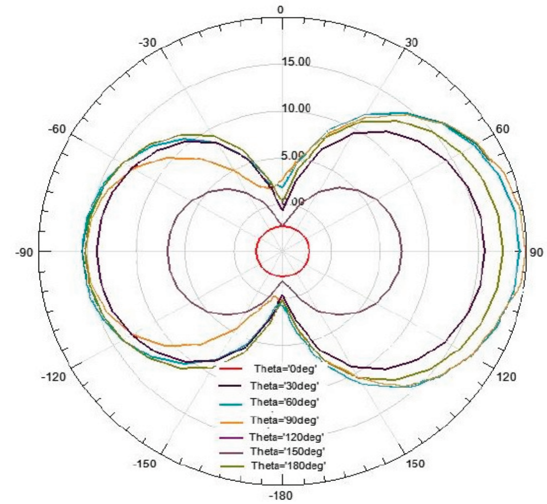


Fig. 6. HFSS simulation of the radiation pattern for the patch antenna with metamaterial.

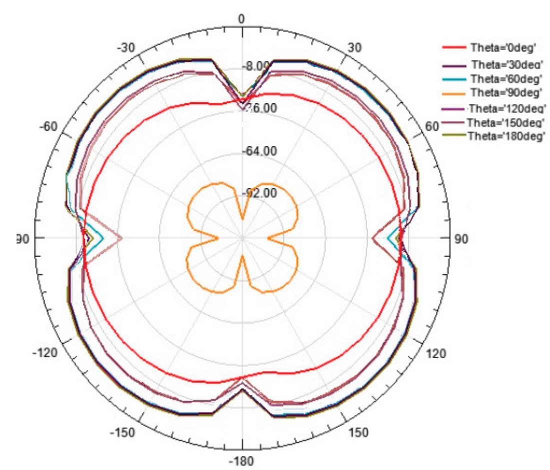
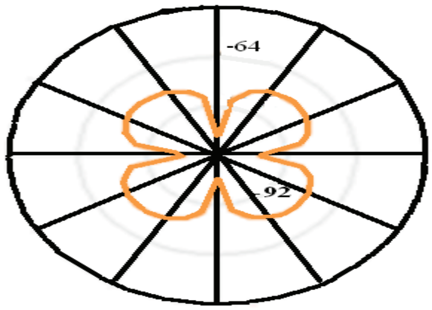


Fig. 7. HFSS simulation of the radiation pattern for the patch antenna without metamaterial.

Beside the simulations of radiation pattern, measurement is also realized to observe the effect of metamaterial on patch antenna by using MATS1000. The HFSS simulation for patch antenna without metamaterial and measurement result for patch antenna with metamaterial are shown in Fig. 8. Two different antennas are used at the measurement. One of them is metamaterial mounted patch antenna and the other one is ring antenna to observe the radiation pattern of H plane. Whereas simulation result of H plane radiation gain is around -72 dB, measurement result is much better (-47.5 dB). These results indicate the enhancement of antenna radiation gain due to the metamaterial.



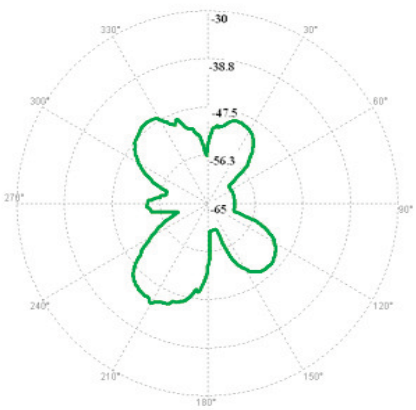


Fig. 8. Simulation and measurement radiation pattern results of patch antenna without and with metamaterial (H plane).

III. CONCLUSIONS

In this study, simulation, fabrication, and measurement are investigated for microstrip patch antenna covered with metamaterial composed of SRR and MS. The results show that good improvement in the antenna characteristics in terms of gain is achieved. The gain of the microstrip patch antenna with metamaterial is increased by 6.69 dB from simulation and 5.68 dB from measurement. It can be concluded that microstrip patch antenna based on metamaterial exhibits improvement on the antenna gain performance. Therefore, metamaterials provide potential application areas to antenna researchers, such as improvement of the gain or radiation properties of any type of antenna.

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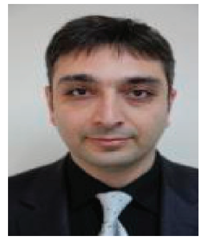

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