High Gain Patch Antenna for 2.4GHz using Metamaterial Superstrate

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***Abstract* — A patch antenna and our proposed metamaterial patch antenna are simulated and compared. A high gain patch antenna using a single layer metamaterial superstrate with a near to zero refractive index (*n*) is proposed. The simulation results provide that the gain of the proposed antenna is increased by about 7dB. Consequently, the high gain antenna can be easily obtained by using our metamaterial superstrate.**

Keywords* — *Patch Antenna, Metamaterial, Superstrate, Single Layer

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1 Introduction

Since Veselago has investigated various properties of metamaterials with the negative permittivity (ε) and permeability (μ), numerous applications of metamaterials such as high-directive antennas and superlens have been continuously explored[1]. Metamaterials are also called doubly negative material(DNG), negative refractive index(NRI) and left handed material(LHM). Metamaterials have been extensively studied in the framework of microwave application recently[2-3]. High gain antennas were developed using metamaterial[4-8]. We have focused on the design of a high-gain antenna with a metamaterial superstrate having a near to zero refractive index (*n*) behavior in a specified frequency band. In this paper, we have presented the patch antenna structure covered with a planar thin metamaterial superstrate whose rdfractive index *n* is nearly zero over a frequency range. The proposed antenna has 7dB more gain than a patch antenna.

2 Antenna Design

Our proposed metamaterial patch antenna(PMPA) consists of an ordinary patch antenna and the proposed metamaterial cover.

The total size of the ordinary patch antenna(OPA) is 319.5mm X 319.5mm, where the patch (38.55mm X 46.95mm) is located at center. The substrate's parameters are relative dielectric constant 2.33, board thickness 1.524mm and copper thickness 0.035mm.

The proposed metamaterial pattern shown in Fig. 1 is made by removing central 5X5 to 7X7 lattices out of the ordinary metamaterial pattern shown in Fig. 2[6-7]. Two patterns are fabricated on top and bottom surfaces of superstrate that has relative dielectric constant 2.22, board thickness 0.5mm and copper thickness 0.018mm.

The unit square lattice shown in Fig. 3 has the outside-length P and the inside-length L.

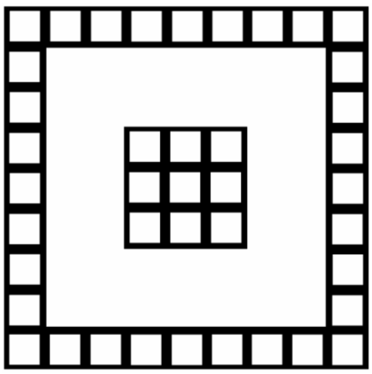

Fig. 1 Proposed metamaterial pattern (bottom-surface)

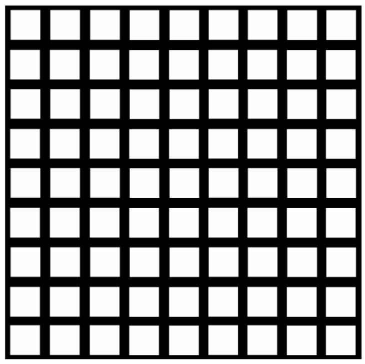

Fig. 2 Ordinary metamaterial pattern (top-surface)

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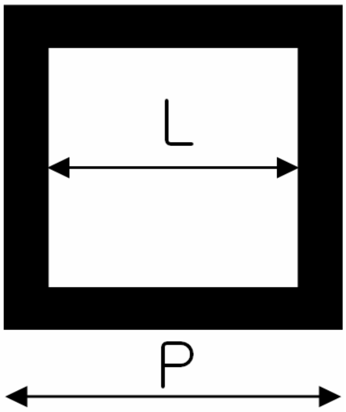


Fig. 3 Unit square lattice

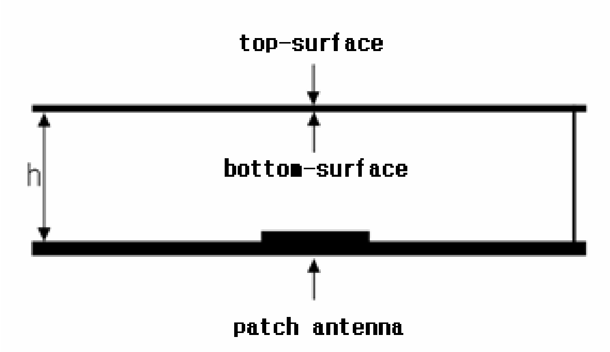


Fig. 4 Structure of proposed metmaterial patch antenna

The structure of our proposed metamaterial patch antenna is shown in Fig. 4. Height(h) is a distance from superstrate to ordinary patch antenna. The parameters are generally $P \approx \lambda/4$, $L \approx \lambda/5$ and $h \approx \lambda/4$, where λ is a wavelength at the operating frequency[8]. P=35.5mm and L=30.32mm are found out in simulation for the maximum gain at 2.4GHz.

3 Simulation Results

Proposed metamaterial patch antenna has h=56.1mm for the maximum gain. And S11 of OPA and PMPA are shown in Fig. 5. The gain pattern shown in Fig. 6 shows that our proposed antenna has a higher gain than an ordinary patch antenna.

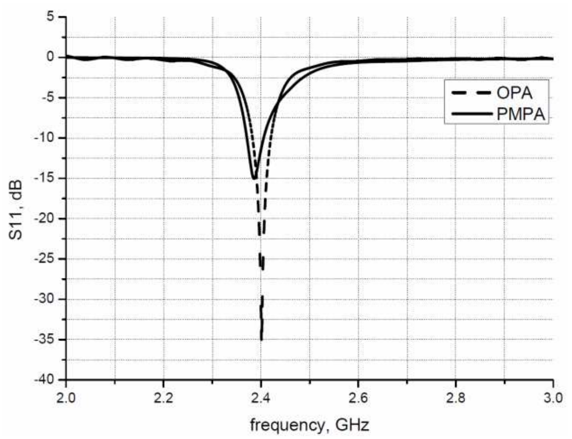


Fig. 5 Comparison of the simulation S-parameter

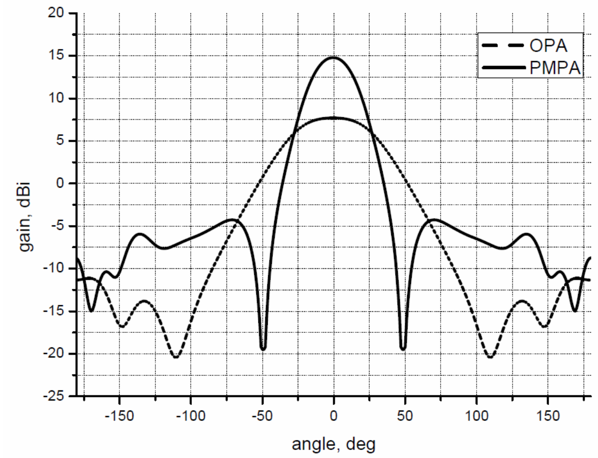


Fig. 6 Gain pattern of patch antennas

The results of simulation are shown in Table 1. The gain of the proposed metamaterial patch antenna is improved by 7dB compared with that of the ordinary patch antenna.

Tab. 1 Comparison of the simulation results

	Frequency (GHz)	S11 (dB)	Gain (dBi)
OPA	2.4	-35	7.7
PMPA	2.386	-15.05	14.7

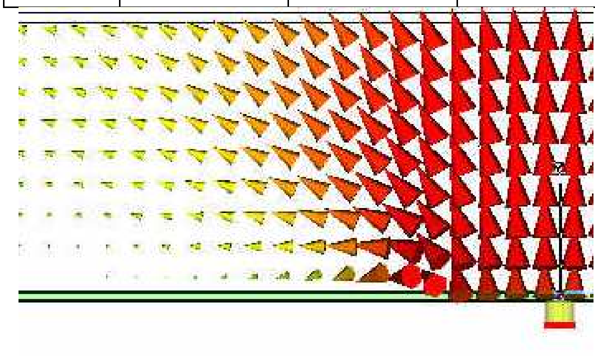


Fig. 7 Power flow of OPA

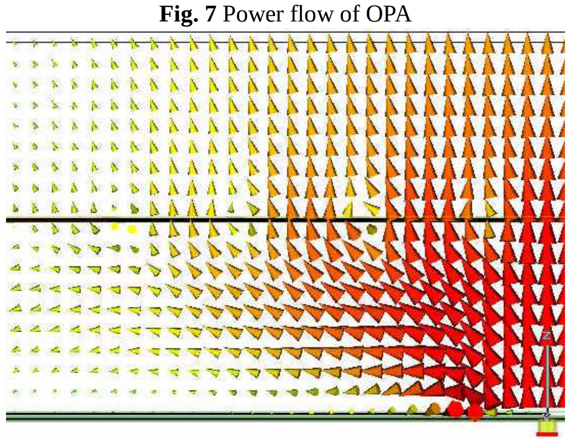


Fig. 8 Power flow of PMPA

Fig. 7 and Fig. 8 show the power flow of antennas. Power leakage in the side lobe direction can be seen in Fig. 7. But in Fig. 8, the power flow in the side lobe direction seems to be concentrated into the broadside direction. So the gain could be increased.

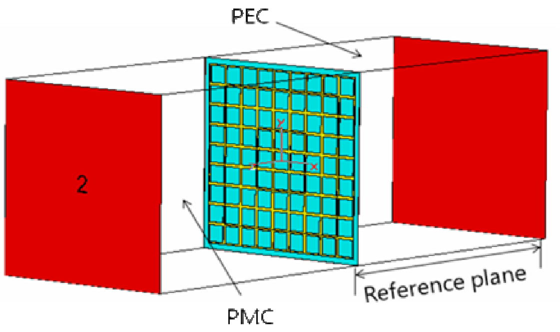


Fig. 9 Simulation setup for the retrieval of effective medium parameters of the proposed metamaterial.

The simulation setup for the determination medium parameters is shown in Fig. 10. The medium parameters are retrieved from the transmission and reflection coefficients by using the approach described in Refs [9-10]. The numerical computation is performed on a single unit cell with periodic boundary condition.

The next expression shows the simulated transmission and reflection coefficient for normal incidence.

$$S_{11} = \frac{(1-z^2)\Gamma_{12}}{1-\Gamma_{12}^2 z^2} \tag{1}$$

$$S_{21} = \frac{(1-\Gamma_{12}^2)z}{1-\Gamma_{12}^2 z^2} \tag{2}$$

$$z = \frac{(S_{11}+S_{21})-\Gamma_{12}}{1-(S_{11}+S_{21})\Gamma_{12}} \tag{3}$$

$$\Gamma_{12} = \frac{1-(S_{21}^2-S_{11}^2)}{2S_{11}} \pm \sqrt{\left[\frac{1-(S_{21}^2-S_{11}^2)}{2S_{11}}\right]^2 - 1} \tag{4}$$

$$\Gamma_{12} = X \pm \sqrt{X^2 - 1} \tag{5}$$

$$X = \frac{\sqrt{\mu_r}}{\sqrt{\varepsilon_r}} = \frac{1+\Gamma_{12}}{1-\Gamma_{12}} \tag{6}$$

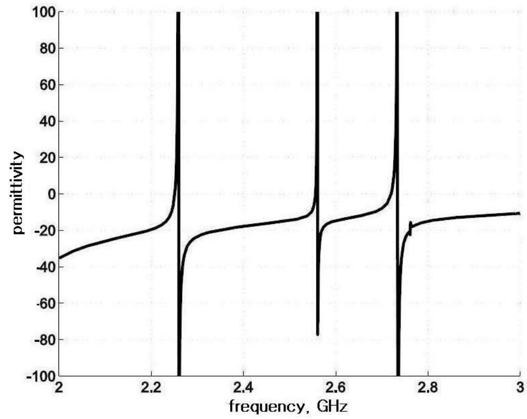
$$Y = \sqrt{\mu_r \varepsilon_r} = j\frac{c_0}{dw}\ln(z) \tag{7}$$

The permittivity and permeability can be obtained from the above equation.

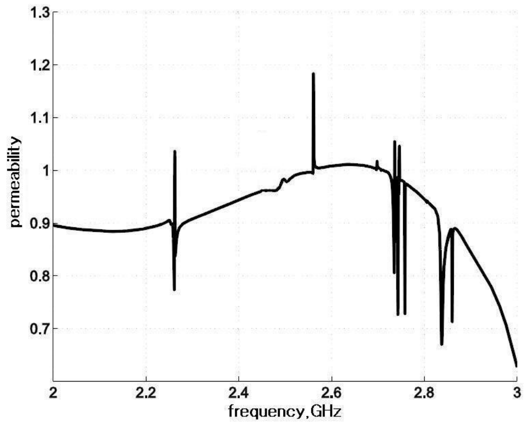
$$\varepsilon_r = \varepsilon_{r,real} - j\varepsilon_{r,imag} = Y / X$$
$$\mu_r = \mu_{r,real} - j\mu_{r,imag} = YX \tag{8}$$

The Snell-Decartes law imply that the refractive index can be defined as[5]

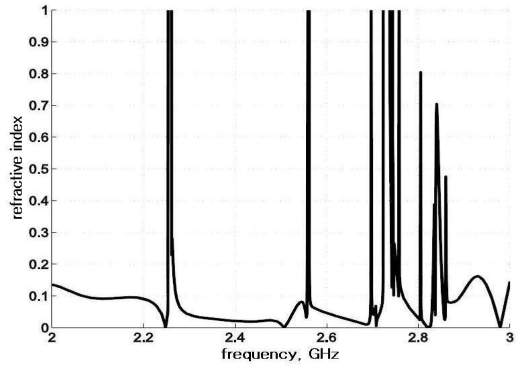
$$n = \sqrt{\mu_r \varepsilon_r} \tag{9}$$



(a) permittivity



(b) permeability



(a) refractive index

Fig. 10 Comparison of simulated and measured effective medium parameters of proposed metamaterial

The retrieved effective parameters (Fig. 10(a) and 10(b)) show a negative real part for the permittivity and a positive real part for the permeability. A near to zero refractive index in the 2.4Ghz band is shown in the Fig. 10(c).

4 Conclusion

Patch antennas have been researched, our proposed metamaterial patch antenna has more gain than those. The simulation results are compared for 2 types of antennas. The ordinary patch antenna and proposed metamaterial patch antenna have gain 7.7dBi and 14.7dBi, respectively. Therefore, the gain of the proposed metamaterial patch antenna is improved by 7dB than that of the ordinary patch antenna.

5 Acknowledgments

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(From P.29)

Tab.2 The statistical chart of test results without using OFDM

Type / Time	Sending bytes number	Correct revived time	Error rate
100	32	98	2%
100	64	98	2%
200	32	195	2.5%
200	64	194	3 %
300	32	293	2.3%
300	64	292	2.6%

The test results show that with the increasing of data, error rate maintains in 2.89% without using OFDM. This is mainly caused by many negative factors, such as channel noise, multipath effect, channel decline. In addition, the equipment of this system also has a certain error rate. After using OFDM method, error rate maintains in 2.4%. It shows that the error rate has been decreased. The results have basically achieved the expected aim and implemented the function of communicating through the tubulous water channel.

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