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Improved Radiation of Micro-strip Patch with Metamaterial as a Cover

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Abstract-

This paper presents design of microstrip patch antenna with metamaterial cover with operating frequency at 2.4 GHz, for wireless communication systems. The Industry, Scientific and Medical (ISM) Band, unlicensed with the range 2.40 - 2.4835 GHz is used as the operation band. The maximum directivity can be achieved by controlling the distance between the patch antenna and metamaterial cover. Return loss of -24.23 dB with VSWR 1.10 at 2.48GHz. The results shows that the proposed antenna has the directivity are 4.74dB for patch without Meta material cover & 5.91dB for patch with metamaterial cover. The antenna parameters are investigated and optimization is performed by varying the distance and thickness of metamaterial.

Keyword – Metamaterial (MTM), Omega Structure, negative permeability and permittivity

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. INTRODUCTION

THE IEEE standard defines an antenna as a part of a transmitting or receiving system that is designed to radiate or to receive electromagnetic waves [1]. In other words, the antenna is an important transitional structure between two transmission medium; free space and guiding devices. Microstrip antennas have unique features and attractive properties such as low profile, light weight, compactness and conformability in structure. With those advantages, the antennas can be easily fabricated and integrated in solid-state devices. Microstrip antennas are widely applied in radio frequency devices with single-ended signal operation. This has recently been used in microwave design with a combination of metamaterials, either as a cover or a substrate [2].

A metamaterial is a structural composite with unique electromagnetic properties due to the interaction of waves with the finer-scale periodicity of conventional materials [3]. The person responsible for discovering the concept of metamaterials in 1967 was Veselago [4]. Veselago assumed the existence of unknown materials with negative permeability and permittivity in the same frequency range. When he studied uniform plane-wave propagation, the materials showed abnormal electromagnetic properties [4-6]. Surprisingly, Veselago's work received little attention until 2000, when Smith further studied LHMs and realized that this metamaterial is a periodically-arranged conducting concrete that also shows extraordinary properties [5].

The first structure to prove the existence of metamaterials was a split ring structure invented in 2001 by Shelby Smith and Schultz at the University of California, San Diego [7]. Three new structures were proposed in 2005, starting with a symmetrical ring structure, then an omega structure, and finally an S structure [8]. In this paper, an omega structure was used to construct the metamaterial substrate as cover because of the perfect conducting shape and the improved performance [8]. The proposed design was simulated and analyzed using HFSS.

2. METAMATERIAL

In this design structure, the combination of FR4 material and the omega structure made of PEC were used to build up the metamaterial cover. The PEC is very important for assuming the ideal case during the simulation to obtain the best results from the metamaterial. The detailed features are shown in Table 1.

TABLE 1: ROGERS RT5880 SUBSTRATE PROPERTIES

Properties	Values
Permittivity,	2.2
Permeability,	1
Substrate Height, h	0.5mm

3. THE PATCH ANTENNA

A rectangular microstrip patch antenna consists of several parts such as feeder line, radiation patch and the substrate. The overall dimensions of the antenna are shown in Figure 1.

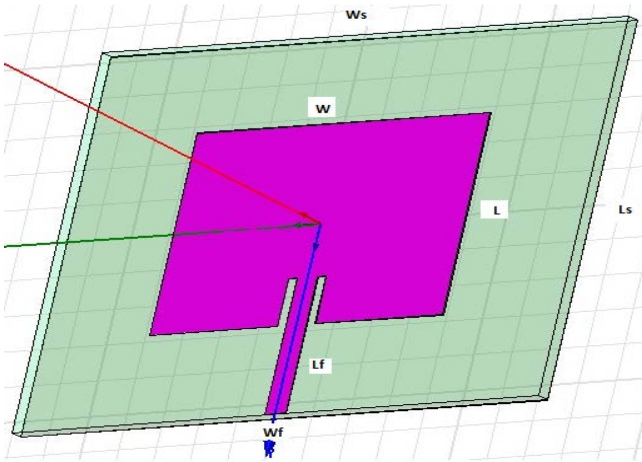

Figure 1: A view of a conventional antenna

Radiation patch, feeder line and ground plane are made of PEC, while the substrate is FR4. The antenna was designed to operate at 2.4GHz. The dimensions of the antenna were obtained by

Step 1: Calculation of the width of Patch (W)-

The width of the Microstrip patch antenna is given as

$$W = \frac{c}{2f_o\sqrt{\frac{(\varepsilon_r+1)}{2}}}$$

For c=3*10^8 m/s2, f_o=2.4GHz, ε_r=4.4

We get W=38.22 mm.

Step 2: Calculation of effective dielectric constant -

Fringing makes the microstrip line look wider electrically compared to its physical dimensions. Since some of the waves travel in the substrate and some in air, an effective dielectric constant is introduced, given as:

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}}$$

For εr=4.4, h=1.6mm, W=38mm

We get $\varepsilon reff$=3.99

Step 3: Calculation of Length of Patch(L)-

The effective length due to fringing is given as:

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{reff}}}$$

For c=3*10^11 mm/s, $\varepsilon reff$=3.99, f_o=2.4GHz

We get *Leff* =30.25 mm

Due to fringing the dimension of the patch as increased by ΔL on both the sides, given by

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

For W=38.4mm, h, =1.53mm, $\varepsilon reff$=3.99

We get ΔL=0.70mm

Hence the length the of the patch is: L= Leff-2ΔL=28.4 mm

Step 4: Calculation of Substrate dimension-

For this design this substrate dimension would be

Ls=L+2*6h=53mm

Ws=W+2*6h=70mm

4. APPLICATION OF METAMATERIAL

Two investigation methods are presented in this paper. The first method is a patch that applies the conventional as the base substrate the second uses a metametrial as the base substrate and third uses a thinner metametrial as a cover over the conventional antenna.

a) Conventional antenna

As a result, the substrate W and L of the Metametrial antenna were optimized by a L=27.6mm and W=38.0mm, respectively. The new calculated antenna dimensions are shown in Table 2.

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Table 2. Calculated dimensions of the patch antenna

Properties	Dimensions(mm)
Patch Width(W)	38.0
Patch Length(L)	27.6
Substrate Width(W)	70.0
Substrate Length(L)	53.0
Feeder Width(W)	3.0
Feeder Length(L)	15.2

b) Metamaterials as Base Substrate

The use of metamaterial as a base substrate means that the FR4 was replaced by a RT5880. As a result, the substrate width and length of the metamaterial antenna were increased by a L=41.2mm and W=48.2mm, respectively. The new calculated antenna dimensions are shown in Table 3.

Table 3: Calculated dimensions of the metamaterial

Properties	Dimensions(mm)
Patch Width(W)	41.2
Patch Length(L)	48.2
Substrate Width(W)	80.0
Substrate Length(L)	75.0
Feeder Width(W)	4.7
Feeder Length(L)	19.2

c) Metamaterial as a Cover

Thirty unit cells (11mmx5mm dimensions) of metamaterial with the same omega structure were combined into a slab to build up a metamaterial cover. The constructed slab was shown in Fig. 2.

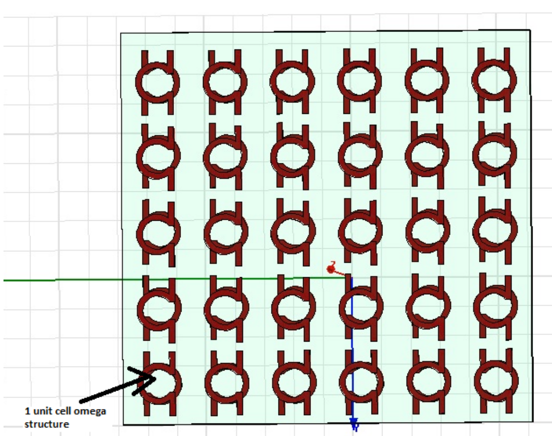


Figure 2: A metamaterial as cover from a combination of 30 unit cells

The constructed cover was located a distance *d* from the conventional antenna to act as a cover. The *d* can be varied to
obtain the best return loss and radiation pattern. The combination of metamaterial cover and conventional antenna was shown in Fig. 3. The best value of *d* obtained after the optimization process was 65 mm, which is about half wavelength. Also the best thickness of cover h obtained after the optimization process was 0.5mm.

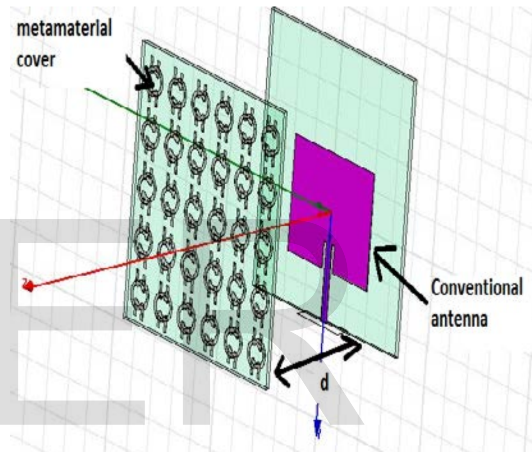


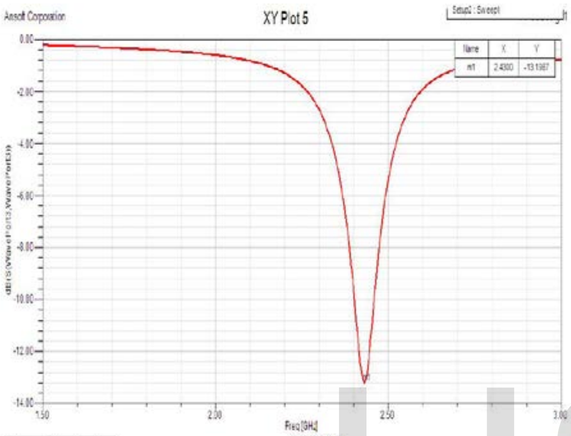
Figure 3: A metamaterial as a cover acts as the conventional patch antenna cover

5. RESULTS AND DISCUSSION

The best dimensions of both antennas were obtained after optimization processes. The performance of the metamaterial cover was higher than the conventional that operating at the same frequency of 2.4 GHz.

Conventional antenna without metamaterial antenna & conventional antenna with metamaterial as cover was designed and simulated. The return loss from this antenna will be used to compare the performance to the other conventional antennas to prove that the metamaterial cover is able to perform better at the operating frequency of 2.4 GHz, compared to the same sized conventional antenna.

Fig.4.a. shows plots of return losses for a conventional antenna (antenna 1), Fig.4.b. shows plots of return losses for a Metametrial antenna(antenna 2) and Fig.4.c.shows conventional antenna with meta cover(antenna 3) that has exactly same dimensions as the antenna on a conventional substrate (antenna 1). All return losses were below -10dB, which is considered good for antennas. The high value of return loss means that the reflection wave return back to the source is very small and the amount of radiation power is very high. This characteristic is very important in radiator devices such as antennas.



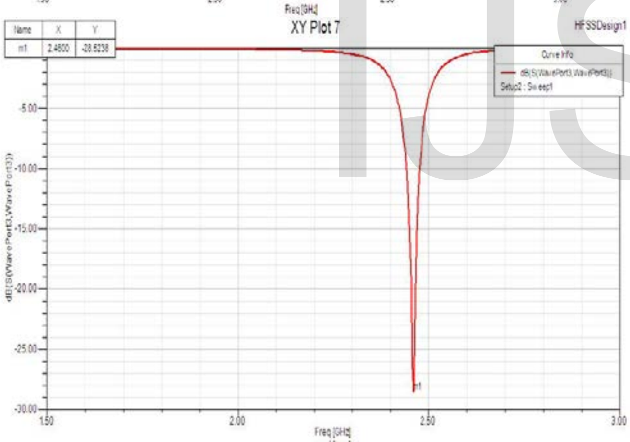
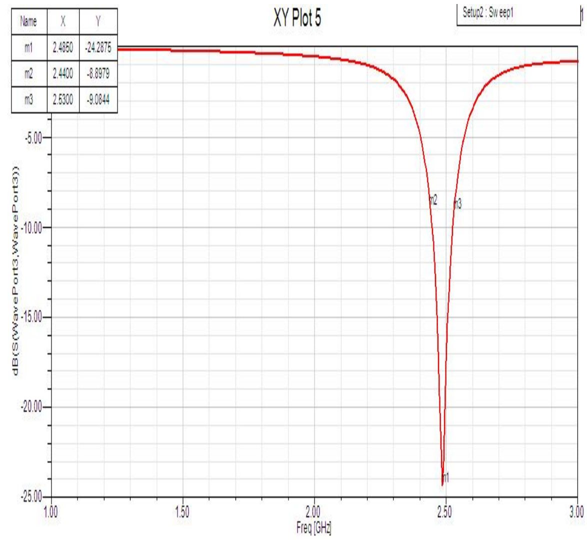


Fig.4.a): Return loss of Conventional Patch antenna

b): Return loss of metmaterial Patch antenna



c): Return loss of conventional Patch antenna with metamaterial cover

The bandwidth of antenna 3 is about 90 MHz, the same as antenna 1. The addition of a met material cover to a conventional antenna did not have much effect on the bandwidth but radiation efficiency will be increased. Antenna 3 is suitable for WLAN applications because of its small bandwidth, high directivity, good return loss and small in size.

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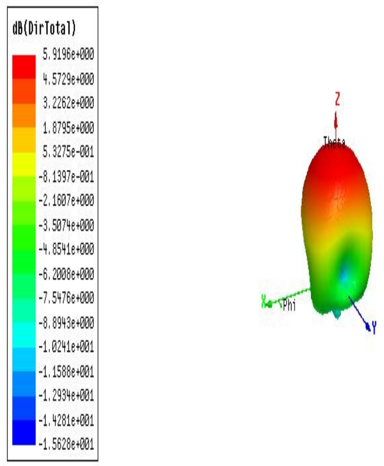

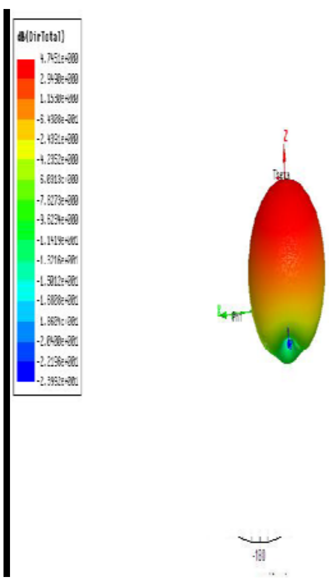

Fig. 5: Directivity of conventional antenna with metamaterial cover

With the additional of a metamaterial as a cover over the conventional antenna, the directivity can be improved. Fig. 5 and show the directivity gains of the same antenna but one with and another one is without the metamaterial cover, respectively. The conventional antenna without the cover has maximum radiation directivity of 4.74 dBi while the antenna with the metamaterial cover has 5.91 dBi. A high radiation directivity of an antenna indicates that the antenna has high power intensity. The focus beam of the antenna will be very sharp and thus increases the performance in propagating signals.A comparison of performance from both conventional with & without Metamaterial cover and is shown in Table 4.

TABLE 4: COMPARISON BETWEEN CONVENTIONAL, METAMETRIAL & CONVENTIONAL WITH METAMETRIAL COVER

Antenna	Frequency (G Hz)	Return Loss(dB	VSWR	Directivity(dB)	Beam Width (deg)
Conventional Antenna	2.43	-13.19	1.56	4.74	82.64
Metamaterial Antenna	2.46	-28.52	1.07	5.93	72.83
Conventional With Metamaterial cover	2.47	-24.82	1.16	5.91	64.45

6. CONCLUSION

An omega structure of metamaterial has been tested and proven at the higher the performance other than conventional antenna. Step- by-step procedures for designing the antennas were presented in this paper. The size of a patch antenna using a metamaterial as cover is same as that of a conventional antenna. On the other hand, a conventional antenna with improved radiation directivity can be realized by utilizing a metamaterial as a cover. The improvement of directivity gain with the usage of a metamaterial as cover is proof that the metamaterial can enhance the overall performance of the antenna. Good return losses were also obtained from the antennas on metamaterial and the conventional design with as cover.

7. FUTURE DEVELOPMENT

Several improvements to enhance the bandwidth of the metamaterial antenna can be taken into consideration for future research. The metamaterial can be designed using different substrate and structure. Different type of patches and feeding techniques may also affect the performance of the antennas. Instead of using a single unit cell, a combination of unit cells can be applied in designing an antenna on metamaterial substrate.

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