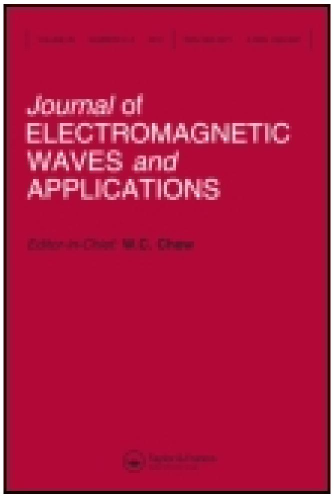

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A Multi-Band Patch Antenna on Metamaterial Substrate

Z.-B. Weng [a] , Y.-C. Jiao [b] , F.-S. Zhang [c] , Y. Song [d] & G. Zhao [e]

[a] National Laboratory of Antenna and Microwave Technology, Xidian University, Xi'an 710071, Shaanxi, China

[b] National Laboratory of Antenna and Microwave Technology, Xidian University, Xi'an 710071, Shaanxi, China

[c] National Laboratory of Antenna and Microwave Technology, Xidian University, Xi'an 710071, Shaanxi, China

[d] National Laboratory of Antenna and Microwave Technology, Xidian University, Xi'an 710071, Shaanxi, China

[e] National Laboratory of Antenna and Microwave Technology, Xidian University, Xi'an 710071, Shaanxi, China

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A MULTI-BAND PATCH ANTENNA ON METAMATERIAL SUBSTRATE

Z.-B. Weng, Y.-C. Jiao, F.-S. Zhang, Y. Song, and G. Zhao

National Laboratory of Antenna and Microwave Technology
Xidian University
Xi'an 710071, Shaanxi, China

Abstract—This paper presents a novel technique to change the impedance characteristics of patch antenna to achieve multi-band. The proposed structure is based on the metamaterial concept. By replacing the conventional substrate of patch antenna with metamaterial, the impedance characteristics can be effectively changed to produce multi-band property. The design is based on the dispersive characteristic of the substrate by using metamaterial structure. To validate the proposed approach, numerical and experimental results are presented; the results show the validity of our approach.

1. INTRODUCTION

Metamaterials have recently attracted a very important number of researchers. Based on metallic structures, the periodic alternation of these components can give rise to very interesting properties such as negative permittivities, negative permeabilities, negative permittivities and negative permeabilities simultaneously, and permittivities that are positive and less than one. Potential applications of the negative parameters have been reported in [1–6]. For directive antenna applications, the last property is usually explored and applied [7]. Indeed, by exciting only one radiating element embedded inside a periodic structure, these antennas are able to provide high directive beams.

Furthermore, metamterials can also be used to achieve multi-band properties. In conventional microstrip, multi-band operation usually achieved by utilizing the multiresonance characteristics of a single patch, by reactively loading the patch with quarter-wavelength stubs, by using shorting posts, by cutting slots, and by adding lumped elements [8, 9]. However, the approach in this paper is based on using the dispersive characteristic of the substrate to create some different effect permittivity, and operates the microstrip antenna at multi-band corresponding to its various resonant modes.

2. ANALYSIS OF THE PROPOSED ANTENNA

On the basis of the general antenna design process, the exploded and top views of the proposed antenna are shown in Fig. 1. It is constituted of two layers. The top substrate contains the radiating element and metamaterial structure. The ground plane is in the bottom layer. The substrate parameters are $\varepsilon_r = 2.65$ with the thickness h_1, the air gap is h_2. The patch antenna is driven by coaxial probe. The size of patch antenna is $W \times L$. The metamaterial structure is composed of very thin copper grids with square lattices whose period is equal to a, the period of square aperture in the copper grids is b. The grids is composed of 5×5 cells, the total length of grids is $5a$. Four modulated parameters, the period size of the metamaterial a, b and the height of the top and the bottom layers h_1 and h_2, are used to modulate the operating frequency.

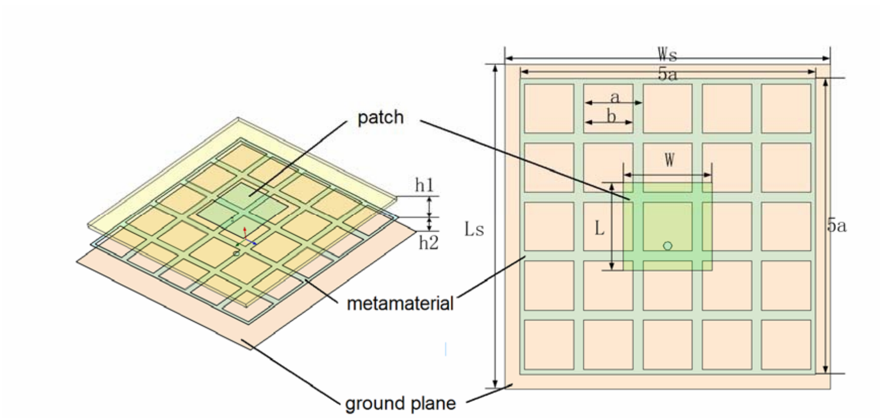


Figure 1. Schematic of the proposed patch antenna.

While the size of the patch is confirmed, the important parameters of the proposed antenna are a, b, h_1, h_2. The parameters of this proposed antenna are studied by changing some parameter at a time and fixing the others. The return loss of the multi-band patch antenna based on metamaterial structure and the radiation characteristics of the antenna are investigated by numerical method. The simulation results are given using Ansoft HFSS 3-D simulator, which is based on the finite element method (FEM). The properties of three general cases

Table 1. Three general case of proposed antenna with different a and b.

Case	a (mm)	b (mm)
1	33	28
2	33	31
3	36	31

specified by values of a and b are summarized in Table 1. We recall that in all of these cases h_1 and h_2 are constant. The calculated return loss curves for each case of Table 1 are plot in Fig. 2.

From the results shown in Fig. 2, we found that the antenna work at multi-band and the resonant frequencies shift to the high side while a or b increases. This property of the metamaterial based antenna give us a new method to realize multiband of patch antenna, and suitable a and b can be chosen to achieve the band we want.

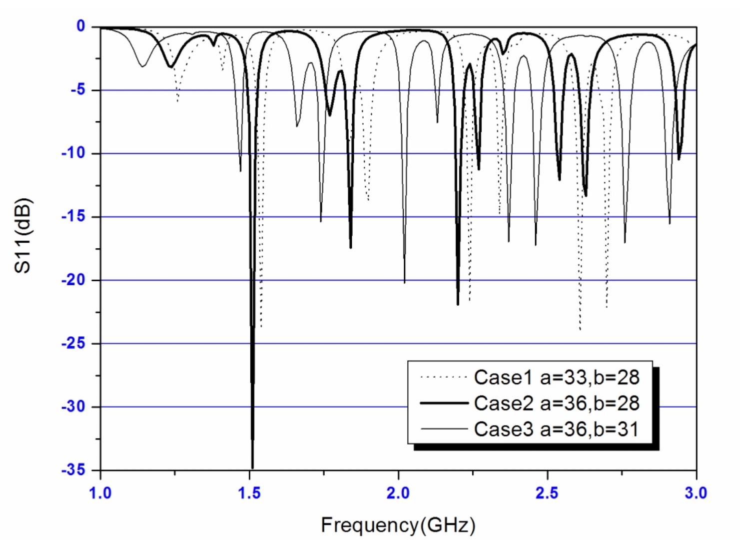


Figure 2. Simulated return loss of the proposed antenna with different values of a and b (Table 1) and $h_1 = 2$ mm, $h_2 = 2$ mm.

Figure 3 shows the effect of h_1 and h_2 parameters (Table 2) in the metamaterial based patch antenna while $a = 30$ mm and $b = 25$ mm. From the simulated results in the Fig. 3, we can conclude that the resonant frequencies shift a little to the high side while h_1 and h_2

increases. In the thesis [10], we can know that the ε_{eff} decreases while a, b, h_1, h_2 increase, so the resonant frequencies shift to the high side while ε_{eff} increase. These characteristics can be clearly concluded from Fig. 2 and Fig. 3.

Table 2. Three general case of proposed antenna with different h_1 and h_2.

Case	h1 (mm)	h2 (mm)
1	1	1
2	2	2
3	3	3

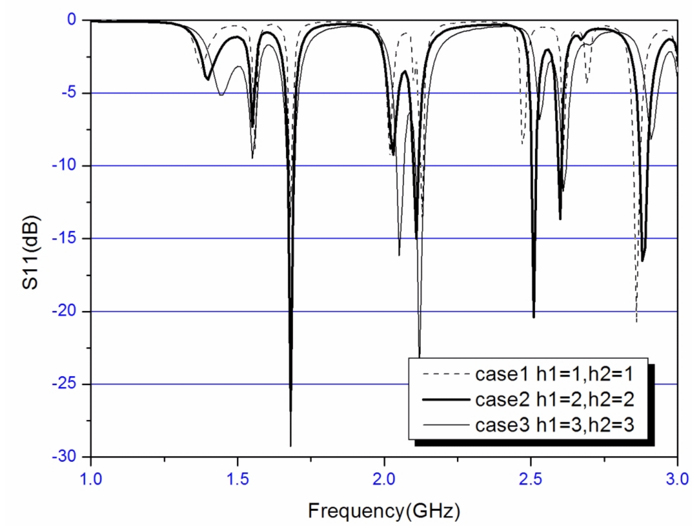
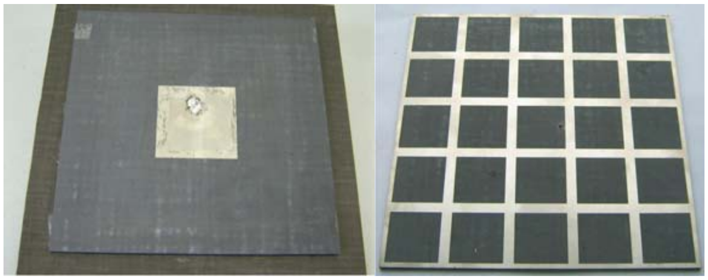


Figure 3. Simulated return loss of the proposed antenna with different values of h_1 and h_2 (Table 1) ($a = 30$ mm, $b = 25$ mm).

3. EXPERIMENT AND RESULTS

At the end of our design procedure, the final dimensions are summarized in Table 3. Fig. 4 presents the photograph of a realized multi-band patch antenna with SMA connector. The return loss was measured by Agilent 8722ES Vector Network Analyzer, the radiation patterns and the gain were tested in the far field chamber. Fig. 5



(a) (b)

Figure 4. (a) Photograph of the realized metamaterial patch antenna and (b) back side of the top layer.

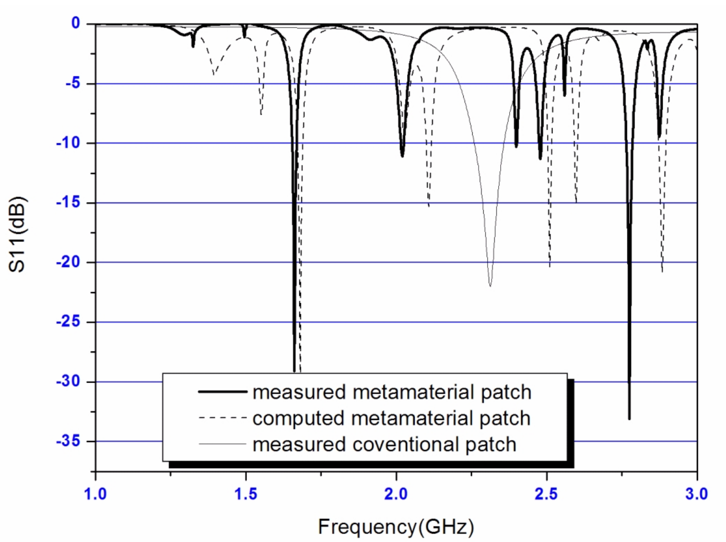


Figure 5. Measured and simulated VSWR for proposed antenna.

shows the measured and simulated VSWR characteristics for proposed antenna and the conventional patch antenna without metal grids was also measured. As shown in Fig. 5, there exists some discrepancy between measured data and the simulated results, the measured resonant frequencies are shifted towards a lower side, The reason is that the fabricated substrate has a higher permittivity than 2.65. The fabricated antenna satisfies the 10 dB return loss (VSWR $<$ 2)

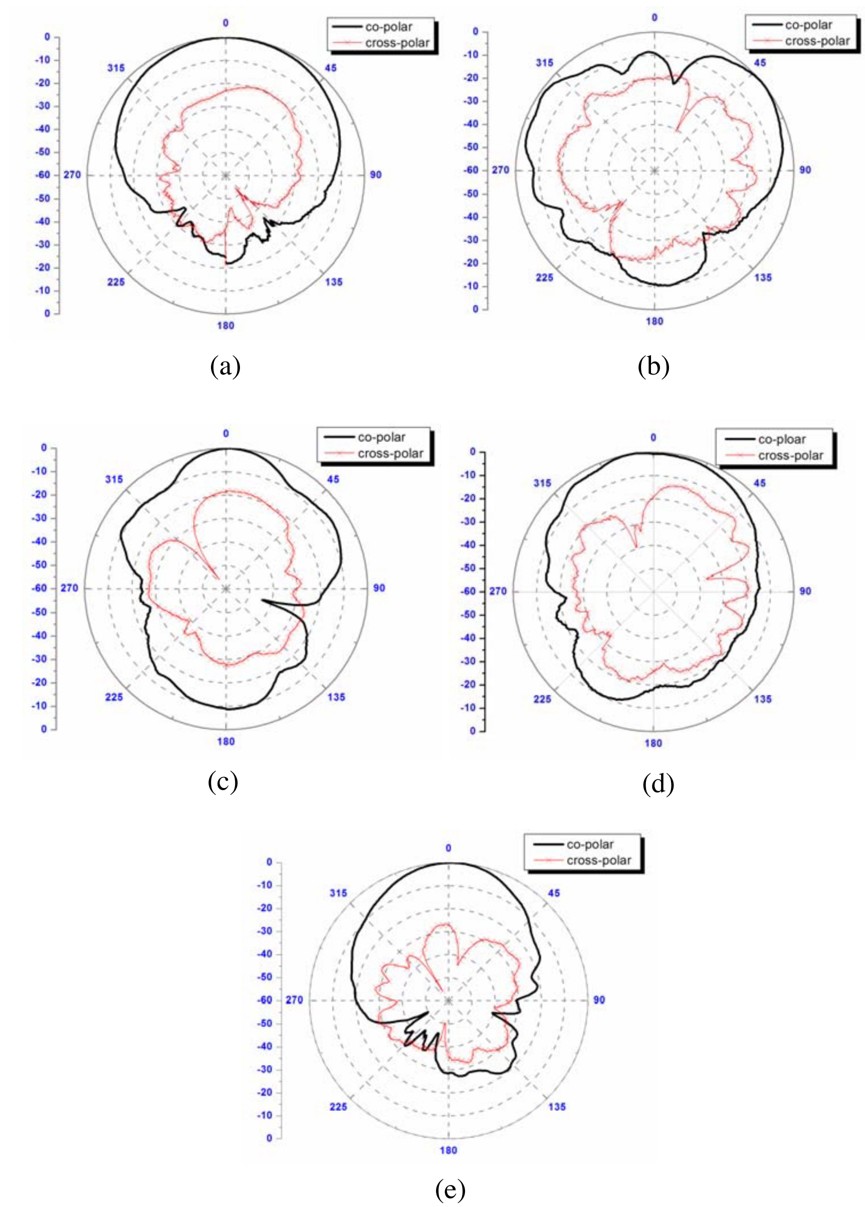


Figure 6. Measured radiation patterns (E-plane) of the proposed antenna at: (a) 1.66 GHz (b) 2.02 GHz (c) 2.4 GHz (d) 2.48 GHz (e) 2.77 GHz.

Table 3. Parameters of fabricated patch antenna.

Parameters	Values (mm)	Parameters	Values (mm)
a	30	W	45
b	25	L	45
h1	2	Ws	165
h2	2	Ls	165

requirement for 1.66 GHz, 2.02 GHz, 2.4 GHz, 2.48 GHz, 2.77 GHz. Fig. 6 shows the measured radiation patterns including the cross-polarisation in E-plane. The antenna gains in these frequencies are also measured. The measured results are tabulated in Table 4.

Table 4. The electrical characteristics of the patch antenna.

Frequency (GHz)	Gain (dB)	HPBW (E-plane)	Return loss (dB)
1.66	5.8	82°	−29.1
2.02	0.8	48°	−11.1
2.40	4.2	34°	−10.1
2.48	3.6	69°	−11.4
2.77	8.2	45°	−33.0

4. CONCLUSION

A novel multi-band patch antenna based on the metamaterial concept has been present and experimentally verified. By replacing the conventional substrate of patch antenna with dedicatedly designed metamaterial substrate, the patch can achieve multi-band, and the measured results show that the radiation characteristics perform well at each resonant frequency. The proposed structure gives us a new idea to design antennas for Multi-band wireless communication systems.

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