Impedance Bandwidth and Gain Improvement for Microstrip Antenna Using Metamaterials

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Abstract. *An improved ultra-wideband (UWB) and high gain rectangular antenna is specifically designed in this paper using planar-patterned metamaterial concepts. The antenna has isolated triangle gaps and crossed gaps etched on the metal patch and ground plane, respectively. By changing the pattern on the ground, the impedance matching characteristics of the antenna are much better. The -10 dB impedance bandwidth of the proposed antenna is 3.85–15.62 GHz, which is about 267% broader. The proposed antenna has an average gain of 5.42 dB and the peak is 8.36 dB at 13.5 GHz. Compared with the original one, the gain of the proposed antenna improved about 1.4 dB. Moreover, the size is reduced slightly. Simulated and experimental results obtained for this antenna show that it exhibits good radiation behavior within the UWB frequency range.*

Keywords

Metamaterial, ultra-wideband, microstrip antenna, high gain.

1. Introduction

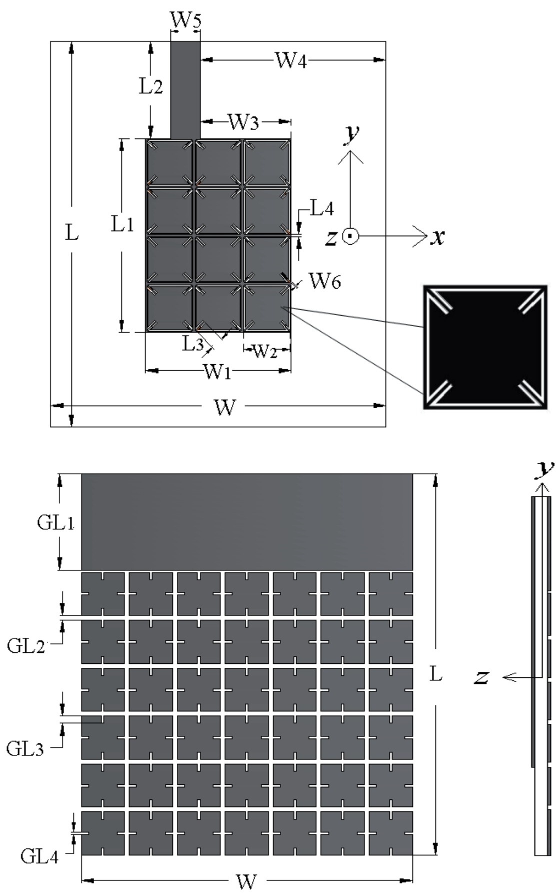
Commercial UWB systems require small low cost antennas and large bandwidth [1]. It is a well-known fact that printed microstrip antennas present really appealing physical features, such as simple structure, small size and low cost. A narrow bandwidth is, however, the main drawback of the microstrip patch antenna. Some techniques have been developed for bandwidth enhancement. These techniques are mainly increasing the thickness of the substrate, using different shaped slots or radiating patches [2], [3], stacking different radiating elements of loading of the antenna laterally or vertically [4-6], utilizing magnetic dielectric substrates [7] and engineering the ground plane as EBG metamaterials [8].

Design techniques have been developed to produce antennas with different properties that can fulfill the requirements in different applications. In some cases, current designed antenna can meet those requirements, while the others cannot. For example, some designs of the antennas can meet impedance bandwidth requirements, but the gains or sizes are not very good [9], [10]. Often the requirements are extremely difficult or physically impossible to achieve. Nonetheless, antenna design techniques keep evolving to meet the application requirements. Recently, new types of fabricated structures or composite materials that mimic media with non-natural environmental management properties were introduced in the microwave and optics fields. These new types of materials are known as metamaterials. With the flexibility and new properties provided by metamaterials, new types of antennas have been conceived [11-13], so making their designs more straightforward.

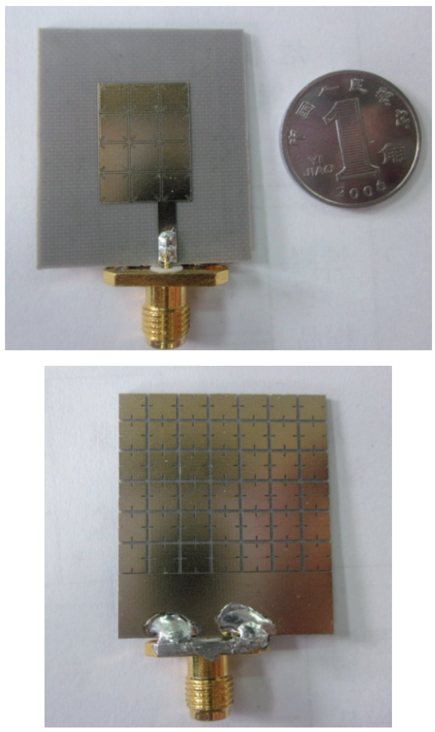
In this paper, a UWB microstrip antenna with higher gain and wider band is proposed. The configuration of the initial antenna with dimensions of 28 × 32 mm^2 is shown in [14]. The bandwidth of that antenna is from 5.3 to 8.5 GHz for $|S_{11}| < -10$ dB and the gain is generally above 4 dB with the peak of 7.2 dB. In the work reported this paper, three improvements were made. The proposed antenna can operate from 3.85–15.62 GHz for $|S_{11}| < -10$ dB and the average gain is 5.42 dB with the peak of 8.36 dB at 13.5 GHz. Moreover, the designed antenna has a smaller size of 27.6 × 31.8 mm^2. Simulated and measured results are presented to validate the usefulness of the proposed antenna structure for UWB applications.

2. Antenna Design

A conventional microstrip patch antenna is usually mounted on a substrate and backed by a conducting ground plane. In the present investigation, a planar left-handed material pattern on the rectangular patch antenna mounted on the substrate is designed to enhance its horizontal radiation as well as broaden its working bandwidth via its coupling with the conducting ground backed to the substrate and patterned in a different way. The geometry of the proposed compact metamaterial antenna is illustrated in Fig. 1 (a), which is printed on a F4BM-2 substrate of thickness 0.8 mm, and permittivity 2.2. The width of the microstrip feedline is fixed at 2.40 mm to achieve 50-Ω characteristic impedance from 3.85 to 16.15 GHz. One the upper layer, four isosceles triangles surrounded by a square frame are



(a)



(b)

Fig. 1. (a) Geometry of the proposed metamaterial antenna and (b) photograph of the fabricated antenna prototype.

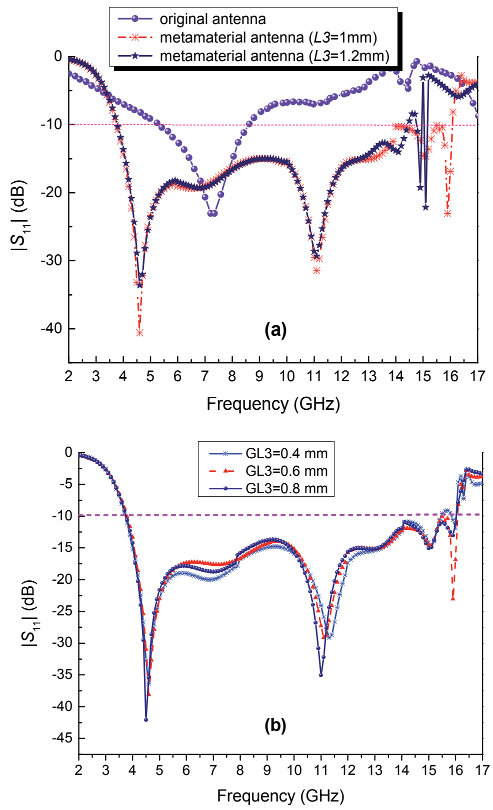
connected at their apex, and from the connected portion, four narrow metal strips are radially connected to the outer frame in the unit cell; On the lower layer, there are the square metal patches with periodic gaps. The left-handed characteristics of these patterns were already demonstrated in [15], [16] and thus will not be further discussed here.

The proposed antenna is investigated by changing one parameter at a time, while fixing the others. To fully understand the behavior of the antenna's structure and to determine the optimum parameters, the antenna was analyzed using Ansoft simulation software high-frequency structure simulator (HFSS). The magnitudes of the physical parameters of the proposed antenna are as follows: L = 31.8 mm, W = 27.6 mm, $L1$ = 16 mm, $L2$ = 8 mm, $L3$ = 1 mm, $L4$ = 0.2 mm, $W1$ = 12 mm, $W2$ = 3.8 mm, $W3$ = 7.5 mm, $W4$ = 15.3 mm, $W5$ = 2.4 mm, $W6$ = 0.1 mm, $GL1$ = 8 mm, $GL2$ = 0.4 mm, $GL3$ = 0.6 mm, $GL4$ = 0.2 mm.

3. Parametric Study

In order to fully understand the influence of these parameters on the impedance bandwidth, a parametric study was carried out by varying each parameter, while holding the remaining parameter values as section 2. This study is conducted by simulation using Ansoft HFSS.

Fig. 2(a) – (c) show the simulated parametric studies on the reflection coefficient $|S_{11}|$, when some parameters are varied. The proposed antenna is an evolution of a metamaterial antenna that was investigated in [14]. The



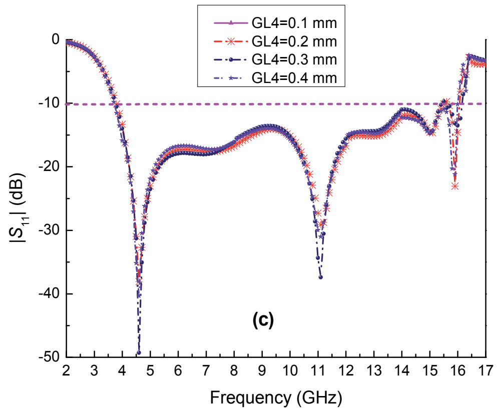


Fig. 2. Parametric studies by varying the (a) length *L*3, (b) length *GL*3 and (c) gap *GL4*.

computed return loss curves of the proposed antenna and the reference metamaterial antenna are obtained and shown in Fig. 2(a). As seen, the -10 dB impedance bandwidth of the reference antenna is 3.2 GHz (between 5.3 and 8.5 GHz), which serves as a benchmark for the improved designs. Fig. 2(a) illustrates that the length of the slots *L*3 has a great impact on the bandwidth. When the proposed antenna is designed to have the $L3 = 1$ mm length of the slots at the top, the -10 dB bandwidth falls within 3.85 and 16.15 GHz, which is 12.25 GHz in bandwidth and is 3.82 times wider than the initial antenna. When the *L*3 becomes 1.2 mm, the -10 dB bandwidth turns within 3.8 and 14.45 GHz, which is 10.65 GHz in bandwidth, and is 3.32 times wider than the initial antenna. So the optimum value of the gap is $L3 = 1$ mm. Fig. 2(b) and (c) illustrate responses of reflection coefficients with different *GL*3 and *GL*4. It is clearly seen that the frequency range is not sensitive to these two parameters. When the values of *GL*3 and *GL*4 increase, the frequency ranges remain unchanged. Note that other parameters such as *W*6 or *GL*2 have the similar conclusions as *GL*3 and *GL*4, but will not be shown here for brevity. Therefore this microstrip antenna has a high manufacturing tolerance. Compared with the initial antenna, the bandwidth of this proposed antenna is very wider. The reason is the increase of current paths on the ground.

4. Results and Discussion

To verify the accuracy of design, the proposed antenna is then fabricated and measured. Fig. 1 (b) shows the photograph of the fabricated antenna prototype. Fig. 3 shows the measured and simulated return loss characteristics of the proposed antenna. The fabricated antenna has the frequency band of 3.85 to over 15.62 GHz. It can be seen that the simulated and measured results are in good agreements. The small discrepancies from 15.62 GHz onward between the simulated and measured results could be attributed to the fabrication tolerances of *L*3. Generally speaking, in order to confirm the accurate return loss characteristics for the designed antenna, it is recommended that the manufacturing and measurement process need to be performed carefully.

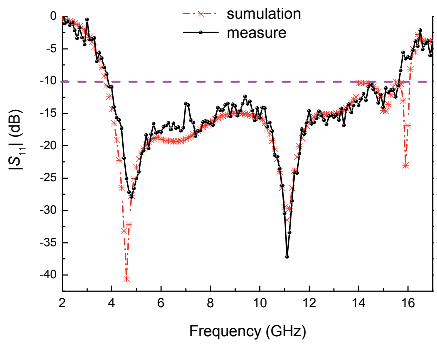


Fig. 3. Measured and computed $|S_{11}|$ values for metamaterial antenna.

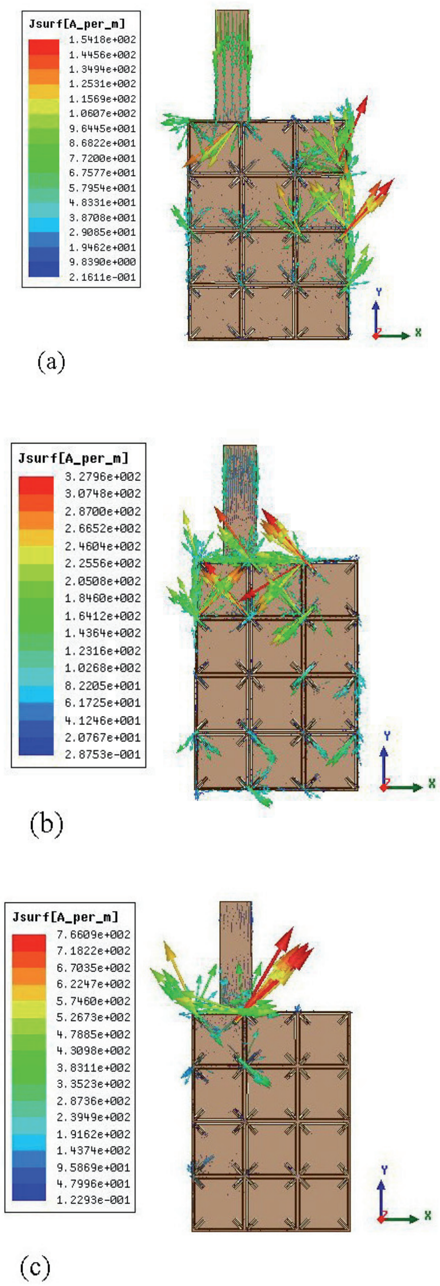


Fig. 4. Simulated current distributions for the proposed antenna at: (a) 5.5 GHz, (b) 9.5 GHz, (c) 13.5 GHz.

To better understand the behavior of the antenna, the simulated current distributions of the radiating element at 5.5, 9.5 and 13.5 GHz are presented in Fig. 4(a), 4(b) and 4(c), respectively. It can be observed in Fig. 4 (a) that the current concentrated on the edge of the right, and then as frequency increases, more and more current concentrated on the top of the patch. As a result, the radiation patterns will gradually close to the -*y* direction.

To further verify the results, the measured co-polarization and cross-polarization radiation patterns are plotted in two-dimensional in Fig. 5, respectively. Seen from the 2D patterns at both of these picked frequencies, the radiated energy is mainly focused around 260° direction in the *x-y* plane. So we may make use of this special characteristic to transmit signal using the antenna as a directional one for beam control.

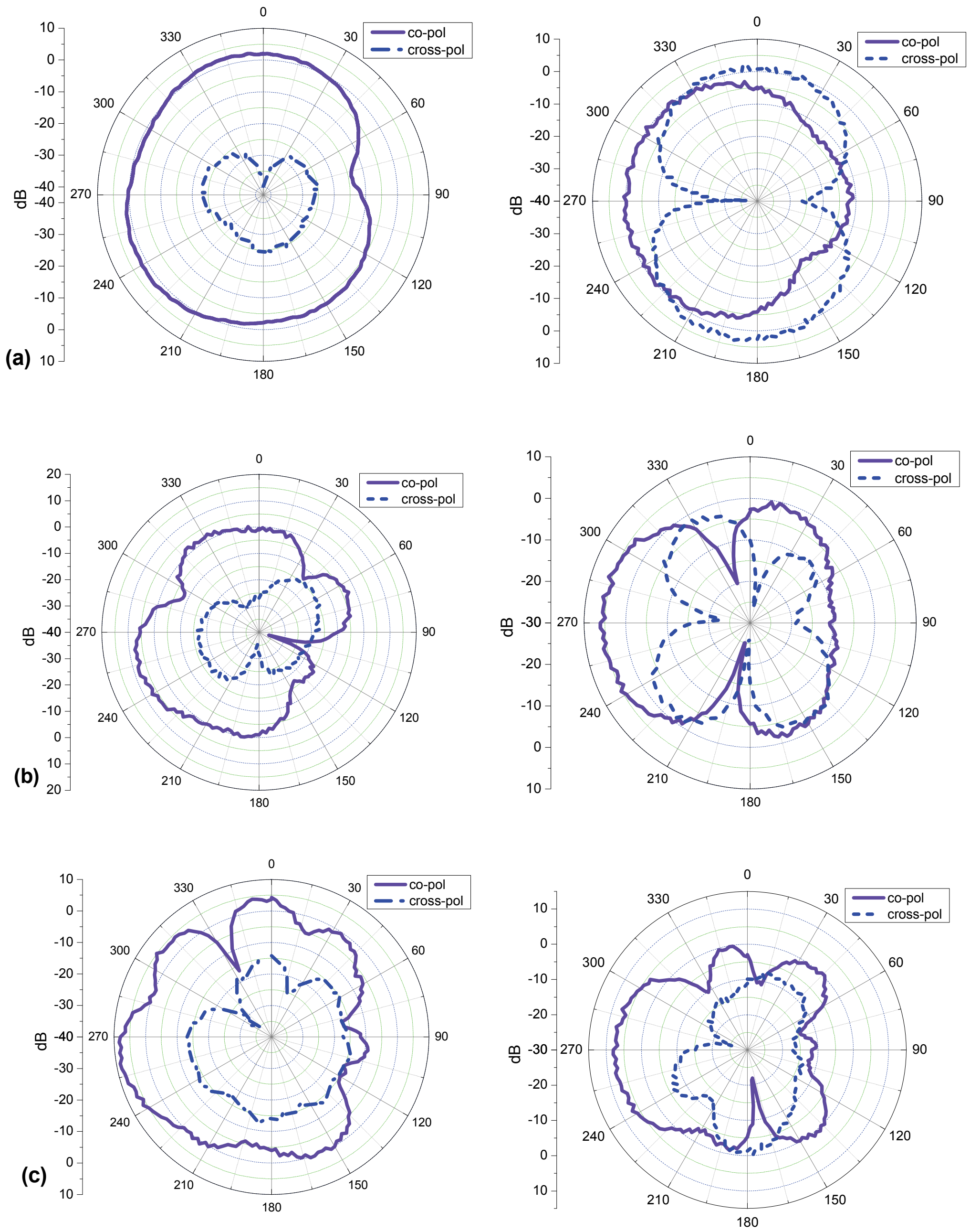


Fig. 5. Measured radiation patterns of co-polarization (solid line) and cross-polarization (dotted line) at different frequencies. (a) 5.5 GHz: *x-y*-plane; *y–z* plane. (b) 9.5 GHz: *x–y* plane; *y–z* plane. (c) 13.5 GHz: *x–y* plane; *y–z* plane.

The measured gain of the proposed metamaterial rectangular patch antenna at various frequencies is shown in Fig. 6. As shown in the figure, the average gain is 5.42 dB and the maximum achievable gain is 8.36 dB at the frequency of 13.5 GHz. Compared with the initial antenna, the average gain of the proposed antenna improved about 1.4 dB and the peak gain improved 1.16 dB.

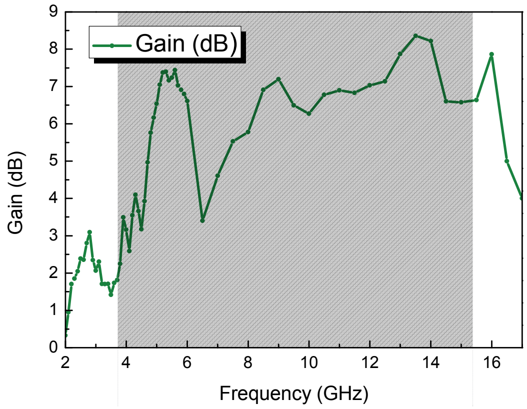


Fig. 6. Measured gain of proposed antenna.

5. Conclusions

In this paper an improved metamaterial rectangular patch antenna with UWB and high-gain patch antenna is successfully designed, fabricated and tested. The dimensions of this improved antenna are 27.6×31.8 mm^2, which is reduced slightly, but the working frequency bandwidth of the patch antenna significantly broadened from 3.85 to 15.62 GHz (at about 4 times). Moreover, the average gain is 5.42 dB with the peak of 8.36 dB at 13.5 GHz. Compared with the initial one, the average gain of the proposed antenna improved about 1.4 dB and the peak gain improved 1.16 dB. The unique radiation characteristics make this antenna would be a good choice for UWB wireless communications in the future.

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