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A Novel Metamaterial Microstrip Antenna of Broadband and High-Gain

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1. Intruduction

Metamaterials represent a type of artificial electromagnetic materials and/or structures of unique electromagnetic characteristics that cannot be observed in nature materials. These characteristics, such as negative refraction, negative group velocity, band gaps and so on, hold good promise in practical applications. Metamaterial research still fails, however, to reshape the microwave industry due to its nature material drawbacks of narrow bandwidth and high loss in microwave frequency regime.

Recently, Li *et al.* [1] had proposed a novel microstrip antenna which has the broad bandwidth successfully obtained and high gain satisfactorily achieved, by applying the planar metamaterial patterned structures directly on the upper patch and bottom ground of the dielectric substrate. The patch antenna can have an excellent performance in comparison with a conventional patch antenna. It was realized that the band-width of the conventional patch antenna has been increased by ten times while the new designed patch antenna using the metamaterials concept has a very high gain in the working frequency band compared with other metamaterial antenna. It was also indicated [2] that the concept implemented based on metamaterial is developed based on the leaky wave enhancement and surface wave suppress.

In this paper, a novel design of this kind of metamaterial microstrip antennas is proposed by integrating simply shaped metamaterial elements. Simulation and experimental data indicate that the antenna return loss bandwidth falls in two frequency bands ranging from 3.4 to 13 GHz and from 14.5 to 17.7 GHz, respectively, which is much broader than the prototypes (5.3 to 8.5 GHz). The antenna gain is generally higher than 4 dB with the peak gain of 7.8 dB; and its efficiency can reach as high as 96%.

2. Antenna Designs

The antenna proposed and presented in this paper is designed to fit into conventional fabrication process, similar to the traditional patch antennas. The antenna structure is shown in Fig. 1, where a 3×4 array of metamaterial antennas consists of a meshed top patch and a patterned ground plane. On the top side of the antenna, a microstrip line is connected to the edge of the patch to feed the meshed antenna. On the back side of the antenna, a patterned ground plane under the microstrip line is utilized to couple the energy transmission in the microstrip line. Also on the back side, a rectangular area is etched to reduce the coupling of the ground plane with the central area of the patch antenna, so that the edge effect of the metamaterial elements can be enhanced.

The essential design thread is to observe the current distribution on the antenna patch to find out which part contributes most to efficient radiation so that the antenna patch layout can be fine-tuned by modifying its elements. Based on this philosophy, we have made an efficient design (whose current distribution is depicted on the right side of Fig. 2 while the current distribution of the earlier design in [1] is plotted in the left side of Fig. 2. For the antenna proposed in Fig. 2, though the surface current distribution is concentrated on the outer patch frame, there are still some strong current distributions inside the structure. Since the radiation of this kind of antennas mostly is contributed by the currents on the outer frame and current inside the patch will need to be minimized. Thus, a new structure is designed in this paper to avoid unwanted currents and to enhance the radiation efficiency. Meanwhile, the new design will try to maintain the dispersion curve of the metamaterial. Based on the above consideration

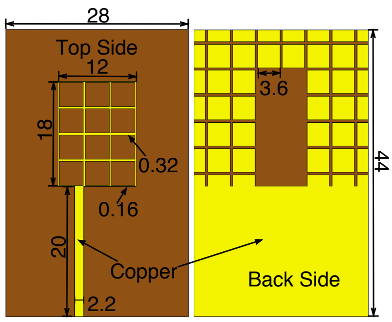

Figure 1: Geometry of the proposed antenna structure (all unit in mm).

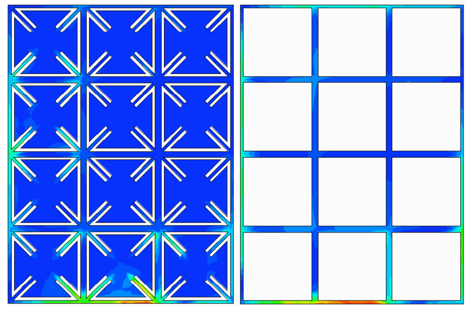

Figure 2: Comparison of simulated surface current distributions on two antennas.

and after a few attempts in simulations, a novel simplified structure is manually optimized for the antenna patch design whose lattice length is 4 mm, line width on the patch is 0.16 mm, gap in the ground structure is 0.4 mm.

Further more, to maximize the current concentration, several elements in the ground are removed. According to simulations and measurements, this modification can enhance the gain of the antenna by about 0.5 dB. However, it will compromise the metamaterial characteristics, and results in a larger back radiation.

A longer microstrip line is considered for a better impedance matching in the lower frequencies, from 8 mm in the prototype to 20 mm in this design. Inevitably, it will enlarge the size of the fabricated antenna. In actual applications, feed line can be very flexible unlike the straight one in this fabrication, thus the enlarged antenna size can be ignored. After all, the patch size doesn't change. The final size of this antenna is 28 mm ×44 mm, the patch size is 12 mm ×18 mm.

3. Simulation and Measurement Results

The antenna was numerically designed, physically fabricated, and practically measured. Fig. 3 shows a photo of the fabricated antenna. In the design, the permittivity of the substrate is $\varepsilon = 2.65$ and thickness is $t = 0.8$ mm. A 50-Ω SMA port is connected to the microstrip line to feed the antenna.

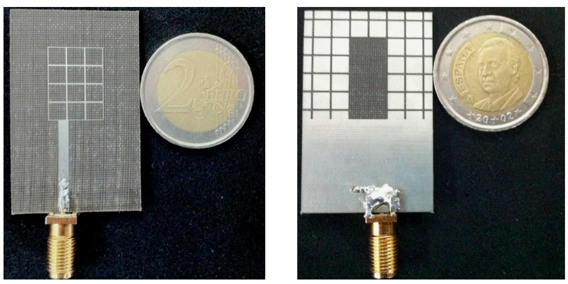

Figure 3: Top and bottom views of the fabricated antenna.

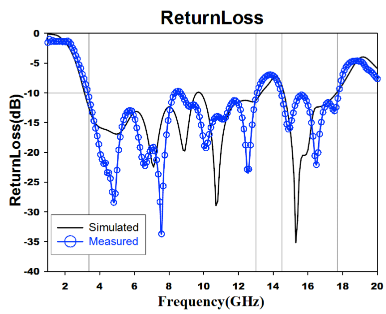

Figure 4: Measured and simulated antenna return loss.

A full-wave finite element method is used in the design, where the return loss and the radiation pattern are numerically calculated. The simulated return loss is presented in Fig. 4, where the −10 dB S11 bandwidth of the antenna falls from 3.4 to 13.5 GHz and from 14.5 to 17.5 GHz, respectively. The measured return loss falls from 3.4 to 13.3 GHz and from 14.5 to 17.7 GHz, respectively. It apparently shows a very good agreement between simulation and measurement results. The bandwidth obtained here is also three times broader than that of a prototype (which is from 5.3 to 8.5 GHz) in [1].

Fig. 5 shows the simulation result of 3D radiation pattern in 7.5 GHz, the main beam of the antenna

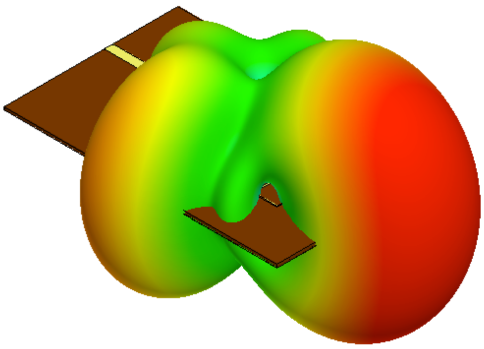

Figure 5: Simulated 3D radiation pattern in 7.5 GHz.

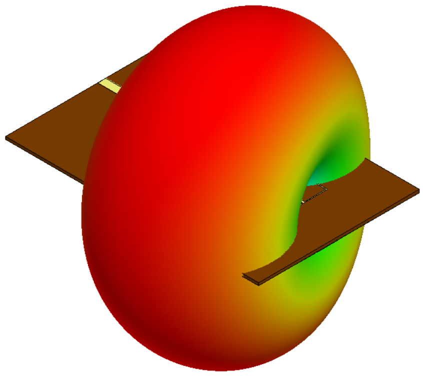

Figure 6: Simulated 3D radiation pattern at 4 GHz.

is in the end-fire direction, which is in the same style of the prototype antenna [1]. It also suggests that the basic radiation principle has not been compromised in this antenna. In the lower band, this antenna radiates like a monopole antenna, due to its electrically small size, as shown in Fig. 6.

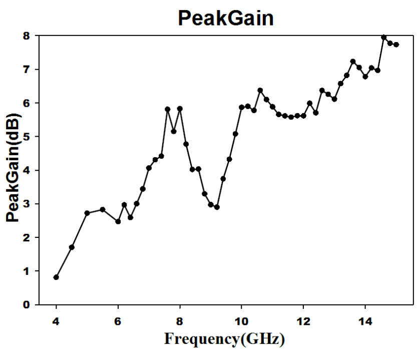

Figure 7: Measured peak gain of the antenna.

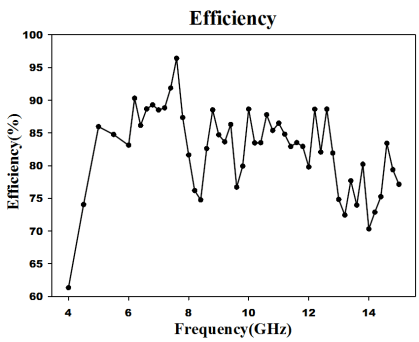

Figure 8: Measured efficiency of the antenna.

The measured peak gain is plotted in Fig. 7. The antenna radiation measurement is made in a microwave chamber, at 4 to 15 GHz. The antenna gain is generally above 4 dB with the peak of 7.8 dB in the working bandwidth. The measured gains are lower than the simulation ones in general by about 1 to 1.5 dB. A lossless substrate is used in the simulation, due to that the loss tangent of the substrate is unavailable, which will lead to a higher simulated gain. The tolerance in the fabrication will also effect the measured results. The efficiency of the microstrip antenna is also measured and shown in Fig. 8. Within the working bandwidth, the efficiency is higher than 75% and as high as 96% at 7.8 GHz, with some exceptions below 4 GHz. In the lower band, the size of the antenna is comparatively smaller than the wavelength, which leads to a lower efficiency.

To further analyze the antenna, the measured co-polarization and cross-polarization 2D radiation patterns are plotted in Figs. 9 and 10, respectively. These two frequencies are chosen from two working bands. It shows that an end-fire radiation pattern is in the *x*-direction of the antenna. The first side lobes are 3-dB less than the main lobe at each frequency. In the lower frequency band, though the return loss is small, but the efficiency is fairly good enough. The end-fire radiation turns into a monopole like radiation due to the small electrical size of the antenna, and it is out of the metamaterial effective band. But still the lower band can be used to transmit EM wave, there could be a dual mode usage of this antenna, omni-directional radiation in lower frequency band and high gain end-fire radiation in the upper frequency band.

(a) (b)

Figure 9: Measured radiation patterns at 10 GHz in (a) xoy-plane and (b) xoz-plane, respectively.

(a) (b)

Figure 10: Measured radiation patterns at 14.6 GHz in (a) xoy-plane and (b) xoz-plane, respectively.

4. Conclusions

A novel broadband and high-gain metamaterial microstrip antenna, which radiates a monopole-type radiation in the lower band and a high-gain end-fire radiation in the upper band, has been presented in this paper. The antenna has two impedance bandwidths which fall from 3.4 to 13 GHz and from 14.5 to 17.7 GHz, respectively. This bandwidth is 3 times broader than that of the prototype (5.3 to 8.5 GHz) in literature. The antenna gain is generally higher than 4 dB, with the peak gain of 7.8 dB. The efficiency of the antenna can achieve as high as 96% and is generally higher than 75% in the working bandwidth.

Acknowledgments

The authors are grateful to the partial nancial support by Project No. 61171046 from National Science Foundation of China, Project No. K201104 from State Key Laboratory of Millimeter Waves, Southeast University, Nanjing 210096, China, and Project No. 9140C080502110C0803 from State Key Laboratory of EM Environment, China Research Institute of Radiowave Propagation, Qingdao, China.

References

[1] Joshua Le-Wei Li, Ya-Nan Li, Tat-Soon, Yeo, Juan R. Mosig and Olivier J.F. Martin, “A broadband and high-gain metamaterial microstrip antenna,” Applied Physics Letters, vol. 96, 164101, 2010.

[2] Joshua Le-Wei Li, Ya-Nan Li, Tat-Soon, Yeo, Juan R. Mosig and Olivier J.F. Martin, “Addendum: ‘A Broadband and High-gain Metamaterial Microstrip Antenna’ [Appl. Phys. Lett. 96, 164101(2010)],” Applied Physics Letters, vol. 99, 159901, November 2011.