Progress In Electromagnetics Research Letters, Vol. 78, 135–139, 2018

A Miniature H-Shaped Patch Antenna Loaded with Mushroom Metamaterials

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Abstract—A miniature patch antenna for handset mobile communication is studied by loading an H-shaped patch associated with fashionable mushroom structures. The mushroom structures work as effective high index metamaterials while the H-shape can lengthen the current path on the patch. They both contribute to reduce the patch length. To verify the conceptual method, an H-shaped patch meta-antenna is demonstrated in full wave simulations and experiments. Good agreement has been observed. A compact patch is achieved for the antenna with a size of $0.15\lambda_0 \times 0.15\lambda_0$. The measured antenna gain is acceptably high as 4.2 dBi.

1. INTRODUCTION

In modern handset mobile communication, miniature patch antennas are of much interest for the advantages of small size, low profile and light weight. A prominent feature of these antennas is that the patch size is smaller than half guided wavelength [1]. In recent years to realize compact configurations, conceptual artificial metamaterials [2–5] have been proposed which are demonstrated effective. In our previous contribution [5], mushroom structures are proposed to be embedded in a natural low index substrate to reduce the patch length. The mushroom structures work as an effective high permittivity meta-substrate. The patch itself is kept integrated. In addition, the compacting effect can also be realized by designing functional structure patterns [6–10] on the patch. As a common alternative to integrated (rectangular or circular etc.) shape, an H-shape is proposed [8] to miniaturize the patch size. Much attention has been focused on H-shaped patch antenna on a natural substrate [8–10].

In this letter, we study a hybrid compacting technique by combining the H-shaped patch [8] and fashionable mushroom metamaterials [5]. A conventional patch antenna usually has a half guided wavelength patch length. By designing functional mushroom structures in the substrate, the patch length will be reduced. And if we further shape the original integrated patch with an H-pattern, the antenna will be even more compact These three kinds of antennas are verified in full wave simulations. The H-shaped meta-antenna is also demonstrated in experiments. The measured results are in agreement with the simulated ones. In experiment, the measured resonant frequency is 2.232 GHz. The physical patch size of the conceptual H-shaped meta-antenna is 20 mm × 20 mm. By normalizing this size to the working wavelength, the normalized electrical size is $0.15\lambda_0 \times 0.15\lambda_0$. We note that this compact design does not sacrifice the antenna gain. The measured antenna gain is 4.2 dBi. Considering the meta-antenna is in such a compact configuration, this gain result is acceptably high which makes the antenna promising for handset communications.

Received 6 August 2018, Accepted 11 September 2018, Scheduled 23 September 2018
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2. ANTENNA DESIGN

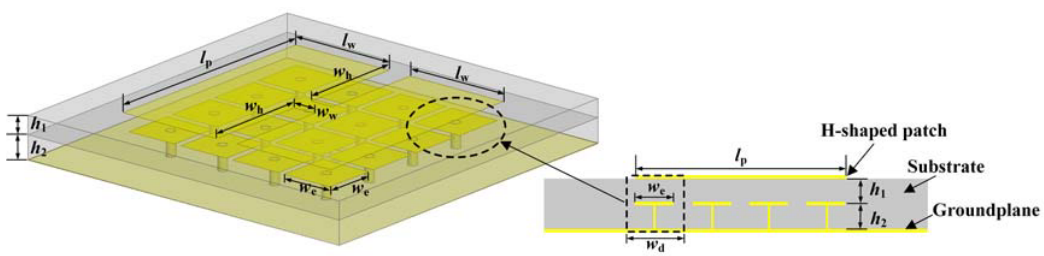
Figure 1(a) shows the configuration of the proposed meta-antenna. We see that an H-shaped patch is designed on the top surface and that the mushroom structures are embedded in the dielectric substrate. The side view of the vertical profile is shown in Figure 1(b). The host substrate in fact includes two sub layers. The thickness for the upper layer is h_1 and for the bottom layer is h_2.

The H-shaped patch and mushroom metamaterials can both reduce the patch length. However, the mechanisms are different. For the H-shaped patch, it is the lengthened current path (see the Figure 11 in [10]) that reduces the resonant frequency. And for the mushroom structures, the size reduction effect is due to an effective high index. According to [5], if the mushroom size w_e is close to the period w_d, the mushroom structures work as a kind of high index metamaterial with effective permittivity given by

$$\varepsilon_r^{eff} \approx \frac{h_1 + h_2}{h_1}\varepsilon_r, \tag{1}$$

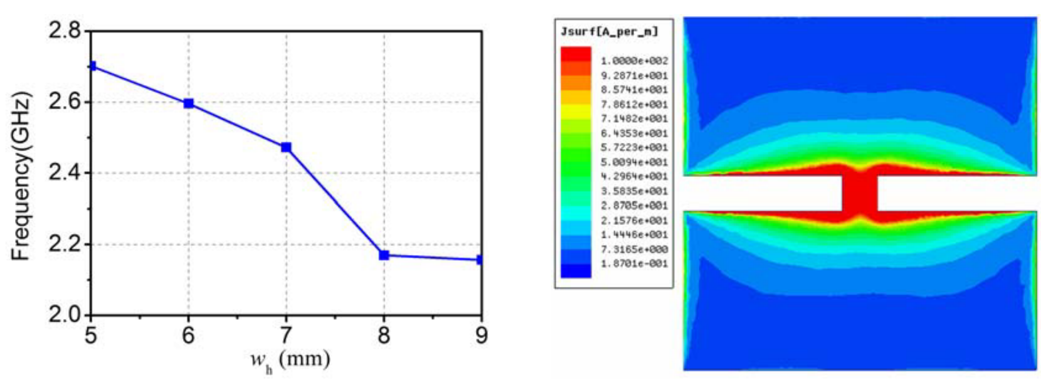
where ε_r^{eff} is the effective permittivity of the meta-substrate and ε_r the effective permittivity for the host substrate. We see that ε_r^{eff} is always larger than ε_r if h_2 is not zero. The enhanced effective permittivity will reduce the patch length. By further increasing the thickness ratio h_2/h_1, the size reduction effect will be more pronounced [5].

The parameters in Figure 1 are as follows: $h_1 = 1.5$ mm, $h_2 = 2$ mm, $w_d = 5$ mm, $w_e = 4.4$ mm, $l_p = 20$ mm, $l_w = 9$ mm and $w_w = 2$ mm. The substrate is with $\varepsilon_r = 2.65$ and $\tan\delta = 0.003$. The remaining parameter w_h associated with the slot length on the H-shaped patch is optimized in Ansys HFSS. The optimization is shown in Figure 2(a). We see that the resonant frequency is reduced with an increasing w_h. Considering that w_h is limited by l_p, the frequency should thus be restricted above a



(a) (b)

Figure 1. Configuration of proposed H-shaped mushroom type meta-antenna. (a) Bird view and (b) side view.



(a) (b)

Figure 2. (a) Simulated resonant frequency with different w_h, and (b) the current on the H-shaped patch with $w_h = 9$ mm. All calculations are based on HFSS.

minimum. We choose $w_h = 9$ mm as the optimum value with a resonant frequency of 2.157 GHz. The current distribution on the patch is shown in Figure 2(b). A maximum intensity is observed on the narrow "bridge" of the H-shaped patch.

In a special case $w_h = 0$, the H-shaped patch meta-antenna will be a meta-antenna with integrated square patch. If we further remove the mushroom structures from the meta-antenna, it will further degenerate to a conventional design. To show the evolution roadmap of these three antennas, the resonance performances are given in Figure 3 which are numerically calculated in HFSS. Their patch sizes are all 20 mm $\times$ 20 mm. The thickness of the natural host substrate ($\varepsilon_r = 2.65$) is 3.5 mm. In simulations, the conventional patch antenna resonates at 4.11 GHz. However the resonant frequency for the mushroom meta-antenna (with integrated patch) is reduced to 2.94 GHz. An H-shaped meta-antenna resonates even lower to 2.157 GHz. The reduced resonant frequency implies an electrically small size. For the H-shaped meta-antenna the patch size is $0.15\lambda_0 \times 0.15\lambda_0$. The evolution of these designs clearly shows that the H-shaped patch and mushroom meta-substrate enable a patch antenna resonating at a much lower frequency. The electrical patch length is hence miniaturized.

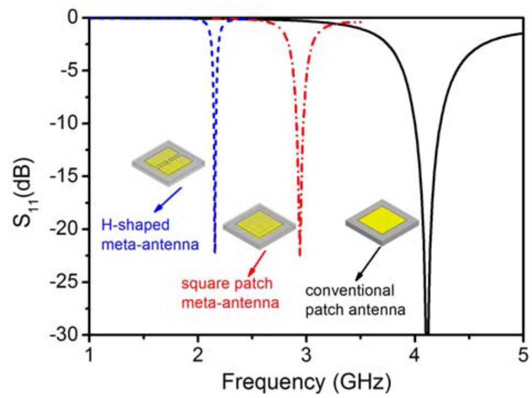
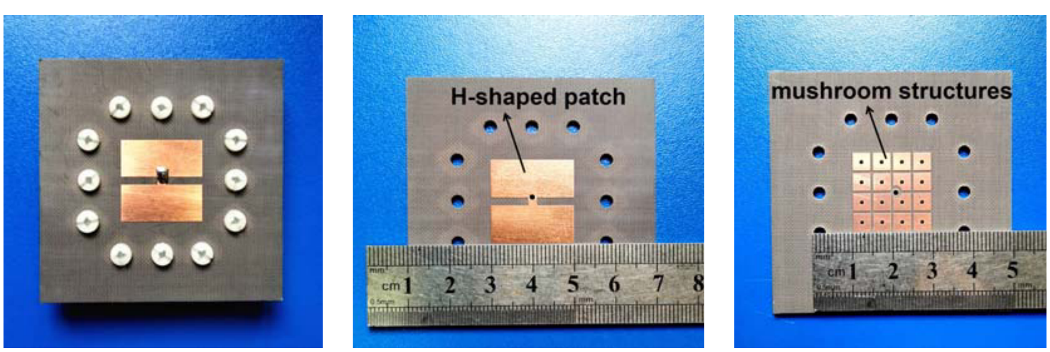


Figure 3. The resonance performances of the three antennas showing simulated S_{11}.

3. EXPERIMENTAL RESULTS

The conceptual H-shaped patch meta-antenna is demonstrated in experiments. The fabricated antenna sample is shown in Figure 4(a) which includes two sub dielectric layers assembled by plastic screws. The upper dielectric layer is given in Figure 4(b) with an H-shaped patch on the top surface. The bottom layer is shown in Figure 4(c) which includes 4×4 period mushroom structures embedded in the substrate.



(a) (b) (c)

Figure 4. (a) The fabricated meta-antenna, (b) the upper dielectric layer showing an H-shaped patch and (c) the bottom dielectric layer with embedded mushroom structures.

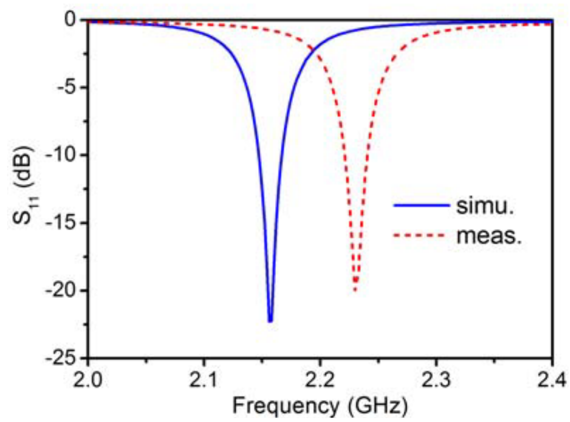


Figure 5. Simulated and measured S_{11}.

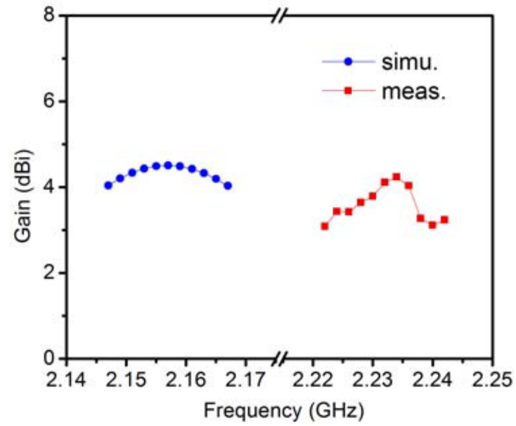


Figure 6. Simulated and measured antenna gain.

The reflection coefficient results from the simulation and experiment are given in Figure 5. From the measured curve, we see that the resonant frequency is 2.232 GHz, in agreement with the numerical prediction. A slight frequency deviation might be caused by the dielectric constant error in fabrication. Possibly a thin air layer between the assembled dielectric layers might also lead to this blue shifted effect. The measured -10 dB bandwidth is nearly 20 MHz. The narrow bandwidth is an intrinsic problem associated with the H-shaped patch antenna [8–10]. By adding an additional stacked patch cover on the H-shaped radiation patch, the bandwidth will be further enhanced [10].

Although the H-shaped patch meta-antenna is with a compact size, it does not sacrifice the gain. The numerically calculated and measured antenna gain results are given in Figure 6. The simulated peak gain is 4.5 dBi and the measured one is 4.2 dBi. The profiles of these two curves are similar. Within the frequency range of -10 dB bandwidth, the measured gain is always higher than 3 dBi which is acceptably high and can be used in portable mobile communication applications.

The radiation patterns of the H-shaped meta-antenna at the resonance frequency are shown in Figure 7 which are measured in the microwave chamber in Shanghai University. Good agreement has been seen between the simulated and measured co-polar patterns. For the cross-polar level, the measured result is lower than -21 dB on the E plane and -22 dB on the H plane. The simulated cross-polarizations are all below -30 dB which are not seen in the figures.

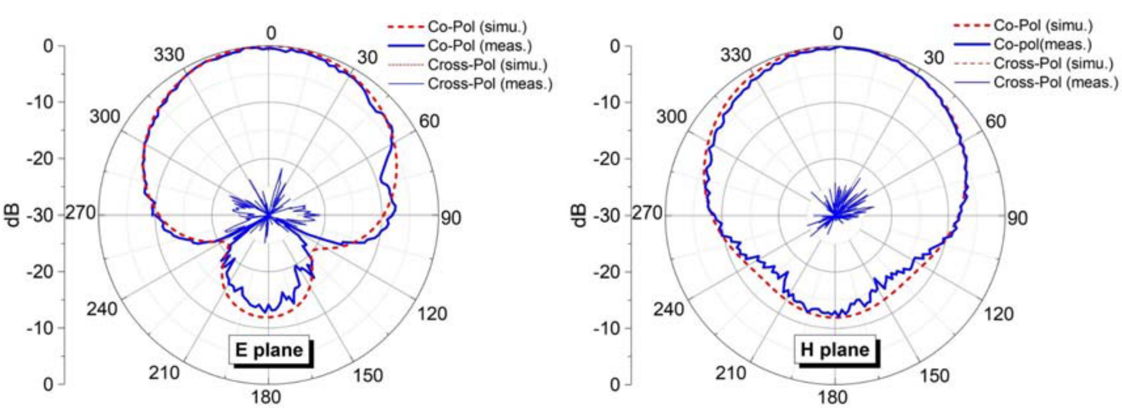


Figure 7. Radiation patterns of the H-shaped meta-antenna.

4. CONCLUSION

A compact H-shaped patch antenna is designed on a mushroom meta-substrate. Both of the shaped patch and the mushroom metamaterials enable the size reduction effect. The antenna performances are demonstrated in full wave simulations and experiments with results in agreement to each other. Experimental results show that an H-shaped meta-antenna with patch size of 20 mm ×20 mm resonates at 2.232 GHz. The normalized electrical size is $0.15\lambda_0 \times 0.15\lambda_0$. The antenna gain is 4.2 dBi. The proposed H-shaped patch antenna is a prospect device for portable communication in future.

ACKNOWLEDGMENT

This work was supported by the Natural Science Foundation of Shanghai (No. 16ZR1446100).

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