The miniaturized patch antenna with enhanced bandwidth based on reactive impedance surface and slotted parasitic patches

Zhihao Mu, Jingnan Ma, Yingjuan Zhao and Changxing Chen*

Department of Basic Science, Air Force Engineering University, Xi 'an 710051, China
*Corresponding author’s e-mail:xachenchangxing@afeu.edu.cn

Abstract. We presented a miniaturized patch antenna with enhanced bandwidth. Reactive Impedance Surface (RIS) was introduced instead of the traditional metal floor, and bandwidth enhancement is realized by loading slotted parasitic patches. The reference antenna and the antenna 1 loaded with the parasitic patch are designed, that impedance bandwidth changed from 8.5% to 23.6%, the peak gain and the front-to-back ratio was also improved by 2.2dBi and 7.8dB respectively; The metal floor of antenna 1 was instead by using RIS periodic structure to design Antenna 2. The absolute bandwidth of both antenna 1 and antenna 2 is about 1GHz. Antenna 2 is 22.4% smaller than the reference antenna and 28.6% smaller than antenna 1. The simulation results show that the proposed bandwidth enhancement and miniaturization methods are effective and ensure a certain improvement in gain.

1. Introduction
Microstrip patch antennas are widely studied in recent years due to their light weight, small size, low profile, easy to be integrated with circuits and simple fabrication methods. However, microstrip antennas have disadvantages such as narrow bandwidth and low gain. With the development of wireless communication system, the bandwidth and size of antenna are required more strictly. The miniaturized methods are commonly as follows[1]: increasing the thickness of substrate, folding technology, meandering technology. However, the thick substrate is easy to excite surface waves, which makes the radiation efficiency decrease. The folding technique reduces the resonant frequency of the antenna by increasing the total path length of the surface current, which achieves miniaturization, but makes the bandwidth and gain worse. By introducing the parasitic patch, improving the feed network and grooving, the bandwidth can be broadened [2-3]. The slotted antenna requires a larger metal ground plane to suppress backward-radiation, and the overall size of the antenna increases.

In order to design a miniaturized bandwidth enhanced patch antenna, this paper introduces slotted parasitic patches to broaden the bandwidth and RIS to realize miniaturization.

2. Antenna design and characteristics
This paper proposes a new method to improve the impedance bandwidth of microstrip antenna based on the slotted parasitic patches [4]. The schematic diagram of traditional patch antenna (reference antenna) and antenna 1 (loaded with parasitic patches) is shown in Figure 1. The model parameters are shown in Table 1.

[The rest of the text follows, including the tables and figures.]
### Table 1. The model parameters of two antennas.

| Parameters | $L_s$ | $L_p$ | $F$ | $h$ | $l_c$ | $l_g$ | $l_s$ | $w_s$ | $l_w$ |
|------------|-------|-------|-----|-----|-------|-------|-------|-------|-------|
| Unit (mm)  | 64    | 24    | 6   | 4.2 | 14.1  | 1     | 8     | 1.5   | 4     |

As shown in Figure 1, the reference antenna is a traditional square patch antenna, antenna 1 is loaded with $y$-pol parasitic patches. Both radiation patches have the same size and the same substrate (Rogers RT/duroid 5880, dielectric constant: 2.2, loss tangent: 0.0009). The simulation is completed by ANASYS HFSS 17.0 and the reflection coefficient of both antennas are shown in Figure 2. The reference antenna operates at 3.65GHz-3.93GHz with a relative bandwidth of 8.5%, while antenna 1 operates at 3.62GHz-4.53GHz with a relative bandwidth of 22.3%. The impedance bandwidth is significantly improved. Figure 3 is the radiation pattern of the reference antenna and antenna 1 operating at the resonant frequency. The broadside gain and the front to back ratio are improved 2.2dBi and 7.8Db respectively compared to the reference antenna.
By using reactive impedance surface RIS [5] instead of traditional metal floor, the radiation field cancellation caused by mirror current of metal floor can be suppressed. Meanwhile, the matching condition can be improved to realize miniaturization. The RIS topological structure and its equivalent circuit are shown in Figure 4(a). The element structure is composed of a two-dimensional periodic square metal sheet embedded between the two-layer dielectric substrate. The metal sheet has a side length of \(a\) and a period length of \(P=10\)mm. The upper substrate is Rogers RT/duroid 5880(h1=1.6mm), and the bottom substrate is TP-2(dielectric constant: 10.2, loss tangent: 0.001, h2=2.6mm). Periodic boundary conditions are adopted and floquet port is used to illuminate TE wave in the direction of -Z. Figure 4(b) is the phase response of RIS periodic structure varying with \(a\).

From figure 4(b) we could know that when \(a\) is 8.5, 9.0 and 9.5mm, the resonant frequency is 2.70, 3.13 and 3.47GHz respectively, and the corresponding reflection phase is 0. The RIS periodic structure has the same resonance as the PMC boundary. When the frequency is lower than the resonant frequency, the phase response is positive and the RIS structure is inductive. When the frequency is higher than the resonant frequency, the phase response is negative and the structure is capacitive. The impedance matching condition of the antenna can be improved by setting the RIS unit size reasonably, so that the antenna miniaturization can be realized.

Because the number of RIS units has little effect on resonance frequency [6], the RIS periodic structure is composed of 6×6 unit cell. The schematics of RIS periodic structure and antenna 2 are shown in figure 5. The parameters of antenna 2 is shown in table 2. The performance of antenna 2 and the comparison between three antennas are shown in figure 6. Antenna 2 works at 2.38-3.50GHz, the...
central frequency is 2.94GHz, and the relative bandwidth reaches 38.1%. Both antenna 1 and antenna 2 had 2.2 dBi gain enhancement in passband.

Figure 5. The schematics of antenna 2. (a) 6×6 RIS periodic structure, (b) top view of antenna 2, (c) side view of antenna 2.

Table 2. The model parameters of two antenna 2.

| Parameters | $\varepsilon_1$ | $\varepsilon_2$ | $p$ | $a$ | $F$ | $h_1$ | $h_2$ | $l_c$ | $l_g$ | $l_s$ | $w_s$ | $l_w$ |
|-----------|----------------|----------------|----|----|----|-------|-------|-------|-------|-------|-------|-------|
| Unit(mm)  | 2.2            | 10.2           | 10 | 8.5| 5.2 | 1.6   | 2.6   | 14.1  | 1     | 8     | 1.5   | 4     |

Figure 6. (a) The reflection coefficient of antenna 2, (b) Gain of three antennas

3. Conclusion
Slotted parasitic patches are used to broaden the impedance bandwidth and the RIS to miniaturize the patch antenna. The simulation results show that the impedance bandwidth changes from 8.5% of the reference antenna to 22.3% after loading the slotted parasitic patches, the peak gain at the operating frequency increases by 2.2dBi, and the front to back ratio by 7.8dB. After the RIS structure was introduced, the size of antenna 2 decreased by 22.4% compared with the reference antenna and by 28.6% compared with antenna 1. Antenna 2 maintains a radiation efficiency of 95.4% in the passband. The proposed miniaturization and bandwidth expansion methods have certain application value in S-band.
References

[1] Ali F, Davoud Z. Miniaturization of patch antennas by curved edges [J]. AEU-International Journal of Electronics and Communications, 2020, 117

[2] Ding K, Gao C, Yu T B. Gain-Improved Broadband Circularly Polarized Antenna Array with Parasitic Patches [J]. IEEE Antennas and Wireless Propagation Letters, 2017, 16: 1468-1471.

[3] Wu J J, Yin Y Z, Wang Z D. Broadband Circularly Polarized Patch Antenna With Parasitic Strips [J]. IEEE Antennas and Wireless Propagation Letters, 2015, 14: 559-562.

[4] Jingchang Nan, Weisheng Wu. Design of a new miniature dual frequency RFID microstrip antenna [J]. Electronic components and materials, 2019, 38(7): 86-89.

[5] Dong, Y D, Hiroshi T, Tatsuo I. Design and Characterization of Miniaturized Patch Antennas Loaded With Complementary Split-Ring Resonators [J]. IEEE Transactions on Antennas and Propagation, 2012, 60(2): 772-785.

[6] Xu H X, Wang G M, Liang J G, et al. Compact Circularly Polarized Antennas Combining Meta-Surfaces and Strong Space-Filling Meta-Resonators [J]. IEEE Transactions on Antennas and Propagation, 2013, 61(7): 3442-3450.