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Design of a Reconfigurable Band-Notch SWB Antenna

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Abstract—This paper introduces a novel planar super-wideband (SWB) antenna with reconfigurable band-notch characteristic. The antenna can work in band-notch mode or band-notch free mode. A good impedance matching is responsible for the SWB characteristic of the proposed antenna by adopting a gradient ground, a gradient feeder line, and a gradient radiating patch. Furthermore, to achieve a reconfigurable notched band function, a 0.3 mmn deep slot which is 16 mm in length and 8 mm in width is dug near the antenna feeder for the placement of dielectric plates etched with different sizes of split ring resonator (SRR). The designed antenna has a size of 200 mm × 109 mm × 0.79 mm, and the measured frequency band of bandwidth covers 0.8–26 GHz with a reconfigurable band-rejection characteristic. The dielectric plates with different SRRs reject the part of WLAN band (5.44–5.55 GHz), X-band satellite downlink band (7.65 GHz–7.82 GHz), and 6.33 GHz–6.59 GHz. A good agreement is achieved within the super-wideband frequency range between simulated and measured results.

1. INTRODUCTION

To avoid the interference of some specific communication bands, such as WLAN band, and WiMAX band, SWB antenna with band-notch characteristics has certain research significance. Generally, band-notch antennas can be constructed by various methods, such as modifying the radiating patch or ground by etching slots on them [1–7], loading L-shaped elements, split rings, and rectangle stub [8–14]. However, most of these stopbands of band-notch antennas are fixed and not operable. In view of this problem, some researchers put forward the design of reconfigurable notched band antennas. These methods can make the antenna own fixed notched band and band-notch free mode, but hardly flexibly control the frequency band where the band notch is located at the same time [15–21]. If some new unwanted band in the working frequency band needs to be suppressed and there is no external electromagnetic shielding, a new antenna may need to be designed, which is not economical in cost.

Therefore, a novel SWB antenna with a reconfigurable notched band is introduced in this paper, realizing adjustable band-notch mode and band-notch free mode. The proposed antenna can work with more band-notch modes including producing/removing notched band and adjusting working frequency of notched band. However, only one of the above notch modes can be realized by most of antennas with a reconfigurable notch. Besides, this antenna also has the SWB characteristic, which provides the possibility for more antenna applications. In Table 1, there is a comparison between the proposed antenna and other band-notch antennas. The proposed antenna is able to realize more band-notch modes. There is a deep slot with a size of 16 mm × 8 mm × 0.3 mm dug on the substrate of the proposed antenna. Through placing dielectric plate etched with different resonant rings in the antenna slot, the notched band appears at different frequencies. When the dielectric plate put into the slot is removed, the antenna will work without notched band.

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Table 1. Comparison between proposed antenna and some band-notch antennas.

Ref.	Electrical Dimension ($\lambda_0 \times \lambda_0$)	Bandwidth (GHz)	A	B	C
[7]	0.36 × 0.36	0.72–25	N	N	N
[13]	0.31 × 0.32	3–24	N	N	N
[16]	0.40 × 0.45	3–11	Y	Y	N
[17]	0.2 × 0.17	3.08–over 14	Y	N	N
[18]	0.14 × 0.14	2.8–10.2	N	Y	N
[19]	0.49 × 0.35	3–11	N	Y	Y
Proposed	0.53 × 0.29	0.8–26	Y	Y	Y

A: Producing/ removing notched band.
B: Adjusting working frequency of notchedband.
C: Continuously adjusting frequency of notched band.

2. ANTENNA ANALYSIS AND DESIGN

Figure 1(a) shows the proposed band-notch SWB antenna. The radiating patch and ground are printed on different planes of the substrate. Taconic tly-5 is selected for the substrate of antenna due to low dielectric constant 2.2 and loss tangent 0.0009.

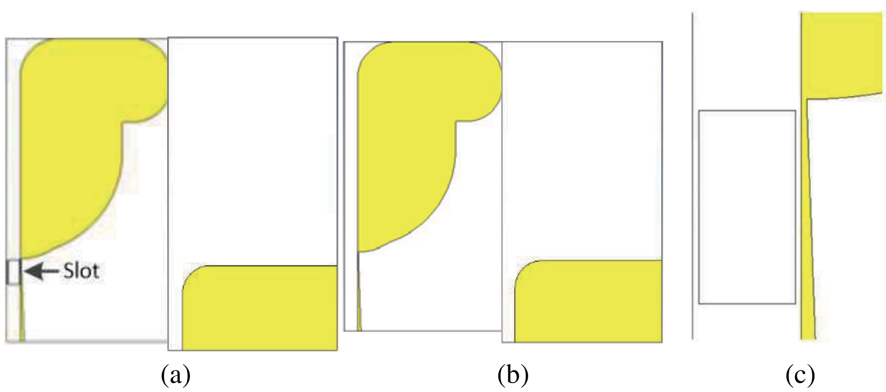


Figure 1. Geometries of the antennas. (a) proposed antenna, (b) original SWB antenna without band-notch character, (c) partial enlarged view of slot in the proposed antenna.

Several methods are adopted to improve impedance matching of the proposed antenna. Firstly, in order to achieve better impedance matching, the feeder line adopts a tapered line to match 50 Ohm characteristic impedance. Secondly, on the upper right corner of the antenna ground, rounded corners are used instead of right angles for creating capacitive coupling to suppress inductance caused by gradual radiating patch [22]. Thirdly, a small semi-circular patch and a large semi-circular patch form a quadratic tapered line at the bottom of radiating patch, which further expands the impedance matching bandwidth.

For avoiding the interference of some narrowband signals to the antenna, the technology of split resonant ring (SRR) is introduced. The working current in a specific frequency band is concentrated near the SRR through the resonance effect of the resonant ring. The currents gathering inside and outside the resonant ring have opposite directions, which cancel each other's radiation [23], thus forming the antenna electromagnetic stopband. So, a deep slot is dug to place the dielectric plate etched with different sizes of SRR. The size of SRR is responsible for the working frequency of the notched band of the antenna. In [24], the working frequency of the SRR can be calculated by Equations (1) and (2).

$$f = \frac{c}{2L \cdot \sqrt{\varepsilon_{eff}}} \tag{1}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} \tag{2}$$

where f represents the resonant center frequency of the resonant ring, L the length of the resonant ring, ε_{eff} the equivalent dielectric constant, and ε_r the relative dielectric constant of the antenna dielectric plate.

The impedance matching of the proposed antenna and the original antenna shows a good agreement in Fig. 2, indicating that the slotting and non-slotting of dielectric plate have little effect on antenna. Besides, the SWB characteristic of the proposed antenna is achieved.

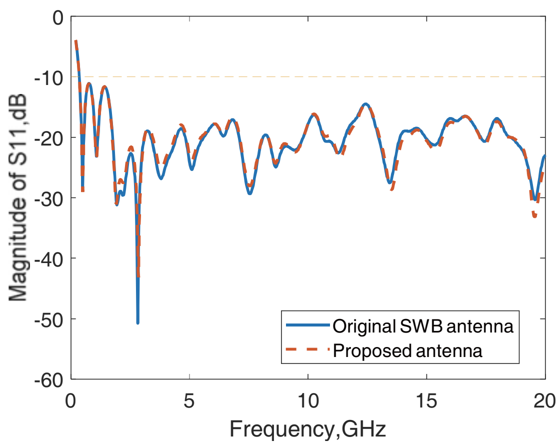


Figure 2. Simulated magnitude of S_{11} for the original SWB antenna without band-notch character and proposed antenna.

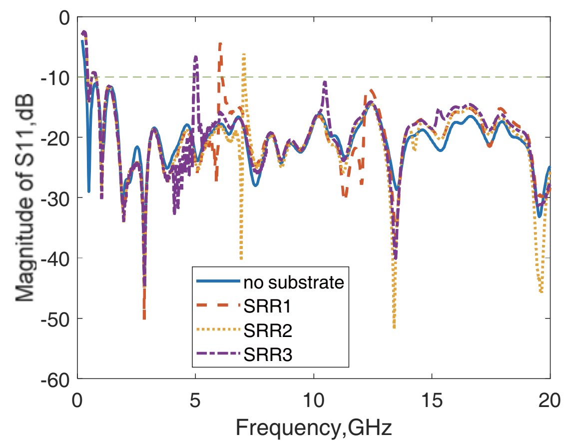


Figure 3. Simulated magnitude of S_{11} for the proposed antenna loaded with dielectric plates of the same material type.

As shown in Fig. 3, dielectric plates of the same material type etched with SRRs of different sizes are put into slot in turn, and the antenna works in a mode with reconfigurable electromagnetic stopband. Besides, the longer the length of the SRR is, the lower the working frequency of notched band of the antenna is. When the dielectric plate in the slot is removed, the antenna works in a band-notch free mode. Furthermore, dielectric plates of different material types etched with the same SRR are put into slot in turn. As shown in Fig. 4, the antenna also works in a reconfigurable band-notch mode. Besides, in the case above, the smaller the dielectric constant is, the higher the working frequency of the notched band is, conforming to the definition of Equations (1) and (2). So, the frequency of notched band of the proposed antenna is flexible and can be changed by the above two ways.

From Fig. 5, when the dielectric plate etched with SRR2 is loaded in slot, the current would gather inside and outside the resonant ring with different flow directions at the working frequency of SRR2. Besides, the current flowing on the radiating patch will decrease sharply, forming the notched band of the antenna.

Considering manufacturing cost, this paper only studies the dielectric plate of the same material type with different sizes of SRRs. Finally, the proposed antenna and the dielectric plate to be added are shown in Fig. 6 and Fig. 7. The slot depth dug on the proposed antenna is 0.3 mm; the height of the dielectric plate to be added is 0.25 mm; the gap between slot and feeder line is 0.5 mm; and the width of the top feeder line is 0.42 mm.

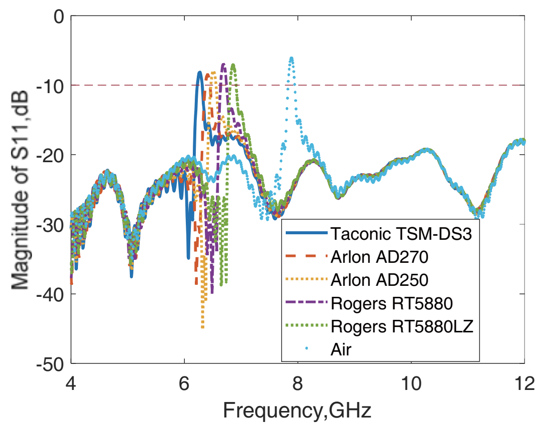


Figure 4. Simulated magnitude of S_{11} for the proposed antenna loaded with dielectric plates of different material type.

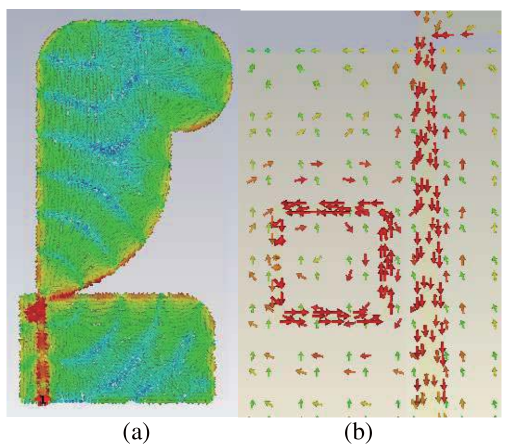


Figure 5. Surface current of antenna loaded dielectric plate with SRR2 at frequency 7 GHz. (a) Overall view of current distribution. (b) Partial view of current distribution near SRR.

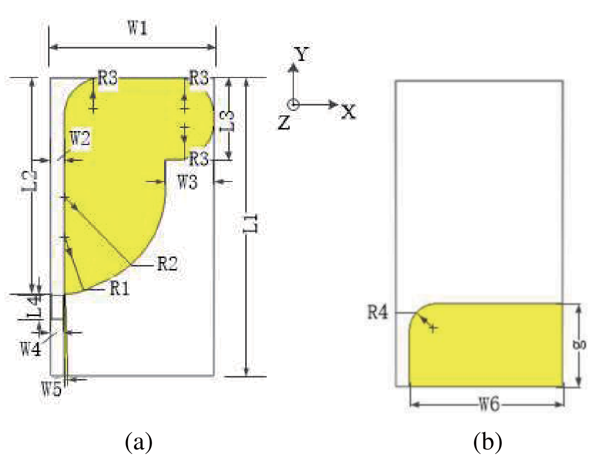


Figure 6. The proposed antenna dimensions. (a) Top view. (b) Back view. The optimized parameters are, respectively, $W1 = 109$ mm, $W2 = 9$ mm, $W3 = 32.4$ mm, $W4 = 8$ mm, $W5 = 2.4$ mm, $W6 = 100$ mm, $L1 = 200$ mm, $L2 = 145.1$ mm, $L3 = 55$ mm, $L4 = 16$ mm, $R1 = 40$ mm, $R2 = 67.6$ mm, $R3 = 25$ mm, $R4 = 18$ mm, $k = 0.5$ mm, $g = 54.2$ mm.

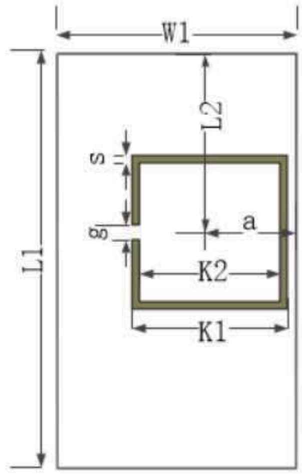
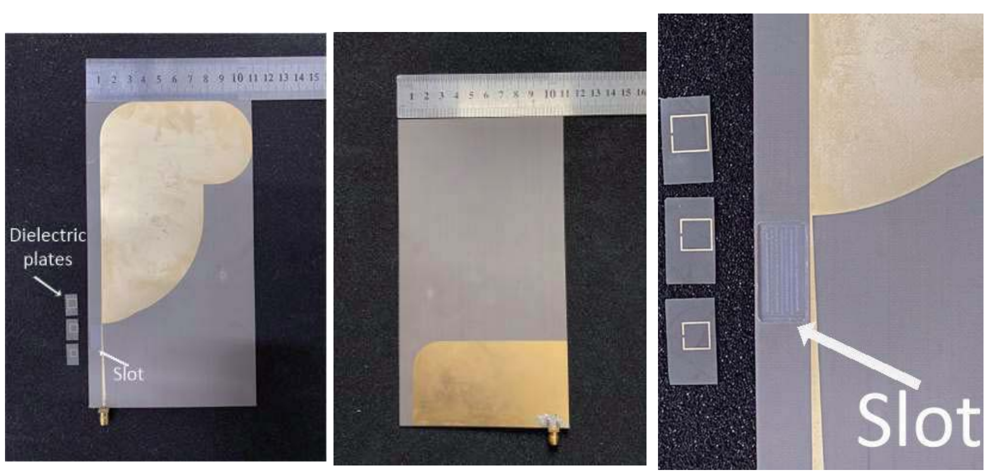


Figure 7. Dimensions of dielectric plates to be added. The optimized parameters are, respectively, $W1 = 8$ mm, $L1 = 14$ mm, $L2 = 6$ mm, $g = 0.5$ mm, $s = 0.25$ mm, $c = 3.3$ mm, $K5 = 6$ mm, $K6 = 5.5$ mm [SRR1: $a = 2.9$ mm, $k1 = 5.2$ mm, $k2 = 4.7$ mm; SRR2: $a = 2.9$ mm, $k1 = 4.5$ mm, $k2 = 4$ mm; SRR3: $a = 3.3$ mm, $k1 = 6$ mm, $k2 = 5.5$ mm].

3. MEASUREMENT RESULTS AND DISCUSSION

The antenna and three dielectric plates with different SRRs are manufactured, as illustrated in Fig. 8. S_{11} parameters of the antenna loaded with no dielectric plate and the antenna loaded with dielectric plates etched with SRR1, SRR2, and SRR3 are tested by KEYSIGHT N5224B vector network analyzer. There is a good agreement achieved between measured and simulated results in Fig. 9(a). When the proposed antenna is not loaded with dielectric plate, the bandwidth of $S_{11} \leq -10$ dB will cover 0.8 GHz–20 GHz. As illustrated in Figs. 9(b), (c), and (d), when dielectric plates a, b, and c are loaded respectively, the notched band will appear at 6.33 GHz–6.59 GHz, 7.65 GHz–7.82 GHz, and 5.44 GHz–5.55 GHz.

In the above case, the antenna works in the band-notch mode. Besides, at the same time, impedance matching of other frequency bands is almost the same as that in band-notch free mode. It can be



(a) (b) (c)

Figure 8. Practical manufactured proposed antenna and dielectric plates with different. SRRs. (a) Top view. (b) Back view. (c) View of slot.

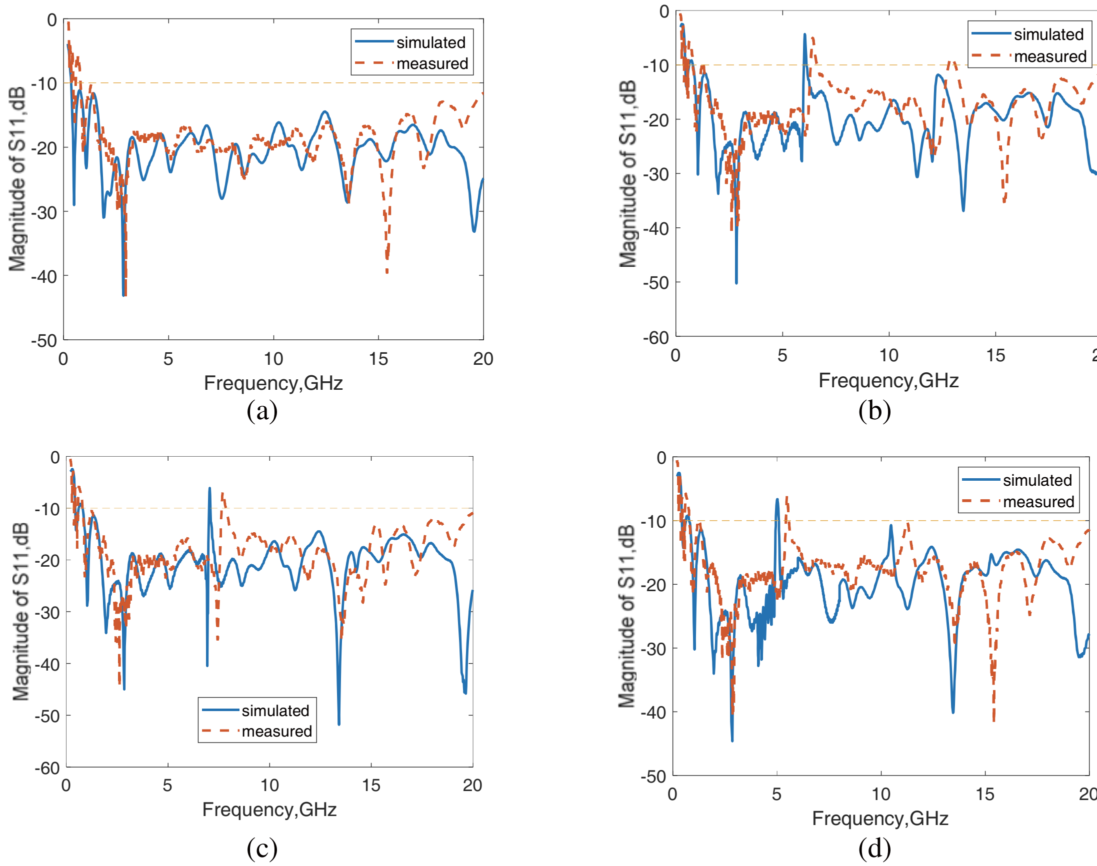


Figure 9. Measured magnitude of S_{11} for multiple modes of proposed antenna. (a) Without substrate plate. (b) SRR1. (c) SRR2. (d) SRR3.

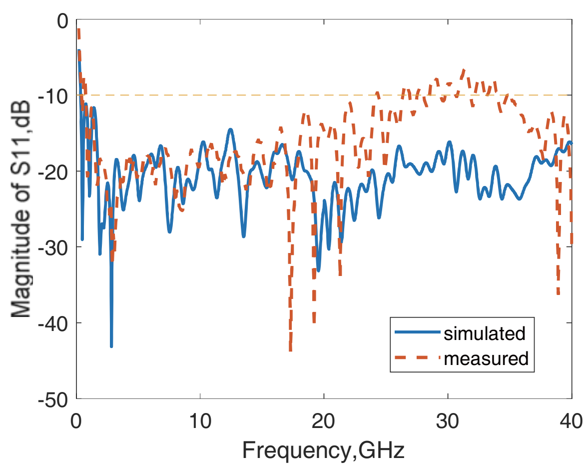


Figure 10. Simulated and Measured magnitude of S_{11} for proposed antenna.

found that the band-notch bandwidth of the proposed antenna loading substrate c or b can cover part of WLAN band (5.15 GHz–5.85 GHz) or X-band satellite downlink band (7.25 GHz–7.75 GHz). The measured notched bands are not the same as the simulated ones because of fabrication errors of the size of SRRs, measurement tolerances, and unwanted electromagnetic coupling when a new substrate is reloaded in an inaccurate place by using adhesive tape in the slot which is bigger in size.

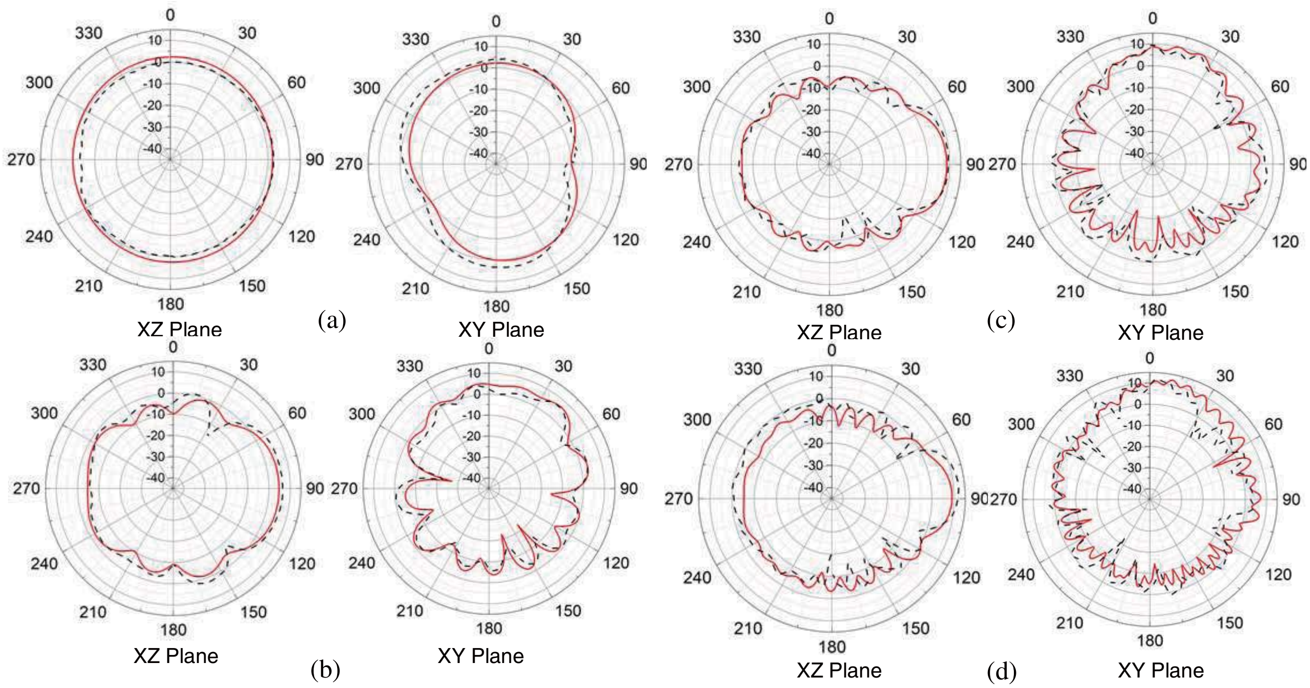


Figure 11. Simulated and measured radiation patterns for XZ-plane and XY-plane of the proposed antenna (band-notch free mode), for four different frequencies: (a) 0.8 GHz, (b) 5 GHz, (c) 10 GHz, (d) 15 GHz [simulated radiation patterns: solid red line; measured radiation patterns: dotted black line].

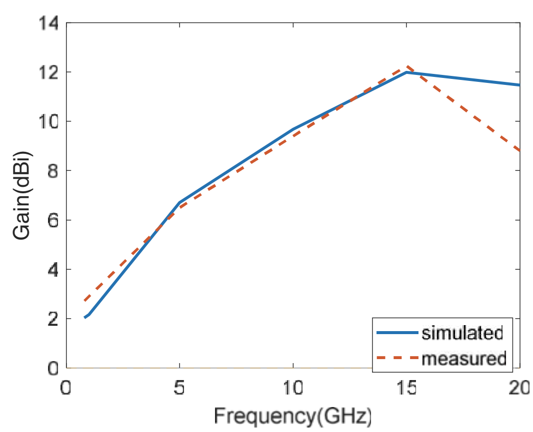


Figure 12. Simulated and measured peak gain of the proposed antenna (band-notch free mode).

In addition, the frequency of measured $S_{11} \leq$-10 dB of the proposed antenna is still higher than 20 GHz. When the measured frequency range is extended to 40 GHz, working band of the proposed antenna can cover 0.8 GHz–26 GHz and 34 GHz–40 GHz, as shown in Fig. 10.

The radiation patterns of the proposed antenna in XZ-plane and XY-plane have been measured, as shown in Fig. 11. A directional pattern is observed at the higher frequency. So, it is a promising candidate for military SWB applications.

Figure 12 shows the simulated and measured results of peak gain for the proposed antenna. The consistence is observed between the simulated and measured results, and the part of the differences in higher frequency are due to the fabrication tolerances and measurement tolerances. Besides, a 2.92 mm to 2.4 mm adapter is used to connect measuring instrument and the proposed antenna which adopts 2.4-

KHD100 connector, because the instrument for measuring peak gain does not support 2.4 mm antenna connector access directly.

The measurement of the peak gain has no effect on the measured results of S_{11} parameter, because the instrument, KEYSIGHT N5224B vector network analyzer, measuring the latter, supports the direct access of 2.4 mm connector of antenna.

4. CONCLUSION

A reconfigurable band-notch SWB antenna is proposed in this work, which achieves different performance states of the antenna by loading different dielectric plates in the slot and removing them. When the dielectric plate with SRR is not loaded in the antenna slot, the band-notch free mode of the antenna can be realized, and the antenna can work between 0.8 GHz and 26 GHz without notched band. When the dielectric plates with different sizes of resonant rings are loaded, the reconfigurable notched band can be achieved, covering part of WLAN band (5.44–5.55 GHz), X-band satellite downlink band (7.65 GHz–7.82 GHz), and 6.33 GHz–6.59 GHz. Besides, a directional radiation pattern of the proposed antenna is achieved at higher SWB frequency. So, the proposed antenna acts as a promising candidate for military applications.

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