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Design of a Reconfigurable Bandnotch Antenna for UWB Applications

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Abstract—In order to improve the practicability and versatility of ultra-wideband (UWB) antennas, a reconfigurable band notch antenna is proposed in this paper. It has a compact size of 18 mm × 16 mm × 1.6 mm. The reconfigurable band notch function is realized by two small tunable units. The tunable unit makes up of a split ring resonator (SRR), a dielectric substrate, and a varactor diode. The simulation results show that the antenna combines the functions of band notch emergence, removal, and movement. The applied reconfigurable method can effectively broaden the continuous movement range of band notch. The measurement proves that the antenna has the band notch reconfigurable function, and the measured results are in good agreement with the simulation ones. The radiation patterns are measured, which are stable and consistent under two modes with and without band notch, showing omnidirectional radiation characteristics. These research results provide reference value for the design of band notch UWB antenna shielding civil narrowband communication band.

1. INTRODUCTION

With the rapid development of communication technology, ultra-wideband (UWB) communication system has gained the attention and focus of researchers. UWB requires that the relative bandwidth ratio is higher than 20%, or the absolute bandwidth is greater than 0.5 GHz. According to Federal Communications Commission (FCC) regulations, UWB communication systems can use the frequency band from 3.1 GHz to 10.6 GHz. The available frequency band usually includes several civil narrowband communication bands, such as C-band satellite uplink/downlink band (5.925–6.425/3.7–4.2 GHz), wireless local area network (WLAN) band (5.15–5.35 GHz, 5.725–5.825 GHz), and X-band satellite uplink/downlink band (7.9–8.4/7.25–7.75 GHz). As the narrowband communication system occupies part of the UWB, the mutual interference between them is inevitable, so band notch UWB antenna has great research value.

There are many ways to achieve band notch in antenna design, including etching geometric slots [1–7] and adding parasitic cells or resonant branches [8–14]. The above notched bands are fixed, and when they need to be removed or need to be changed, the antenna has to be redesigned. Some researchers have proposed reconfigurable band notch antennas. The reconfigurable band notch antennas can realize the emergence and removal of the band notch, or continuously move the band notch within a limited range [15–24]. As shown in Table 1, the PIN diode can be used to realize the switching control of the band notch [25, 26], and the varactor diode can realize continuous tunability of the notched band in a limited and narrow range [27]. Most of the above works do not integrate the functions of band notch emergence, removal, and movement. There is a reconfigurable method that can generate, remove, and move the band notch [23]. However, if this method is used to achieve continuous movement of the band

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Table 1. Comparison of adjustment methods of reconfigurable band notch antennas.

Ref.	Adjustment Method	Generating or removing band notch	Adjusting band notch frequency	Continuously moving band notch frequency
[25]	Adjusting PIN diode	Y	N	N
[26]	Adjusting PIN diode	N	Y	N
[27]	Adjusting Varactor diodes	N	Y	Y
[28]	Adjusting 10 ideal MEMS switches	N	Y	N
Proposed	Replacing tunable units and adjusting varactor diodes	Y	Y	Y

notch over a wide band, a large number of different dielectric plates need to be designed, leading to a large fabrication cost. How to make UWB antenna combine the functions of band notch emergence, removal, and continuous movement in a wide range with less cost is an interesting research direction.

This paper presents a reconfigurable band notch antenna for UWB applications. The proposed monopole antenna has two slots on both sides of the feeder line. The proposed tunable unit makes up of an SRR, a dielectric substrate, and a varactor diode. The band notch can be produced by placing tunable units in the slots or removed by not placing. In the band notch mode, the band notch can be continuously moved by tuning the capacitance of varactor diodes. When the capacitance value reaches the limit, the movement range can be broadened by using different tunable units.

2. ANTENNA DESIGN

The rectangular patch monopole antenna is shown in Fig. 1(a). It has a compact size of $18\,\text{mm} \times 16\,\text{mm} \times 1.6\,\text{mm}$. The antenna is printed on an FR4 substrate with a dielectric constant of 4.3 and loss tangent of 0.025. The proposed antenna structure is shown in Fig. 1(b). It digs slots on both sides of the feeder line. The two slots are used to place the structures which can produce the band notch.

CST software is used for simulation design. The comparison of the simulated S_{11} between original antenna and different optimized antennas is shown in Fig. 2. The two corners of the bottom of the rectangular patch is cut off to enhance the current in the vertical direction and to make impedance matching better between the feeder line and the rectangular patch. The ground adopts a trapezoidal structure, and a rectangular notch is etched in the middle of the upper side. They can reduce the

Table 2. The parameters of the antenna structure.

Parameter	Value (mm)	Parameter	Value (mm)
W	16	$L3$	3.5
$W1$	7	$L4$	2.5
$W2$	1.8	$L5$	2
$W3$	1	$L6$	4.3
$W4$	4	$L7$	4
$W5$	0.25	$L8$	1
$W6$	0.4	d	1
L	18	h	1.6
$L1$	11	x	2.25
$L2$	6	y	0.85

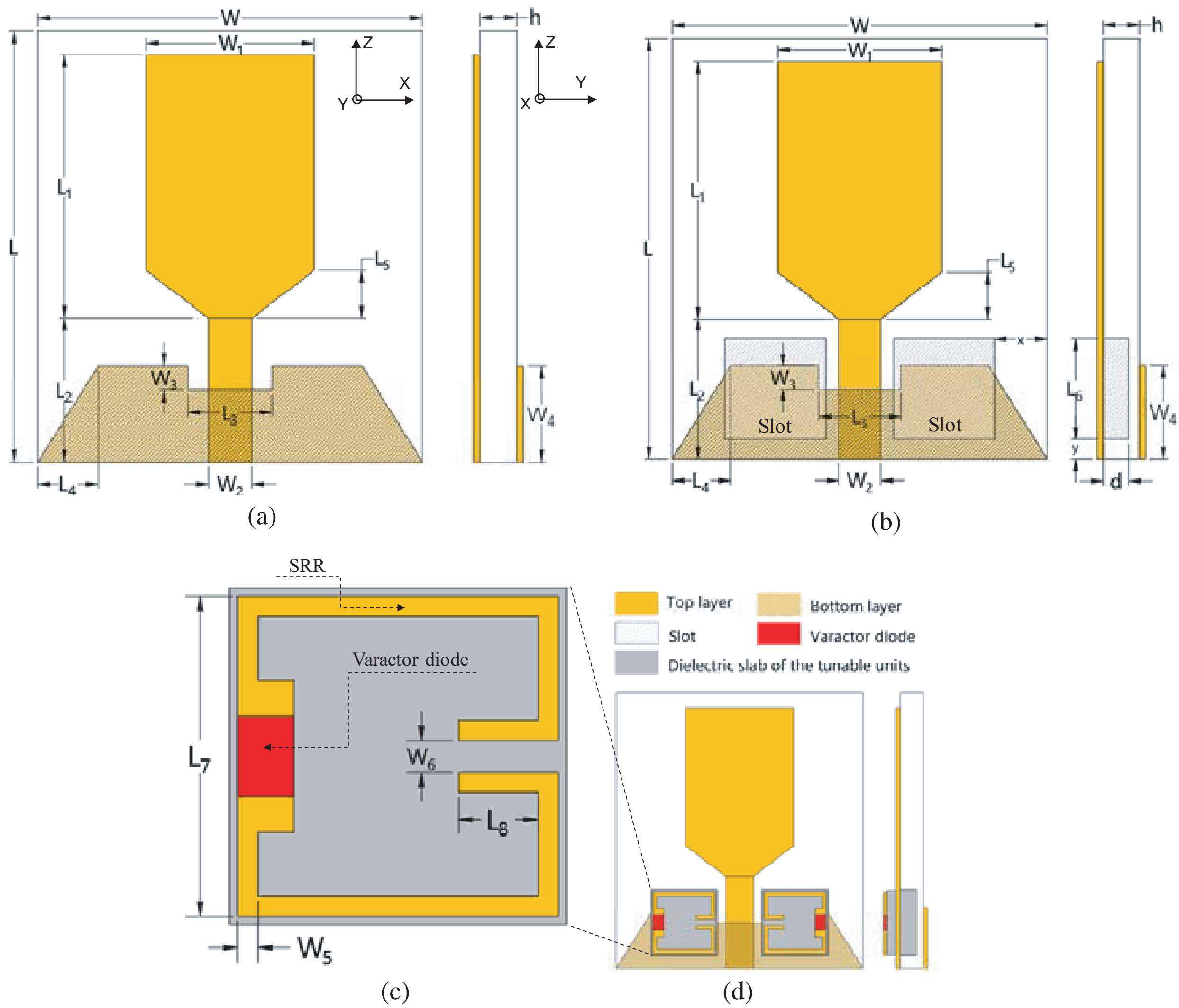


Figure 1. Geometries of the antennas. (a) The antenna without slots. (b) The proposed antenna with two slots. (c) Tunable unit. (d) The proposed antenna loaded with tunable units.

coupling effect between the bottom of the antenna patch and the ground, and further expand the band of $S_{11} < -10$ dB. The band of the optimized antenna is 3.87–10.56 GHz.

The proposed structure for producing the band notch is called tunable unit as shown in Fig. 1(c). The parameters of the antenna structure are shown in Table 2. When no tunable units are placed as shown in Fig. 1(b), the antenna is in the band notch free mode. When the tunable units are placed into the slots of the antenna as shown in Fig. 1(d), the antenna is in the band notch mode.

The tunable unit is composed of an SRR, a dielectric substrate, and a varactor diode. The center frequency of band notch can be calculated by Equations (1) and (2) [29]:

$$f = \frac{c}{2l_0\sqrt{\varepsilon_{eff}}} \tag{1}$$

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

where c is the speed of the light, ε_{eff} the effective dielectric constant, ε_r the relative dielectric constant of the dielectric material, and l_0 the length of the SRR.

The parameters of the SRR can be calculated from formula (3):

$$l_0 = 4 \times (L_7 - W_5) - W_6 + 2 \times L_8 \tag{3}$$

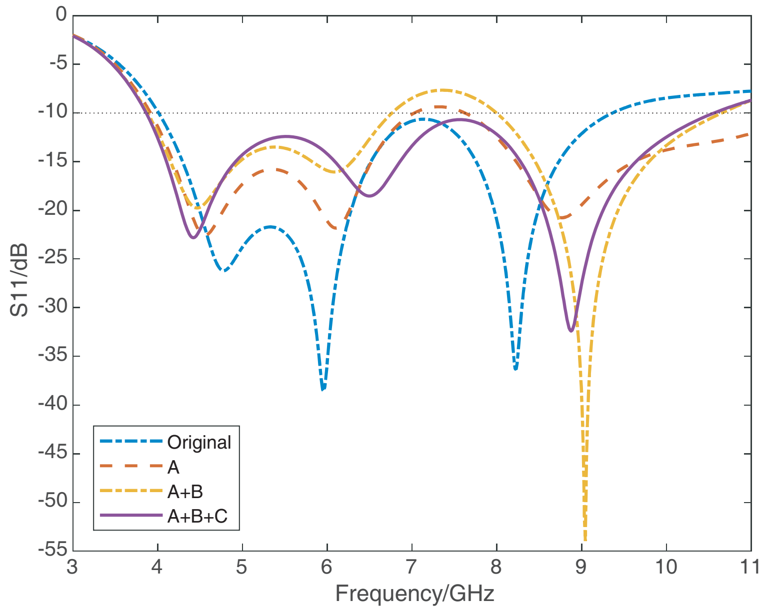


Figure 2. Comparison of simulated S_{11} between original antenna and different optimized antennas. "A" indicates the two corners of the rectangular patch is cut off, "B" indicates a rectangular notch is etched in the middle of the upper side of the ground, "C" indicates the ground is adopted a trapezoidal structure.

In this paper, a set of tunable units are designed that can produce a band notch at the center frequency of 7 GHz. Firstly, the dielectric material with the dielectric constant of 2.2 is selected, and l_0 is calculated to be 16.94 mm according to Equations (1) and (2). Then, all the parameters of the SRR are calculated according to formula (3). Finally, the parametric optimization design is carried out in the simulation software.

SRR can be equivalent to LC resonant circuit. By adding a varactor diode to SRR, the value of the equivalent capacitance is tunable. The equivalent circuit of the tunable unit is shown in Fig. 3. The resonant frequency of the tunable unit can be calculated by formula (4):

$$f = \frac{1}{2\pi\sqrt{LC_{eq}}} = \frac{1}{2\pi\sqrt{L(C_0 + C_v)}} \tag{4}$$

where L is the equivalent inductance, C_{eq} the equivalent capacitance, C_0 the equivalent capacitance of the SRR, and C_v the capacitance of the varactor diode.

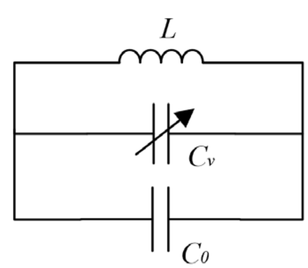


Figure 3. The equivalent circuit of the tunable unit.

According to formula (4), when the capacitance of the varactor diode increases, the resonant frequency will decrease, and the notched band will move towards low frequency.

According to formula (2), the decrease of ε_r will lead to the decrease of ε_{eff}. Then according to formula (1), the center frequency of band notch will move towards high frequency. The continuous movement range of band notch is limited by the electrical control of varactor diodes. Some tunable units with the same structure but different dielectrics are made to expand the movement range.

3. SIMULATION AND DISCUSSION

The comparison of the simulation results of the two modes is shown in Fig. 4. In the band notch free mode, the working band is 3.87–10.56 GHz, and the relative bandwidth ratio (RBW) is 92.72%. In the band notch mode, the dielectric substrate of the tunable units is 1.5 mm thick Rogers RO3003 with a dielectric constant of 3 and loss tangent of 0.001. The antenna produces significant band notch within the working band. The results illustrate that the antenna can work in two modes with and without band notch, respectively.

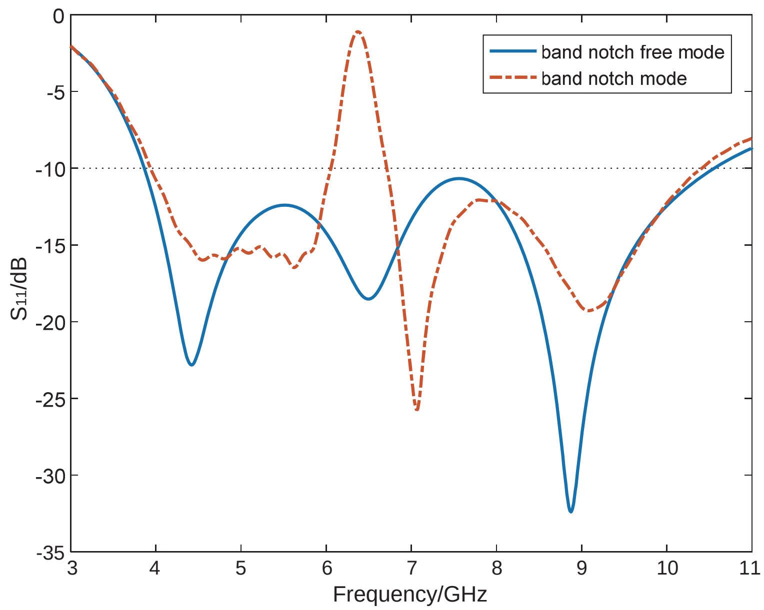


Figure 4. The simulated S_{11} of two modes.

In the band notch mode, the method proposed in this paper can realize the movement of band notch. The simulation results in Fig. 5(a) are obtained by tuning the capacitance value of varactor diodes when the above tunable units are used. With the increase of capacitance value, the notched band moves towards low frequency. Fig. 5(b) shows the results that the tunable units made of different dielectric substrates are placed into the proposed antenna's slots in turn. With the increase of the relative dielectric constant of dielectric substrate, the notch band moves towards low frequency. The combination of the two methods can realize the wide continuous movement range of notch band.

When the tunable range of varactor diodes is merely 0.35–3.20 pF, and the relative dielectric constant of tunable units is 2–6.15. A wide movement range of band notch can be obtained. The partial results are shown in Fig. 6. The continuous movement range of band notch center frequency is 5.06–7.81 GHz. The movable notched band can cover from 4.68 to 8.47 GHz. If the value range of the relative dielectric constant and the capacitance of tunable units is larger, the proposed antenna can realize a wider movement range of band notch.

The surface current distribution in the band notch mode is shown in Fig. 7. When the band notch occurs, the current distribution converges around SRRs, and the current density on the rectangular radiation patch decreases, resulting in large attenuation of the antenna radiation near the band notch.

The above results prove that the band notch center frequency can flexibly move. The antenna can effectively shield some narrowband communication bands by using the above reconfigurable method, and some other simulation results are shown in Table 3.

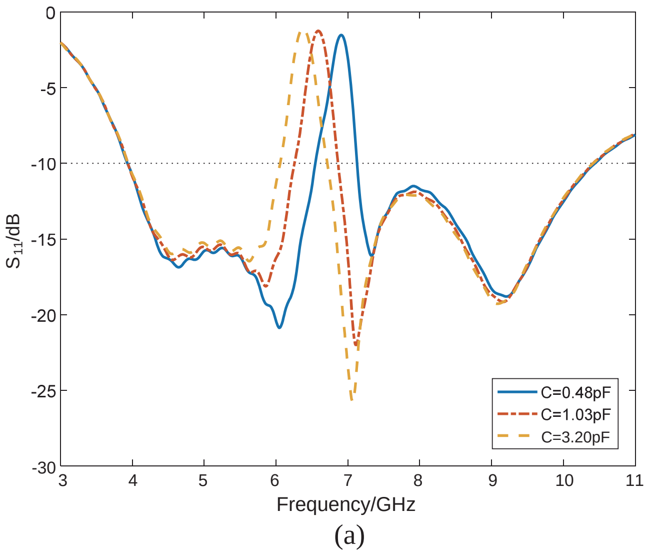


Figure 5. The simulated S_{11} of the notch mode. (a) The proposed antenna with different capacitance values of varactor diodes. (b) the proposed antenna with different dielectric substrates at capacitance value of 3.20 pF.

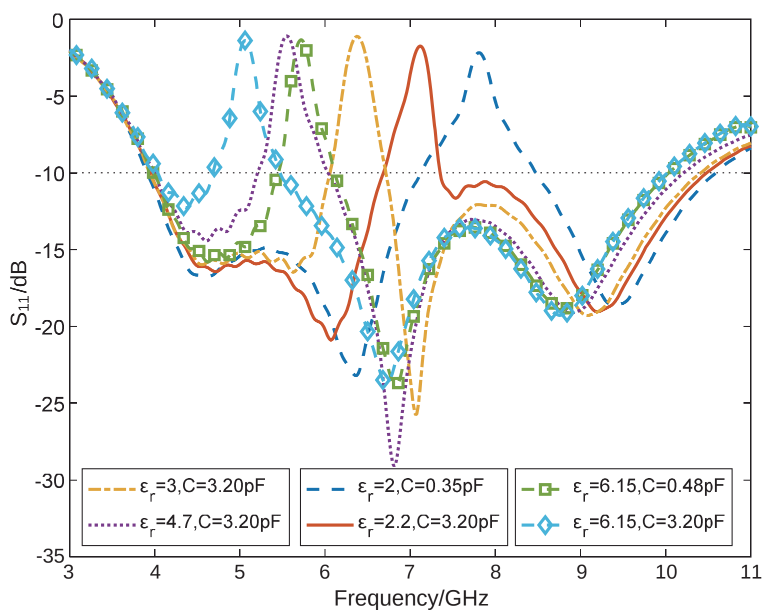
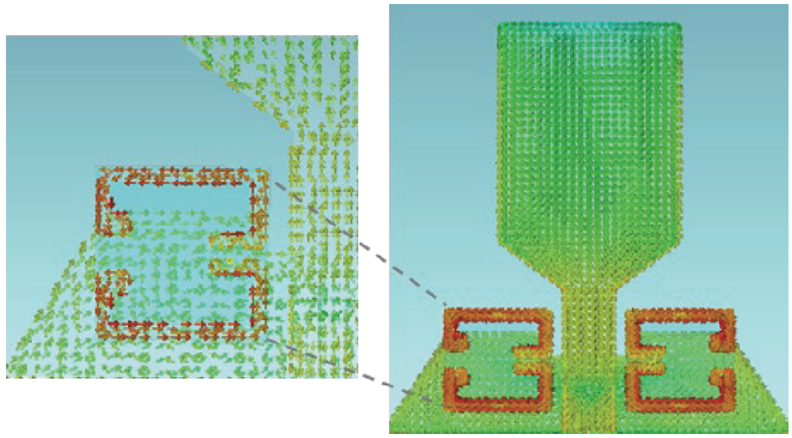


Figure 6. The simulated S_{11} for the proposed antenna.

4. MEASUREMENT AND DISCUSSION

The antenna and tunable units are manufactured as shown in Fig. 8. The varactor diode is SMV2020-079LF. Its capacitance value can be tuned in the range of 0.35–3.20 pF (20–0 V). When there is no voltage, its capacitance value is 3.2 pF. The external bias circuit is shown in Fig. 9. The varactor diode is connected in series with two choke inductors of 100 nH (L_g). C_p will decrease with the increase of V_{bias}, and the band notch will move toward high frequency.

The S_{11} parameters are tested by KEYSIGHT N5224B vector network analyzer. The result of



(a) (b)

Figure 7. Surface current distribution of proposed antenna loaded with tunable units. (a) Partial view of current distribution near tunable unit. (b) Overall view of current distribution.

Table 3. Partial simulation results of notchedband at different relative dielectric constants and capacitance values.

Tunable units ε_r	capacitance value (pF)	Notch center frequency (GHz)	Notched band (GHz)	Shielded narrowband communication band
6.15	0.80	5.43	5.11–5.86	WLAN band (5.15–5.35 GHz, 5.725–5.825 GHz)
6.15	0.48	5.72	5.46–6.10	ISM band (5.725–5.875 GHz)
4.7	3.20	5.80	5.50–6.22	ISM band (5.725–5.875 GHz)
4.7	0.48	6.16	5.90–6.50	C-band satellite uplink band (5.925–6.425 GHz)
2	0.48	7.39	6.89–8.10	X-band downlink band (7.25–7.75 GHz)
2	0.35	7.81	7.12–8.47	X-band satellite uplink and downlink band (7.9–8.4, 7.25–7.75 GHz)

the proposed antenna without tunable units in the band notch free mode is shown in Fig. 10(a). The simulated working band is 3.87–10.56 GHz, and the measured working band is 3.90–12.00 GHz. There is a good agreement realized between simulated and measured results.

The result of the proposed antenna with tunable units in the band notch mode is shown in Fig. 10(b). The relative dielectric constant of the tunable units is 2.2, and the capacitance value is 3.20 pF. The simulated working band is 3.92–10.53 GHz that has a notched band of 6.68–7.36 GHz, and the measured working band is 3.66–12.29 GHz that has a notched band of 6.59–7.35 GHz. The working band and notched band are basically consistent between simulated and measured results. The notched bandwidth can meet the shielding requirement of general narrowband communication band.

It should be mentioned that the size of the antenna is small, and the size of the connector is relatively large, so the influence of the connector cannot be ignored. The measured results are greatly affected by the SMA connector and welding.

As shown in Fig. 11, the radiation patterns for E-plane (YZ-plane) and H-plane (XY-plane)

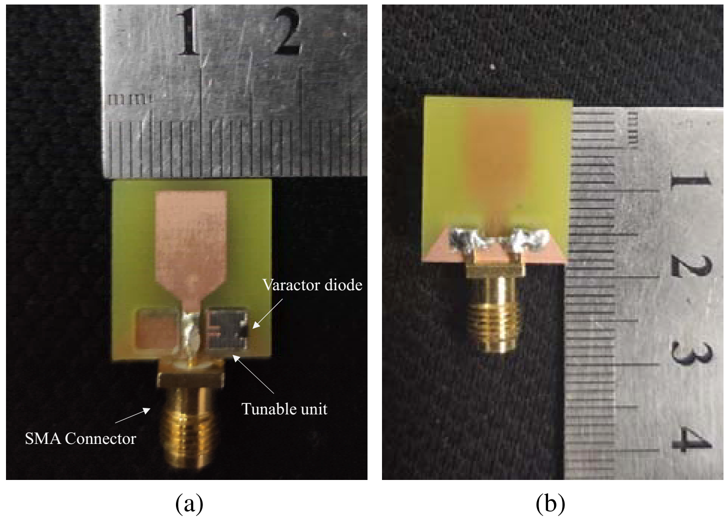


Figure 8. Geometry of the proposed antenna. (a) Top view. A tunable unit is placed into the right slot, the left slot is empty. (b) Bottom view.

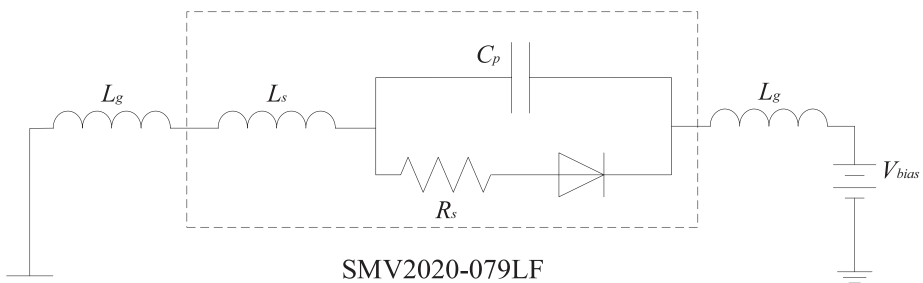


Figure 9. The external bias circuit with the varactor diode.

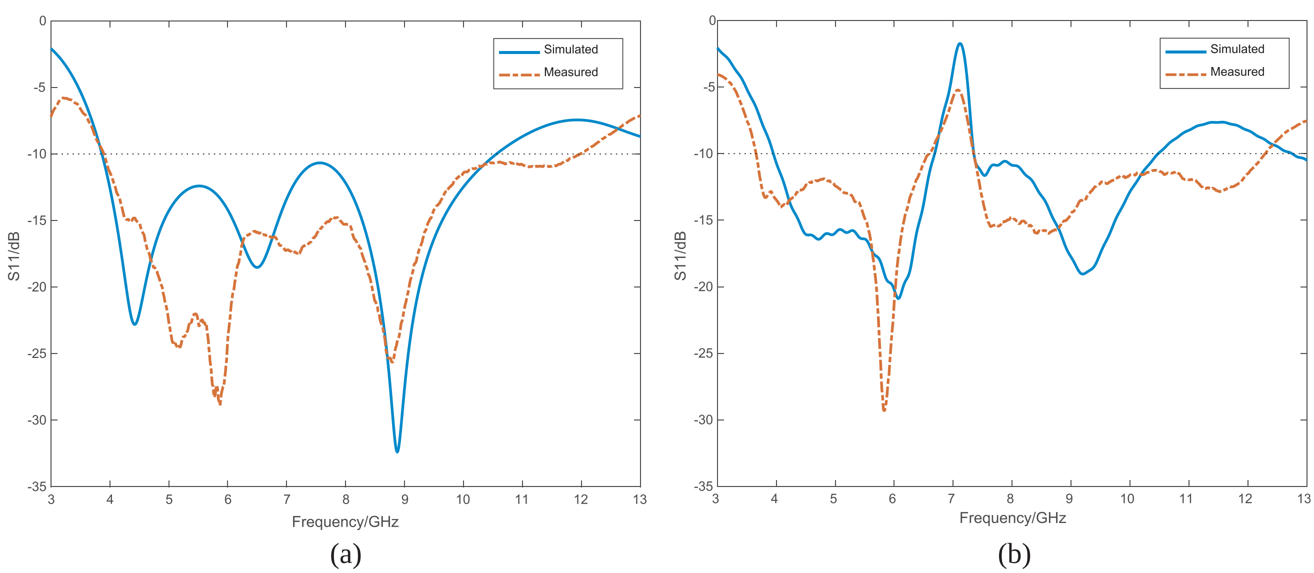


Figure 10. The simulated and measured S_{11}. (a) The proposed antenna without tunable units. (b) The proposed antenna with tunable units.

are tested in a microwave anechoic chamber. The proposed antenna has omnidirectional radiation characteristics. In Fig. 11(a) and Fig. 11(c), the pattern shapes remain basically consistent between two states with and without tunable units. In Fig. 11(b), the gain decreases significantly when the antenna is loaded with the tunable units. As shown in Fig. 10(b), the band notch is generated near

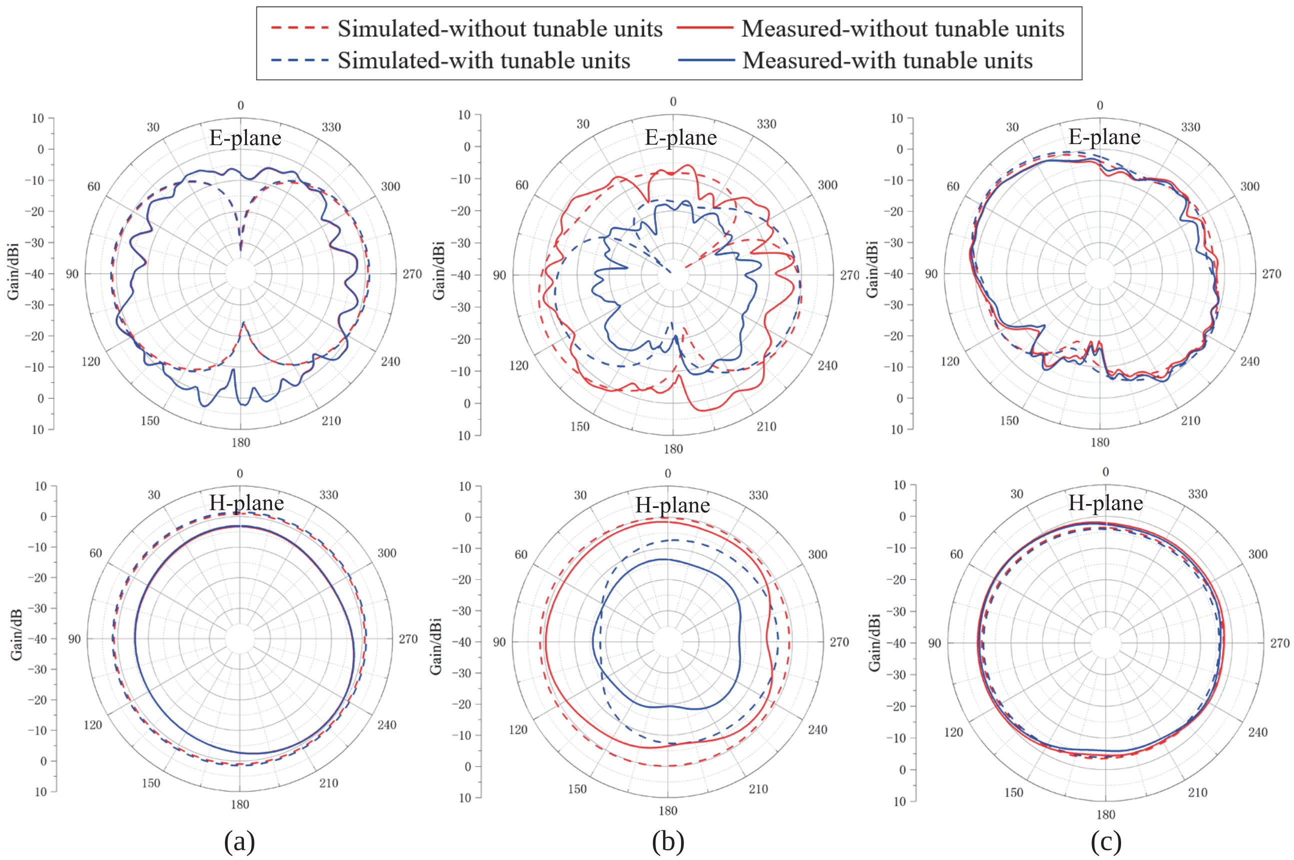


Figure 11. The simulated and measured radiation patterns for E-plane (YZ-plane) and H-plane (XY-plane). (a) 4 GHz. (b) 7 GHz. (c) 10 GHz.

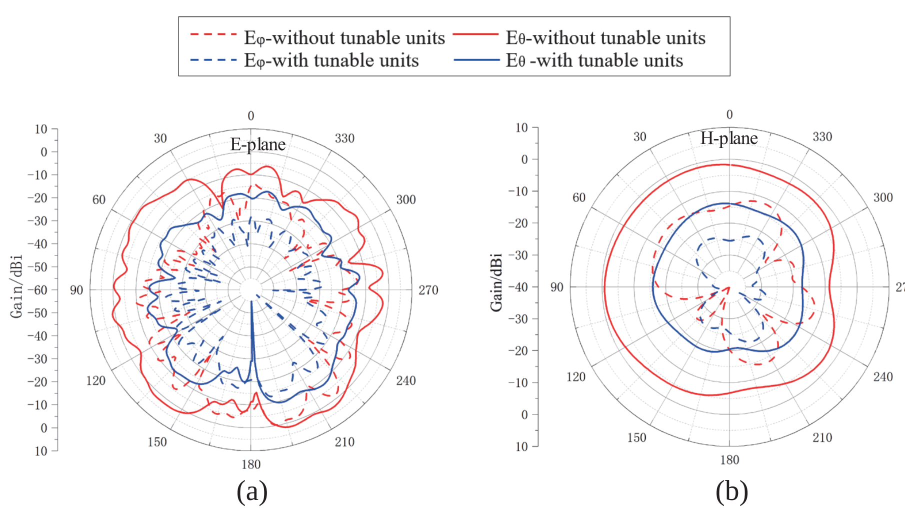


Figure 12. The measured results of the cross-polarization at 7 GHz.

7 GHz. The measured cross-polarization at 7 GHz is shown in Fig. 12. In H-plane pattern, the maximum cross-polarization isolation is 22.1 dBi with tunable units and 51.4 dBi without tunable units.

The measurement results of peak gain are shown in Fig. 13. When the tunable units are placed in the slots, the peak gain near 7.08 GHz presents notch characteristic. The measured antenna has characteristic of high gain in the band of 4–6 GHz. It may come from several factors, such as the difference between the dielectric substrates of the SRR and the antenna, the impact of the test environment, and the poor performance of SMA connector. The peak gain value of the antenna experienced the undulation of rising first, and then falling. The simulated radiation efficiency results are shown in Fig. 14, and an obvious notch occurs near 7.08 GHz when the antenna is loaded with tunable units.

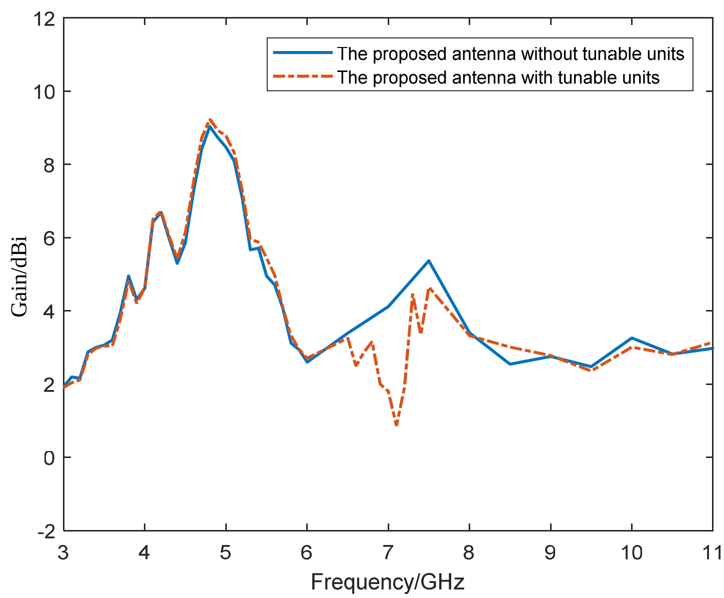


Figure 13. The measured results of the peak gain.

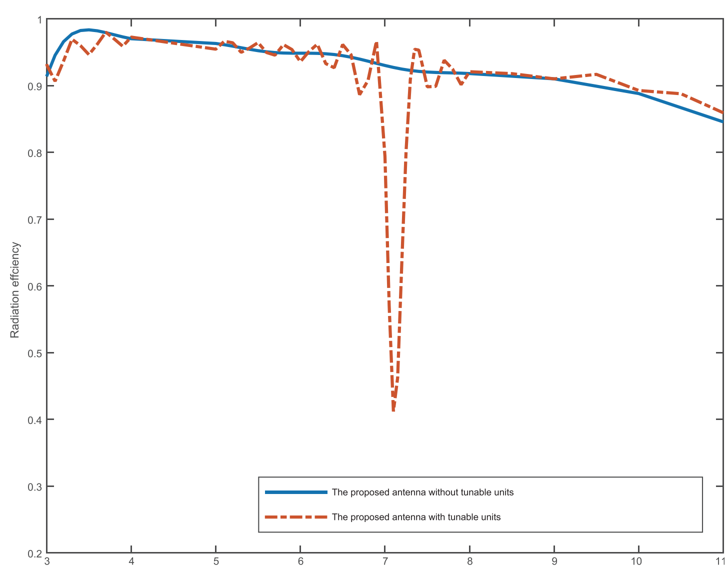


Figure 14. The simulated radiation efficiency.

5. CONCLUSION

In this paper, tunable units are loaded in the proposed antenna's slots to realize reconfigurable band notch function. By electrical control of the varactor diodes and replacement of the tunable units made of different dielectric substrates, the antenna can produce, remove, and continuous move band notch in a wide band range. Due to the limitation of experimental conditions, the measurement only verifies the function of band notch emergence and removal. The measured and simulated results are in good agreement. The measured radiation patterns are stable and consistent under two modes without and with tunable units. The proposed reconfigurable method has reference significance for the design of band notch reconfigurable antennas.

REFERENCES

1. Emadian, S. R. and J. Ahmadi-Shokouh, "Very small dual band-notched rectangular slot antenna with enhanced impedance bandwidth," *IEEE Trans. Antennas Propag.*, Vol. 63, No. 10, 4529–4534, Oct. 2015.
2. Deng, J. Y., Y. Z. Yin, S. G. Zhou, and Q. Z. Liu, "Compact ultra-wideband antenna with tri-band notched characteristic," *Electron. Lett.*, Vol. 44, No. 21, 1231–1232, Oct. 9, 2008.
3. Ojaroudi, M. and N. Ojaroudi, "Low profile slot antenna with dual band-notched function for UWB systems," *Microw. Opt. Techn. Lett.*, Vol. 55, No. 5, 951–954, May 2013.
4. Dissanayake, T. and K. P. Esselle, "Prediction of the notch frequency of slot loaded printed UWB antennas," *IEEE Trans. Antennas Propag.*, Vol. 55, No. 11, 3320–3325, Nov. 2007.
5. Lee, W. S., D. Z. Kim, K. J. Kim, and J. W. Yu, "Wideband planar monopole antennas with dual band-notched characteristics," *IEEE Trans. Microw. Theory Tech.*, Vol. 54, No. 6, 2800–2806, Jun. 2006.
6. Chung, K. H., J. M. Kim, and J. Choi, "Wideband microstrip-fed monopole antenna having frequency band-notch function," *IEEE Microw. Wirel. Compon. Lett.*, Vol. 15, No. 11, 766–768, Nov. 2005.
7. Xu, J., D. Y. Shen, G. T. Wang, X. H. Zhang, X. P. Zhang, and K. Wu, "A small UWB antenna with dual band-notched characteristics," *Int. J. Antennas Propag.*, Vol. 2012, 2012.
8. Azim, R., M. T. Islam, and A. T. Mobashsher, "Design of a dual band-notch UWB slot antenna by means of simple parasitic slits," *IEEE Antennas Wirel. Propag. Lett.*, Vol. 12, 1412–1415, 2013.
9. Rostamzadeh, M., S. Mohamadi, J. Nourinia, C. Ghobadi, and M. Ojaroudi, "Square monopole antenna for UWB applications with novel rod-shaped parasitic structures and novel V-shaped slots in the ground plane," *IEEE Antennas Wirel. Propag. Lett.*, Vol. 11, 446–449, 2012.
10. Zhu, F., et al., "Design and analysis of planar ultra-wideband antenna with dual band-notched function," *Progress In Electromagnetics Research*, Vol. 127, 523–536, 2012.
11. Siddiqui, J. Y., C. Saha, and Y. M. M. Antar, "Compact dual-SRR-loaded UWB monopole antenna with dual frequency and wideband notch characteristics," *IEEE Antennas Wirel. Propag. Lett.*, Vol. 14, 100–103, 2015.
12. Jiang, W. and W. Q. Che, "A novel UWB antenna with dual notched bands for WiMAX and WLAN applications," *IEEE Antennas Wirel. Propag. Lett.*, Vol. 11, 293–296, 2012.
13. Choi, N., et al., "Compact UWB antenna with I-shaped band-notch parasitic element for laptop applications," *IEEE Antennas Wirel. Propag. Lett.*, Vol. 8, 580–582, 2009.
14. Ojaroudi, N. and M. Ojaroudi, "Dual band-notch square monopole antenna with a modified ground plane for UWB applications," *Microw. Opt. Technol. Lett.*, Vol. 54, No. 12, 2743–2747, Dec. 2012.
15. Anagnostou, D. E. and A. A. Gheethan, "A coplanar reconfigurable folded slot antenna without bias network for WLAN applications," *IEEE Antennas Wirel. Propag. Lett.*, Vol. 8, 1057–1060, 2009.
16. Horestani, A. K., Z. Shaterian, J. Naqui, F. Martin, and C. Fumeaux, "Reconfigurable and tunable S-shaped split-ring resonators and application in band-notched UWB antennas," *IEEE Trans. Antennas Propag.*, Vol. 64, No. 9, 3766–3776, Sep. 2016.

17. Saha, C., J. Y. Siddiqui, A. P. Freundorfer, L. A . Shaik, and Y. M. M. Antar, "Active reconfigurable ultra-wideband antenna with complementary frequency notched and narrowband response," *IEEE Access*, Vol. 8, 100802–100809, 2020.
18. Yang, H. L., X. L. Xi, L. L. Wang, Y. C. Zhao, X. M. Shi, and Y. N. Yuan, "Design of reconfigurable filtering ultra-wideband antenna with switchable band-notched functions," *Int. J. Microw. Wirel. Technol.*, Vol. 11, No. 4, 368–375, May 2019.
19. Alam, M. S. and A. Abbosh, "Reconfigurable band-rejection antenna for ultra-wideband applications," *IET Microw. Antennas Propag.*, Vol. 12, No. 2, 195–202, Feb. 7, 2018.
20. Han, L. P., J. Chen, G. R. Han, X. W. Chen, R. B. Ma, and W. M. Zhang, "A miniaturized reconfigurable unlicensed ultra-wideband antenna with multiple band-notch performance," *Int. J. RF Microw. Comput.-Aid. Eng.*, Vol. 31, No. 8, Aug. 2021.
21. Han, L. P., G. Cheng, G. R. Han, and W. M. Zhang, "Reconfigurable ultra-wideband monopole antenna with single-, dual-, and triple-band notched functions," *Int. J. RF Microw. Comput.-Aid. Eng.*, Vol. 29, No. 9, Sep. 2019.
22. Aghdam, S. A., "Reconfigurable antenna with a diversity filtering band feature utilizing active devices for communication systems," *IEEE Antennas Wirel. Propag. Lett.*, Vol. 61, No. 10, 5223–5228, Oct. 2013.
23. Sun, J. H., H. Jing, H. C. Zhou, Y. Wang, P. Wang, and Y. F. Qin, "Design of a reconfigurable band-notch SWB antenna," *Progress In Electromagnetics Research Letters*, Vol. 99, 1–9, 2021.
24. Li, T., C. Zhu, X. Y. Cao, and J. Gao, "Compact UWB antenna with sharp tunable band-notched characteristics," *Microw. Opt. Technol. Lett.*, Vol. 58, No. 3, 529–532, Mar. 2016.
25. Sharbati, V., P. Rezaei, and M. M. Fakharian, "Compact planar UWB antenna with enhanced bandwidth and switchable band-notch function for WLAN and DSRC," *IETE J. Res.*, Vol. 63, No. 6, 805–812, 2017.
26. Lakrit, S., S. Das, A. El Alami, D. Barad, and S. Mohapatra, "A compact UWB monopole patch antenna with reconfigurable band-notched characteristics for Wi-MAX and WLAN applications," *AEU — Int. J. Electron. Commun.*, Vol. 105, 106–115, 2019.
27. Elkorany, A. S., G. T. Ahmed, H. A. Mohamed, and Z. F. Elsharkawy, "Reconfigurable band notch butterfly-wing shaped ultra-wide band antenna using varactor diodes," *Microsyst. Technol.*, Vol. 27, No. 7, 2695–2703, Jul. 2021.
28. Nemati, N. and M. Bemani, "A novel reconfigurable microstrip fractal UWB antenna with six variable rejection frequency bands," *Int. J. Microw. Wirel. Technol.*, Vol. 12, No. 2, 148–154, Mar. 2020.
29. Gao, P., S. He, X. B. Wei, Z. Q. Xu, N. Wang, and Y. Zheng, "Compact printed UWB diversity slot antenna with 5.5-GHz band-notched characteristics," *IEEE Antennas Wirel. Propag. Lett.*, Vol. 13, 376–379, 2014.