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A Vivaldi Antenna with Switchable and Tunable Band-Notch Characteristic

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Abstract—This paper proposes an ultrawideband (UWB) Vivaldi antenna with switchable and tunable band-notch characteristics. One stepped-impedance resonator (SIR), which has high quality factor Q and small size, is introduced to create band-notched characteristic with narrow notch band and high notch band edge selectivity. By loading two varactor diodes, a wide tunable notched band is achieved. The center frequency of notch band can tune from 3.1 GHz–6.8 GHz. In order to make the full use of UWB spectrum when there is on coexisting narrow-band applications, switchable band-notch characteristic is desired. Through rational parameters design, the center frequency of notched band is out of UWB range when the DC bias voltage of the varactor diode is 0 V. In this way, switchable band-notch characteristic is achieved.

1. INTRODUCTION

In February 2002, the Federal Communications Commission (FCC) assigned 3.1 GHz from 10.6 GHz to UWB spectrum for civil use. UWB communication systems and UWB indoor positioning systems have achieved great development due to appealing characteristics in high speed transmission rate and high multi-pathway resolution, etc. However, There are some other narrow-band applications existing over the UWB bandwidth, including WiMax (3.3 GHz–3.8 GHz) and WLAN (5.15 GHz–5.35 GHz, 5.725 GHz–5.825 GHz), etc. The coexisting narrow-band applications can affect the performance of UWB systems. In order to effectively mitigate the undesirable interferences generated from other narrow-band servers within the range of the bandwidth of UWB wireless systems, UWB antennas should have band-notch characteristics.

Various kinds of technologies have been proposed to design a UWB antenna with band-notch characteristic. Typically, different slots are inserted into the radiating elements or ground planes to reject narrow-band applications [1–6]. Another category of UWB antenna with band-notch characteristics has been achieved by introducing parasitic elements [7–9]. However, once the antenna is fabricated, the center frequency of notch band is fixed. With the development of wireless technology, more and more narrow-band applications will share spectrum with UWB systems. UWB systems will be interfered by different narrow-band signals in different operating environments. In this case, fixed notched band cannot satisfy the demand in different environments. Therefore, a UWB antenna with switchable and tunable band-notch characteristics is desired.

Several UWB antennas with tunable band-notch characteristic have been published. In [10], an antenna has tunable band-notch by loading PIN diodes. The design by loading PIN diodes only realizes four states of band-notch. It cannot be tuned continuously. In [11–17], varactor diodes are inserted to obtain tunable notched band. In [18, 19], the notched band can be adjusted by loading a variable capacitor. However, variable capacitors have a large size.

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In this paper, a UWB Vivaldi antenna with switchable and widely tunable band-notch characteristics is proposed. The Vivaldi antenna proposed by Gibson in 1979 has many features such as good performance in time domain, wide band and high gain [20]. One SIR is inserted to obtain notched band. Tunable band-notch is achieved by loading varactor diodes. The bandwidth of the notch band is narrow due to the high quality factor Q of SIR. In addition, transition band between notched band and the operating band is sharp. Compared with the wide notched band, the narrow-band interference can be rejected effectively, and the pulse signal of UWB systems is less affected. Through rational parameters design, the center frequency of notched band is out of UWB range when the DC bias voltage of the varactor diode is 0 V. The band-notch is on off state. The switchable band-notch characteristic is obtained. We can adjust the center frequency of the notched band by changing the bias voltage of the varactor diode. Simulated and measured results show that the proposed Vivaldi antenna can operate in the whole UWB band except the notched band. When the DC bias voltage of the varactor diode is 0 V, the band-notch is off. With changing DC bias voltage, the center frequency of notched band changes from 3.1 GHz to 6.8 GHz.

Compared with other structures designed to obtain notch band, the proposed SIR structures have a more compact size. In this way, the antennas with the SIR structure have the possibility of miniaturization. Compared with the designs which carve slots on radiation structures of ground plates, the proposed design does not perturb the radiation structures or the ground plates. Furthermore, the SIR structure can be employed on any microstrip fed antennas.

The remainder of the paper is organized as follows. The configuration of Vivaldi antenna with switchable and tunable band-notch characteristics and the design of SIR structures are depicted in Section 2. Section 3 describes the simulated and experimental results of the Vivaldi antenna. Conclusion is given in Section 4.

2. ANTENNA DESIGN

The antenna proposed in this paper based on a traditional microstrip-fed Vivaldi antenna. A signal is fed from a 50 Ω coaxial cable. Fig. 1 plots the structures of the proposed Vivaldi antenna. The antenna is printed on a Rogers-4350 substrate with the size of 50 mm × 40 mm. The dielectric constant of the substrate is 3.48, and the thickness of the substrate is 0.762 mm.

The Vivaldi antenna has a symmetrical tapered patch and a stepped microstrip line. The tapered patch used as a radiation patch is printed on the face plane of the antenna. The tapered patch consists

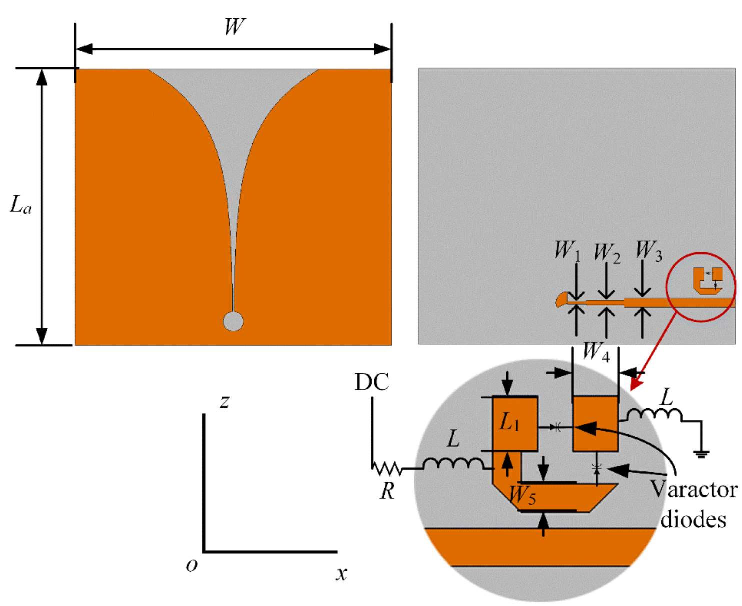


Figure 1. Structures of proposed vivaldi antenna.

of two exponential tapered-lines. Two exponential tapered-lines form an exponential slot line. The exponential tapered-lines of the Vivaldi antenna are defined as

$$y = c_1 e^{\alpha x} + c_2 \tag{1}$$

$$c_1 = \frac{y_2 - y_1}{e^{\alpha x_2} - e^{\alpha x_1}} \tag{2}$$

$$c_2 = \frac{y_1 e^{\alpha x_2} - y_2 e^{\alpha x_1}}{e^{\alpha x_2} - e^{\alpha x_1}} \tag{3}$$

where α is the gradient index of the tapered-lines. c_1, c_2 depend on the starting point and the terminal point of the tapered slot. The aperture width of the antenna is designed at approximately half wavelength at the lowest operating frequency. In this paper, the lowest operating frequency is set to 3.1 GHz. The stepped microstrip line used as a fed line is printed on the back plane of the antenna. It has three parts. The first part is used to excite the exponential slot by field coupling. The width of the first part, W_1, is designed to achieve good matching between the microstrip line and the exponential slot line. The second part is fixed to W_2 to achieve impedance transformation. The third part which connects to SMA connecter is used to obtain 50 Ω characteristic impedance.

A folded SIR is inserted near the feed line to obtain the notched band [21]. The schematic of the SIR is shown in Fig. 2.

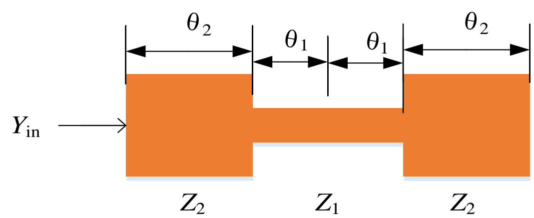


Figure 2. Schematic of the SIR.

Theory of transmission line is used to analyze the SIR. The input admittance Y_{in} is defined as

$$Y_{in} = \frac{-2jY_2(K\tan\theta_1 + \tan\theta_2)(K - \tan\theta_1\tan\theta_2)}{K(1-\tan^2\theta_1)(1-\tan^2\theta_2) - 2(1-K^2)\tan\theta_1\tan\theta_2} \tag{4}$$

where Z_1, Z_2 are the characteristic impedances of the transmission lines, and θ_1, θ_2 are the electrical length of the transmission lines.

$$K = \frac{Z_2}{Z_1} \tag{5}$$

where Z_1, Z_2 are the characteristic impedances of the transmission lines, and θ_1, θ_2 are the electrical length of the transmission lines. The resonance condition can be obtained as following

$$Y_{in} = 0 \tag{6}$$

Figure 3 shows the structure of the folded SIR. To better understand the function of a folded SIR, the frequency characteristics of the folded SIR with different parameters are independently simulated by high-frequency structure simulator HFSS 15.0. As shown in Fig. 4, with the increase of L_L and W_L, the resonant frequency of the SIR decreases as well.

To change notch frequency, we must change the size of SIR. In this paper, two varactor diodes with a DC bias circuit are inserted in SIR to change the center frequency of notched band. The proposed varactor diode is Skyworks SMV2019-079LF. The capacitance C of the varactor diode changes from 2.2 pf–0.3 pf by increasing the DC bias voltage from 0 V to 20 V. A current limiting resistor $R = 10\,\mathrm{k\Omega}$ is used to protect the varactor diodes. Two AC-blocking inductors $L = 270\,\mathrm{nH}$ is used to isolate the RF signal.

To achieve the switch function, we optimize the parameters of SIR. A set of suitable parameters ensure that the center frequency of notched band is out of the operating band range when the DC bias voltage is 0 V.

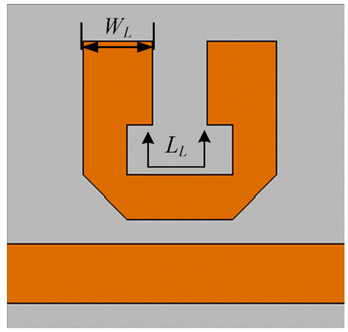


Figure 3. Structure of the folded SIR.

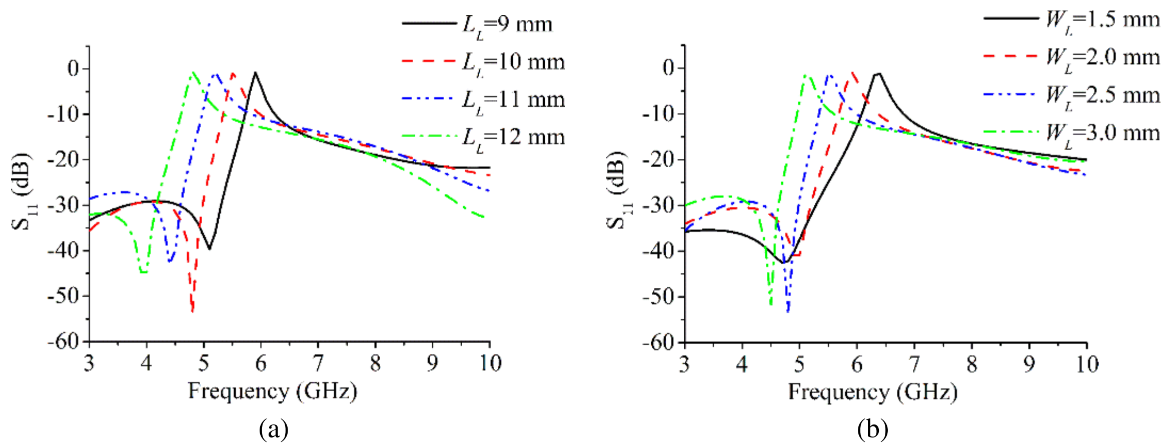


Figure 4. S_{11} for different lengths of (a) L_L ($W_L = 2.5\,\text{mm}$) and (b) W_L ($L_L = 10\,\text{mm}$).

Analysis on some parameters is performed to optimize electrical property by using HFSS. Some key optimized parameters of the antenna are specified as follows: $W = 50\,\text{mm}$, $L_a = 44\,\text{mm}$, $L_1 = 2$, $W_1 = 0.1\,\text{mm}$, $W_2 = 0.8\,\text{mm}$, $W_3 = 1.4\,\text{mm}$, $W_4 = 1.05\,\text{mm}$, $W_5 = 1.65\,\text{mm}$.

3. RESULTS AND ANALYSIS

The proposed antenna is manufactured, and a picture of the antenna is shown in Fig. 5.

To better understand the performance of the proposed antenna, the simulated surface current distributions of the proposed antenna at passband and notched band is shown in Fig. 6. Fig. 6(a) shows the current distributions of the proposed Vivaldi at passband. As shown in Fig. 6(a), the currents concentrate on feed line. This phenomenon shows that the band-notch is not achieved. Fig. 6(b) shows the current distributions of the proposed antenna at notched band. It can be seen that the currents concentrate on SIR. Therefore, the energy cannot be fed to radiation element, and the notched band is obtained.

To verify the design in this paper, the proposed antenna is measured. The impedance bandwidth of the Vivaldi antenna is measured with the Agilent technologies N5230A vector network analyzer.

Figure 7 gives the simulated S_{11} of the antenna for different capacitances C. Fig. 8 gives the measured S_{11} of the antenna for different voltages V. The simulated and measured results show that the proposed antenna realizes a wide impedance bandwidth from 3.1 GHz–10.6 GHz with an electrically switchable and widely tunable notched band. The center frequency of the notched band can continuously turn from 3.1 GHz to 6.8 GHz. With the decrease of the bias DC voltage, the center frequency of the notched band decreases as well. In addition, the notched band is on off-state when the DC bias voltage V is 0 V. The S_{11} of different bias DC voltages are similar except the notched band. It is shown that the SIR structure only applies to notched band, and the pass band is interfered slightly.

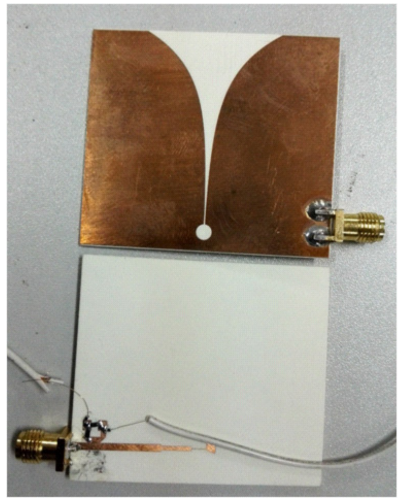
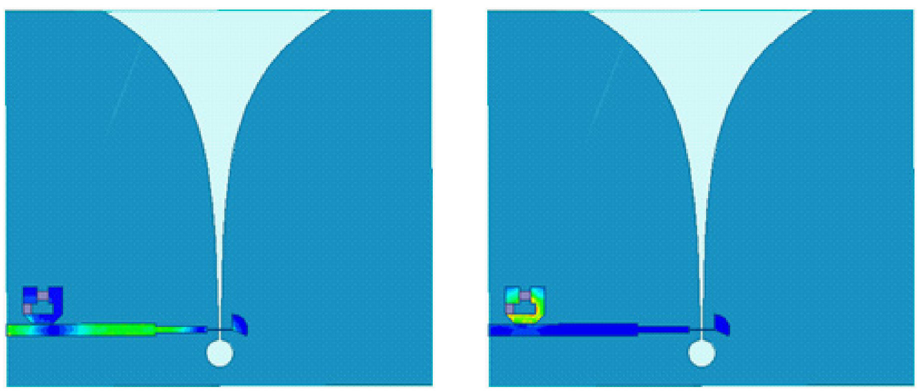


Figure 5. Picture of the proposed antenna.



(a) (b)

Figure 6. Surface current distributions at (a) passband and (b) notched band.

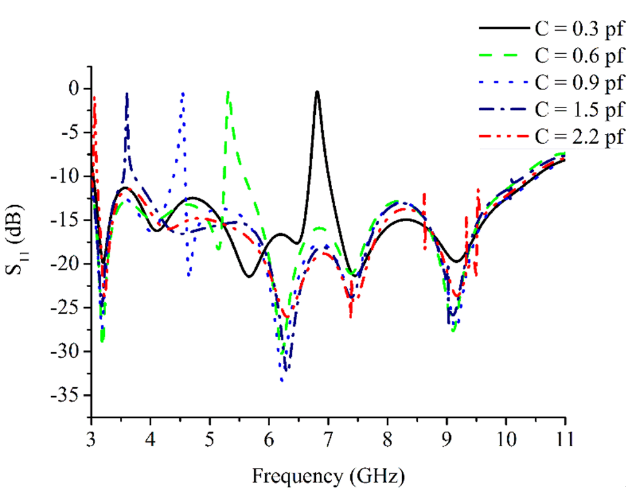


Figure 7. Simulated S_{11} of different C.

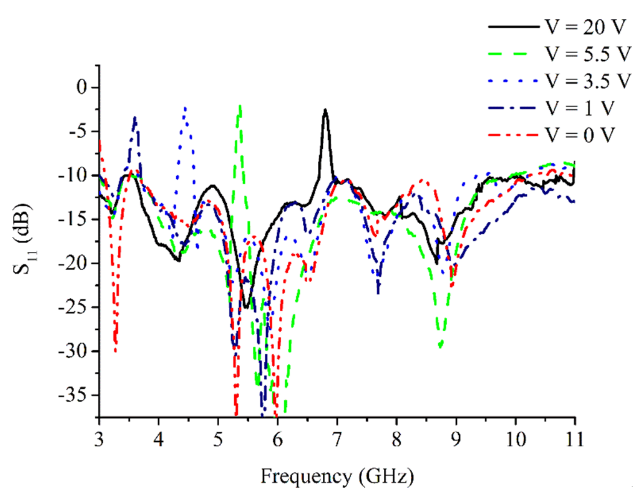


Figure 8. Measured S_{11} of different V.

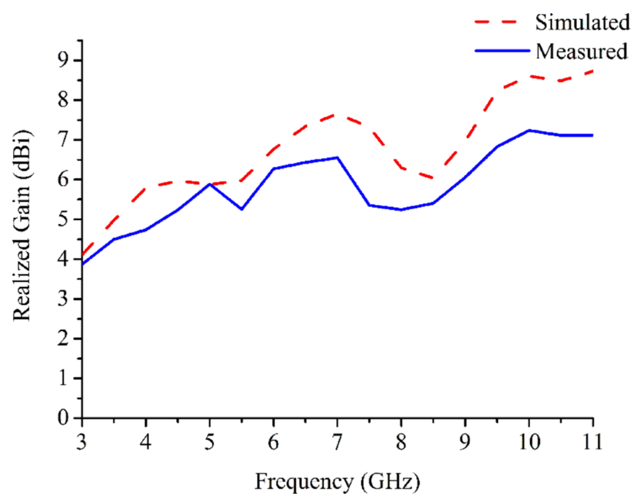


Figure 9. Simulated and measured gain.

Table 1. Performance summary of the tunable UWB antenna.

Ref	Type of antenna	Operating frequency band (GHz)	Device used	Tunable notched frequency range (GHz)
[12]	Monopole	3–14	Varactor diode	5.1–5.9
[13]	Monopole	0.75–6	Varactor diode	2.4–3.1
[14]	Monopole	3.1–10	Varactor diode	4.6–6.2
[15]	Monopole	3.1–10.6	Varactor diode	5.07–5.83
[17]	Monopole	1.5–5.5	Varactor diode	2.38–3.87
[18]	Pyramidal	3.1–10	Varactor capacitor	4.8–7.4
[19]	Inverted F-L	3.1–10.6	Varactor capacitor	3.2–6
This work	Vivaldi	3.1–10.6	Varactor diode	3.1–6.8

Figure 9 shows the simulated and measured gains of the proposed Vivaldi antenna when the DC bias voltage is 0 V. The simulated gain changes from 4 dBi to 9 dBi, across the operating frequency band. On the contrary, the measured gain ranges from 3 dBi to 7.5 dBi within the entire operating frequency band. The difference between the simulated and measured results is caused by the experiment environment and the insertion loss of the SMA connector.

The measured co-polarization radiation patterns for the E-plane (xoz) and H-plane (yoz), at 3.5 GHz, 7 GHz, 9 GHz respectively when the DC bias voltage is 0 V, is shown in Fig. 10. The front-to-back ratios remain over 10 dB in the whole UWB band. Based on the results, the Vivaldi antenna demonstrates excellent directionality.

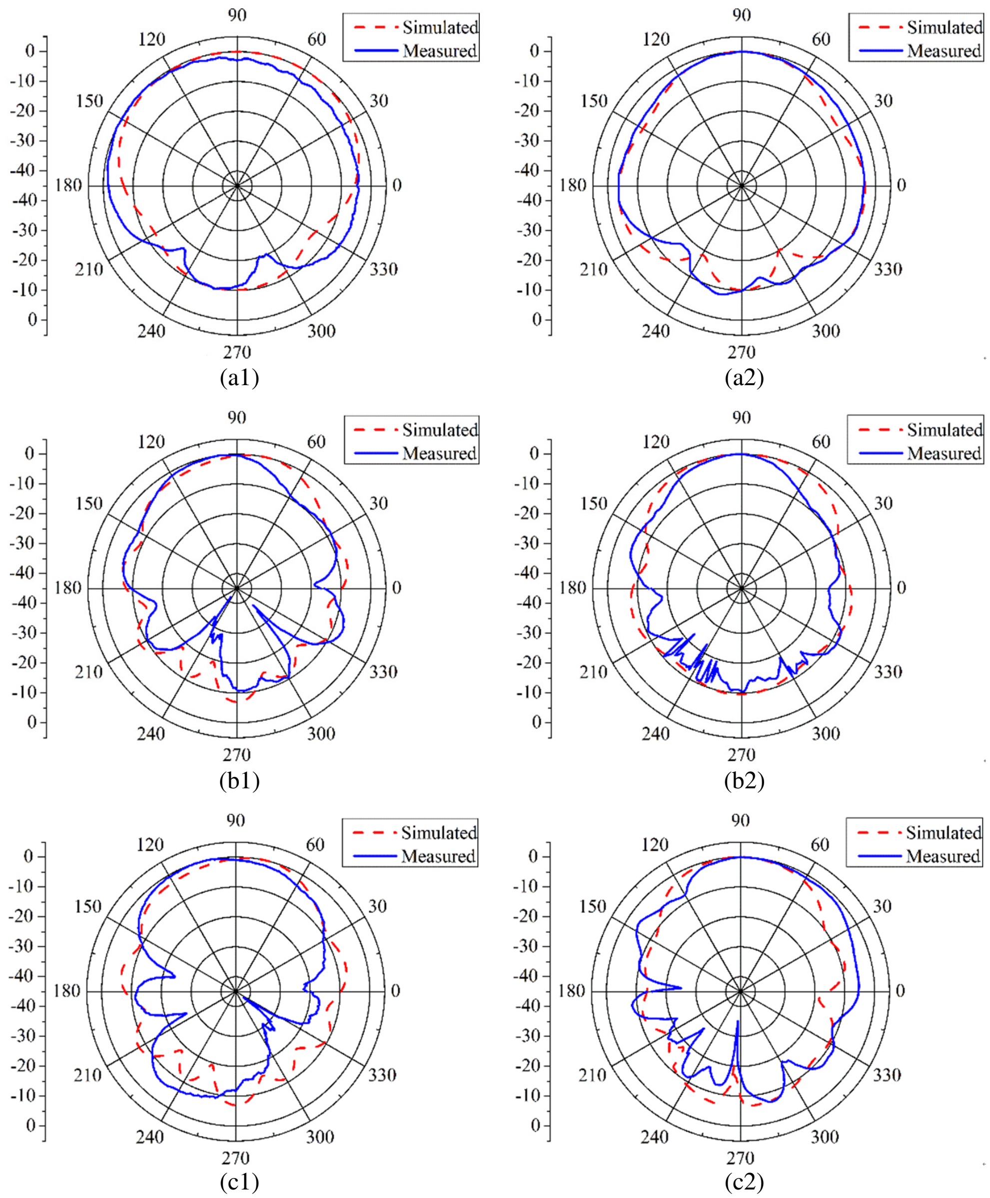


Figure 10. Measured radiation patterns for the *E*-plane (*xoz*) and *H*-plane (*yoz*) at (a) 3.5 GHz, (b) 7 GHz, and (c) 9 GHz. (a1) *E*-plane, (a2) *H*-plane, (b1) *E*-plane, (b2) *H*-plane, (c1) *E*-plane, (c2) *H*-plane.

Table 1 compares the characteristics of the proposed Vivaldi antenna to other designs in [11–15, 17–19]. It is obvious that the antenna proposed in this paper has wider notched band tuning range.

4. CONCLUSION

An ultrawideband (UWB) Vivaldi antenna with switchable and tunable band-notched characteristics is designed and analyzed. The proposed antenna achieves an impedance bandwidth ranging from 3.1 GHz–10.6 GHz. The proposed antenna achieves a switchable and tunable notched band by inserting an SIR. By adjusting the DC bias voltage, the notched band can turn from 3.1 GHz to 6.8 GHz. As a result, the wider turning range of notched band ensures that more coexisting frequency band can be rejected. The pulse signal of UWB systems will be less disturbed due to the narrow bandwidth of notched band.

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