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THE BAND NOTCH SENSITIVITY OF VIVALDI ANTENNA TOWARDS CSRRs

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Abstract—Complementary split ring resonators (CSRRs) are applied on a UWB Vivaldi antenna to eliminate some unwanted narrow band services. Based on the sensitivity of band rejection, we successfully separate the whole radiating patch of a Vivaldi antenna into three subareas: The feeding area, where the Vivaldi antenna demonstrates a highly sensitive response to CSRRs with a narrow notching band; The transition-area, where CSRRs transfer a ultra wideband (UWB) Vivaldi into a narrow band antenna; and the rest area, where CSRRs are proved to have little effects on the antenna bandwidth property. A band notch Vivaldi antenna with 4.8 GHz to 5.4 GHz rejection band is demonstrated to verify our study from both simulated and measured results.

1. INTRODUCTION

Since the rules for the commercial use of ultra wide band (UWB) range from 3.1 to 10.6 GHz was first approved by Federal Communications Commission (FCC) in 2002, the feasible design of UWB system has become a highly competitive topic in academy and communities. To avoid some existing narrow band services, ultra wideband (UWB) antennas with band rejection functionality have been extensively studied. Printed monopoles have become the most commonly employed platform to implement the design of band-notch antennas [1–8]. The main reason for such a choice is basically due to the fact that printed monopoles can be notched easily with various kinds of slots and in most areas of the radiating patch. However, printed monopole antennas generally have unstable radiation patterns in the

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whole working band, and the radiation may go even worse when adding additional slots. In the meanwhile, Vivaldi antenna cannot be notched easily in most area of its radiation patch [9–11], but a band-notch Vivaldi antenna normally possesses an almost constant endfire radiation within the whole UWB range [12–16].

In this letter, we propose a research to investigate the sensitivity of the band-notch property of a UWB Vivaldi antenna, by etching CSRRs [17–19] on different areas of the radiating patch. As a result, we separate the radiating patch into three subareas according to the sensitivity of band rejection: The feeding-area where the Vivaldi antenna presents a highly sensitive response to the CSRRs with a narrow notching band; the transition-area where CSRRs transfer the UWB Vivaldi into a narrow band antenna; the rest area where CSRRs are proved to have little effects on the antenna property. Consequently, the most sensitive position is selected, and a demonstration Vivaldi antenna with a band rejection covering the WLAN IEEE 802.11a application is operated with both simulated and measured results.

2. ANALYSIS AND DESIGN

As shown in Fig. 1, the Vivaldi antenna has been designed on FR4 of $\varepsilon_r = 4.4$. The structural parameters of the design are: $t = 0.6\,\text{mm}$ refers to the thickness, $b \times b$ with $b = 80\,\text{mm}$ refers to the antenna whole size. The profile of the taper slot is defined as $y = \pm[0.2e^{0.0727x} - 0.2]$ with $a = 60\,\text{mm}$ as the terminal opening size. A circular slot is inserted at $h = 11\,\text{mm}$ from the bottom of the antenna with radius $r_s = 3.7\,\text{mm}$. On the reverse side, the antenna is fed with a $w = 0.7\,\text{mm}$ width, $L = 14\,\text{mm}$ length microstrip line, terminated with a quarter circle shaped stub of $r_m = 2.6\,\text{mm}$. The feed line is placed $L_f = 26.3\,\text{mm}$ away from the edge of the slab. The notching band is primarily determined by the perimeter of the outer split ring [20], which nearly equals the half-wavelength and resonates at 5.1 GHz in this design, the details of the CSRRs structures are listed as follows: $R_{out} = 2.6\,\text{mm}$, $R_{in} = 2.0\,\text{mm}$, $w_1 = 0.4\,\text{mm}$, $d = 0.2\,\text{mm}$, $g = 0.2\,\text{mm}$.

The position of the etched CSRRs has a great impact on the band-notch property. As shown in Fig. 2, the radiation element can be categorized into three subareas with different colors, based on the notching sensitivity. The red area, we called the feeding-area, is the most sensitive to achieve a notching band. The feeding-area is determined by the profile of the circular stub on the lower end and the feed line on the back of the antenna, and the width of this area roughly equals the twice the diameter of the CSRRs. In this area, the electric field vectors from the back feed line pass through the

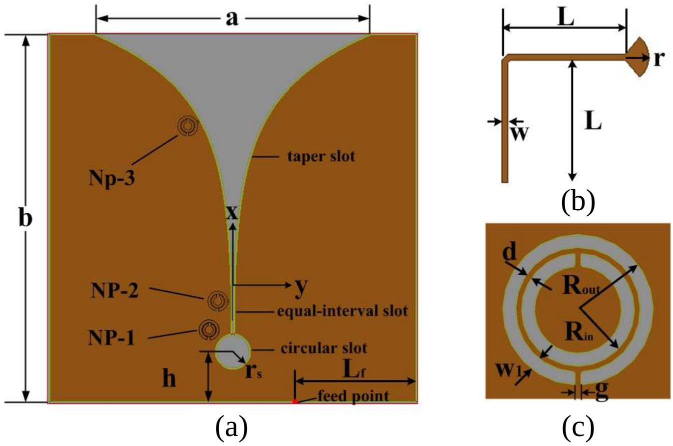


Figure 1. Antenna configuration. (a) Radiating patch, NP refers to the notching position. (b) Feeding line on the reverse side. (c) CSRRs.

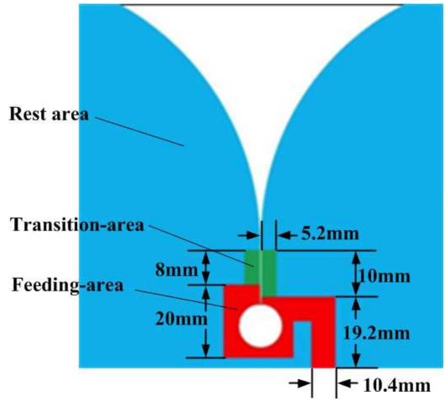


Figure 2. Subareas in the radiation patch of the Vivaldi antenna according to the band notching sensitivity.

CSRRs vertically, and as a result, the CSRRs present the strongest resonance and a narrow band rejection is thus generated. In the green area, termed as the transition-area, the CSRRs are coupled with the taper slot to stop the currents of all working band except those at the resonant frequency. As a result, the UWB Vivaldi is transferred into a narrow-band antenna. The borderline of this area is determined by the diameter of CSRRs and the length of the equal-interval slot, which connects the circular slot and the taper slot. In the rest blue area, the CSRRs appear to have little effect on the antenna bandwidth property.

3. RESULT

A band notch Vivaldi antenna with 4.8 GHz to 5.4 GHz rejection band is obtained and demonstrated to verify our study from both measured and simulated results. The radiating patch is separated into three subareas by the sensitivity of the band-notch property with an etching of CSRRs.

As shown in Fig. 3, the first case is the VSWR of the original UWB Vivaldi antenna, which has a very good impedance matching from 3 GHz to 12 GHz. The second to the fourth cases are the simulated VSWR of the Vivaldi antenna when the CSRRs are etched on the NP-1, NP-2, and NP-3, as shown in Fig. 1, locating in the feeding-area, the transition-area, and the rest area, respectively. It can be seen that the antenna presents a band-notch, a narrow-band, and a wide-band radiation when the CSRRs are etched on the aforementioned three positions. The last case is the measured VSWR of the antenna notched by the CSRRs on NP-1. It has a very good agreement with the second case of the simulation result. A narrow band rejection from 4.8 GHz to 5.4 GHz is thus obtained. The gain of this band-notch Vivaldi antenna is shown in Fig. 4, and a 10 dB gain reduction is clearly observed.

The surface current distributions of the Vivaldi antenna at 5.1 GHz with/without the CSRRs on NP-1 are shown in Fig. 5. It can be seen that the currents on the original antenna mainly concentrate on the taper slot closed to the transition-area and the feed line on the back

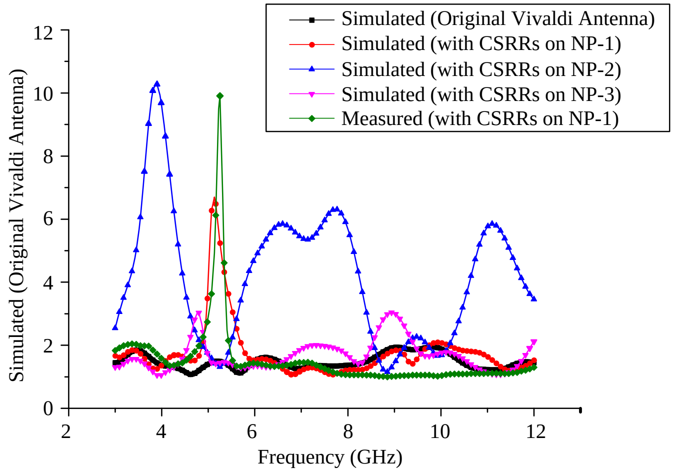


Figure 3. The VSWR of the original Vivaldi antenna and the band notch Vivaldi antennas with CSRRs etched in different subareas.

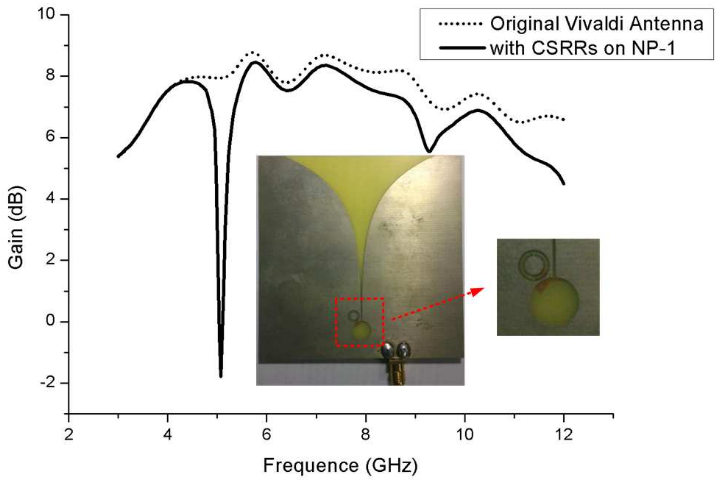


Figure 4. The gain of the original Vivaldi antenna and the band notch Vivaldi antenna. The inserted picture refers to the photograph of the designed band-notch Vivaldi antenna with CSRRs on NP-1.

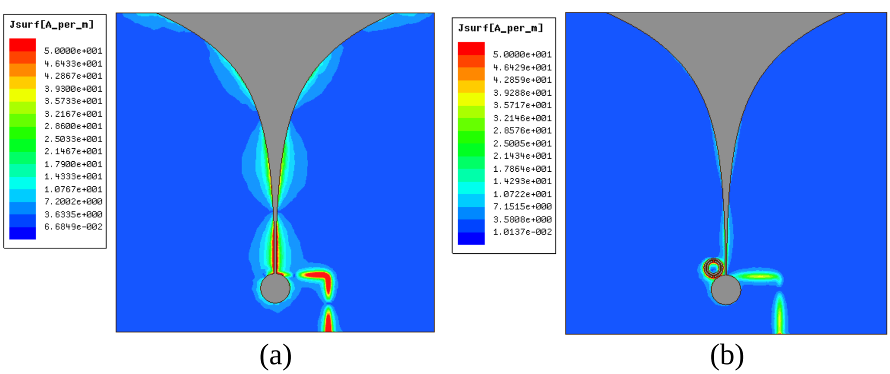
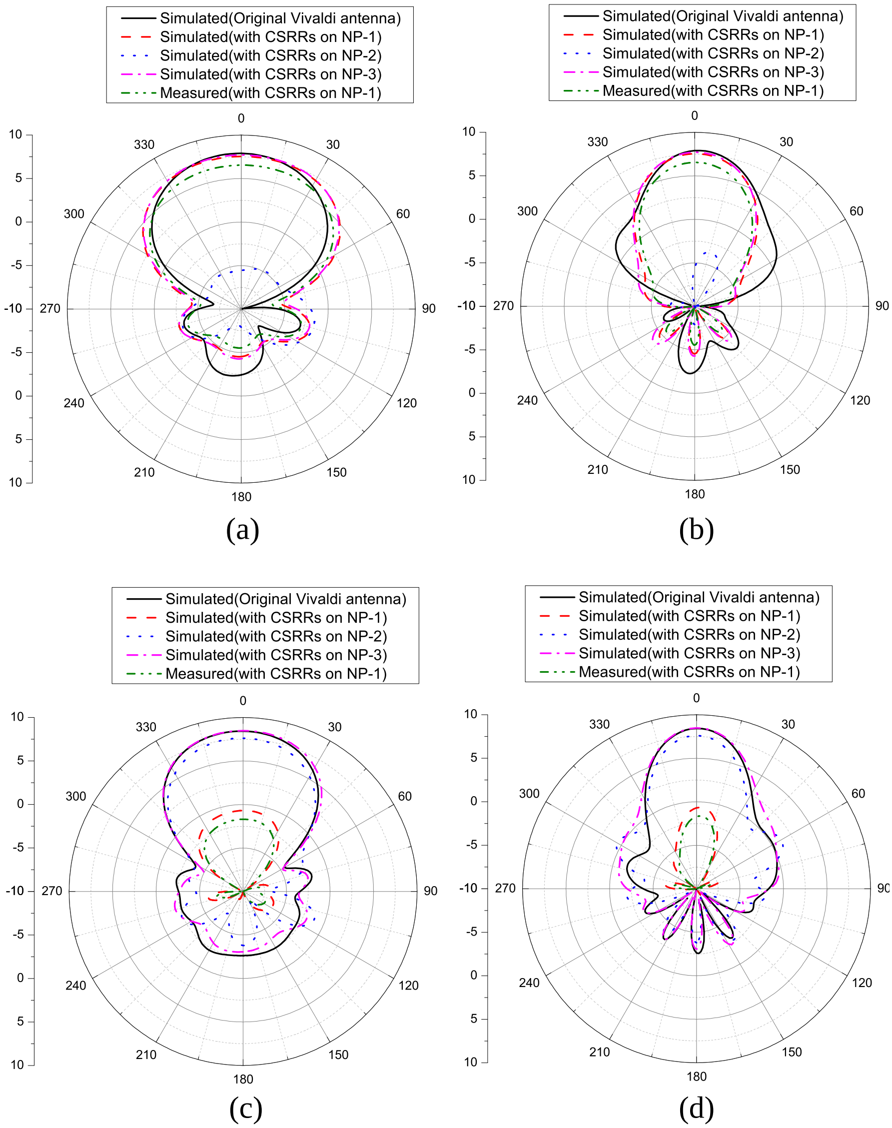


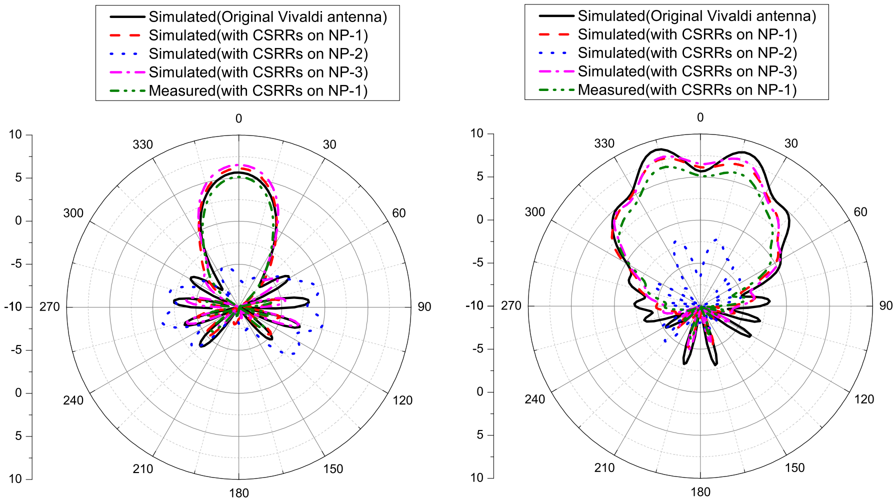
Figure 5. Current distribution at 5.1 GHz on the conductors of the (a) original Vivaldi antenna, (b) with CSRRs on NP-1.

side. When the CSRRs are inserted on NP-1, the currents are flowing around the slot, and the corresponding interference will be destructed. As a result, there is no radiation at 5.1 GHz when we have the CSRRs etched on NP-1 on the original Vivaldi Antenna.

The radiation patterns of the Vivaldi antenna at 4 GHz, 5.1 GHz, and 11 GHz are shown in Fig. 6, with CSRRs inserted in different areas.

The antenna in four mode shows a similar radiation characteristic across the whole operating band in both E plane and H plane. And in the corresponding notched band, the gain of the antenna is less than 0 dB, consistent with the result above.





(e) (f)

Figure 6. Simulated and measured radiation pattern of the band-notch Vivaldi antenna at frequencies of 4 GHz, 5.1 GHz, and 11 GHz. (a) 4 GHz H-plane, (b) 4 GHz E-plane, (c) 5.1 GHz H-plane, (d) 5.1 GHz E-plane, (e) 11 GHz H-plane, (f) 11 GHz E-plane.

4. PARAMETRIC STUDIES

For the CSRRs, w_1, d and g as chosen as constants throughout the design, and R_{in} and R_{out} thus have the relationship $R_{in} = R_{out} - w_1 - d$. Therefore, the resonant frequency of the employed CSRRs can be determined by the value of R_{out}, which further determines the notching frequency range [21]. Different size of CSRRs have been etched on the radiation patch in order to achieve the desired notching band and we can clearly observe from Fig. 7, the center frequency of the notched band decreases as the radius increases. The resonance half-wavelength of the CSRRs has an empirical formula $L_{total} \approx \frac{\lambda}{2}$, where L_{total} represents the perimeter of the CSRRs, λ means the wavelength of the resonance frequency. The band-notch bandwidth of Vivaldi antenna towards CSRRs can generally reach 10%, with usually a -10 dB gain drop in notching frequency. However, the radiation pattern maintains the same throughout the working frequency band.

As we can see from Fig. 8, the distance between CSRRs and circular slot also makes a great contribution to the band notch property. When the CSRRs are placed further away from the center

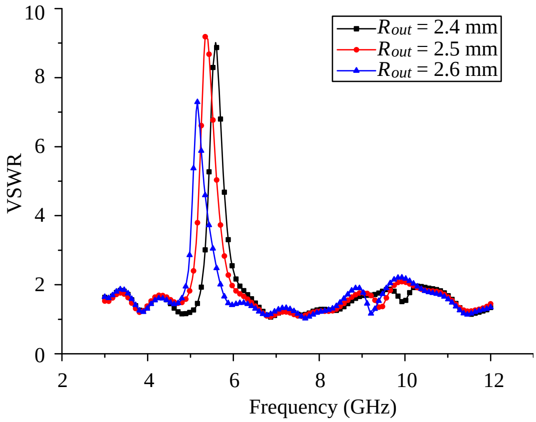


Figure 7. Simulated VSWR of the proposed Vivaldi antenna with different (R_{out}).

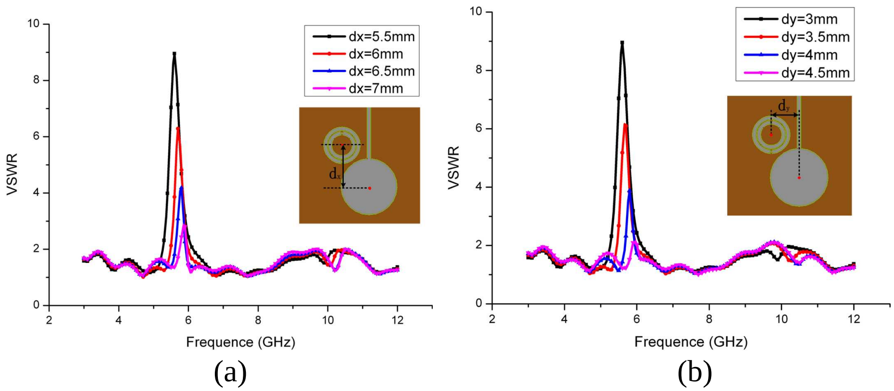


Figure 8. Simulated VSWR of the proposed Vivaldi antenna with different position respect to the center circular slot. (a) In x direction with different d_x, (b) in y direction with different d_y.

of the circular slot in either x direction or y direction, the notching property will deteriorate. This is because when the CSRRs are inserted more closed to the circular slot, the electric field vectors pass through the rings more vertically, and the current distribution becomes stronger.

5. CONCLUSIONS

The sensitivity of the band-notch property of a UWB Vivaldi antenna has been presented in this paper. The radiating patch has been separated into three subareas, as the feeding area, transit area, and rest area, according to etching CSRRs on the bandwidth property of the original Vivaldi antenna. A band notch Vivaldi antenna with 4.8 GHz to 5.4 GHz rejection band has been finally demonstrated and verified our study from both simulated and measured results.

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