

Optimization of Notch Band Frequency in Communication Technology Using Different SRR Types in Vivaldi Antenna

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Abstract

This research was based on M-Vivaldi (Modification Vivaldi) antenna design, which had a bandwidth of 2.4-9.1 GHz with a total antenna size of 150 x 75 mm. In the M-Vivaldi design, Split Ring Resonator (SRR) was incorporated to introduce a band-notch effect. The SRR came in various types, including Complementary Square-Split Ring Resonator (CS-SRR), Complementary Circular-Split Ring Resonator (CC-SRR), Half Circular-Split Ring Resonator (HC-SRR), and Flower-Split Ring Resonator (F-SRR). These different SRR types created distinct notch band, resulting in a combination of all SRR types into All Complementary-Split Ring Resonator (AC-SRR). The research focused on five notch band, namely 1.5-2.3 GHz, 2.4-2.8 GHz, 3.2-3.7 GHz, 3.2-4.8 GHz, and 6.4-7 GHz. These notch band effectively mitigated interference in Ground Penetrating Radar (GPR), Wireless Local Area Network (WLAN), Worldwide Interoperability for Microwave Access (WiMax), and Band Satellite communication.

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INTRODUCTION

Cellular networks are evolving through different generations, each characterized by distinct data transmission capabilities. The first generation, referred to as 1G, operated at speeds of 2.4–9.6 kbps. Subsequently, the second generation (2G) witnessed an increase in speeds to 0.1–0.3 Mbps, which further escalated in the third generation (3G) to 0.5–10 Mbps. The latest advancement, known as the fourth generation (4G), achieved significant data speeds of up to 100-300 Mbps (Shayea et al., 2021). It is crucial to acknowledge that each cellular network generation has seen a distinguished improvement in data speed. At the heart of a telecommunication system lies antenna, which plays a crucial role in transmitting data through radio frequency signals. These signals are then conveyed through the air and received by the recipient antenna (Zheng et al., 2022). To cope with the demand for higher data speeds, antenna with broad bandwidth, such as Vivaldi or tapered antenna slots capable of operating at Ultra Wide Band (UWB) frequency, are essential (Saleh et al., 2022). Vivaldi antennas are widely used in UWB radar sensors because of their low profile, compact size, simple structure, and low cost (Seo et al., 2020), and they have also been developed for ground-penetrating radar systems (Hu et al., 2023).

The use of UWB antenna, particularly in the presence of narrowband antenna, has encountered challenges related to interference (Althuwayb et al., 2021; Lakrit et al., 2020). Narrowband antenna possess limited bandwidth, often not exceeding 1 GHz. These antenna are extensively used in various systems including Ground Penetrating Radar (GPR) at 1.6-1.9 GHz (1.75 GHz), Wireless Local Area Networks (WLAN) at 2.4-2.48 GHz (2.45 GHz), 5.15-5.35 GHz (5.25 GHz), WiMax at 3.3 – 3.7 GHz, and C Band Satellite at 3.1-3.3 GHz (Rao & Govardhani, 2020). The operational frequency of narrowband antenna frequently intersects with a bandwidth of UWB antenna, resulting in disruptions.

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To address this issue, various methods have been explored, one of which includes the use of Split Ring Resonator (SRR). These resonators introduce gaps in antenna designs to influence frequency output (Liu et al., 2023; Singh & Sharma, 2021). Zhang et al. (2022) placed double SRRs near the feed line of a UWB antenna, together with an elliptical slot, to obtain tunable notch bands that cover the WiMAX and WLAN bands. SRR methods can be further developed into intricate forms such as Complementary Split Ring Resonator (CSRR). Ramakrishna et al. (2021) combined L-shaped slots, an H-shaped resonator, and rectangular split-ring resonators placed near the microstrip feed line, generating four notch bands at WiMAX (3.1–3.6 GHz), WLAN (4.92–6.12 GHz), the downlink X-band for satellite communication (7.5–8.4 GHz), and the X-band (10.2–11 GHz). Another variation of SRR, as explored by Al-Bawri et al. (2020), involves symmetric split ring resonator (SSRR) metamaterial cells loaded on a compact monopole antenna, which produced a wide operating bandwidth of 3.08–14.1 GHz. Similarly, Khadar and Sahu (2023) used a Double Split Ring Resonator (DSRR) model, which achieved impedance bandwidths of 3.38–4.08 GHz and 4.64–5.2 GHz (about 700 MHz and 560 MHz), suitable for WiMAX devices, WLAN, communication satellites, and satellite navigation radio.

Rao and Govardhani (2020) etched slots in the radiating patch, feed line, and ground plane of an elliptical monopole antenna to obtain five notch bands, including WiMAX (3.3–3.75 GHz), WLAN (5.15–5.85 GHz), and X-band satellite communication (7.9–8.4 GHz). Furthermore, a Circular Split Ring Resonator (C-SRR) array was integrated into a horn-antenna, introducing a frequency-notched response with a wide and strong rejection band (Roy et al., 2021). On a Vivaldi antenna, Hu et al. (2021) combined a split ring resonator and an open-circuit half-wavelength resonator to obtain dual band-notched characteristics for Wi-Fi 6E applications. A square CSRR structure was also added to a coplanar Vivaldi antenna with a wavy structure to notch several frequency bands (Nurhayati, Zulkifli, et al., 2024), and coplanar Vivaldi antennas with shielded and copper-tape patches on a felt substrate have been developed for medical and IoT applications (Nurhayati, Fahmi, et al., 2024).

Although these studies show that resonator-based structures can suppress interference, most of the reviewed designs are built on monopole or horn antennas, or rely on a single resonator type to create the notch bands. A systematic comparison of different SRR geometries, and of their combination, on a Vivaldi antenna that must reject several narrowband systems at once (GPR, WLAN, WiMAX, and C-band satellite) is therefore still needed.

This research used Vivaldi antenna measuring in figure 1. The dimensional measurements of the Vivaldi antenna are listed in Table 1. dimension 150x75mm, with a bandwidth of 2.4-9.1 GHz on figure 4. To establish notch band frequency, several types of SRR in figure 2 were used, including Complementary Square-Split Ring Resonator (CS-SRR), Complementary Circular-Split Ring Resonator (CC-SRR), Half Circular-Split Ring Resonator (HC-SRR), and Flower-Split Ring Resonator (F-SRR) design figure SRR in figure 3. Each type of SRR contributed to the creation of notch band, and their integration culminated in the formation of All Complementary-Split Ring Resonator (AC-SRR). Result surface current in 3 GHz not SRR in figure 5.

Therefore, this study aims to optimize the notch band frequencies of a modified Vivaldi antenna (M-Vivaldi) by using different SRR types, namely CS-SRR, CC-SRR, HC-SRR, and F-SRR, and by combining all of them into the AC-SRR configuration. The contributions of this study are: (1) a comparison of the notch band produced by each SRR type on the same Vivaldi antenna, (2) an AC-SRR design that produces five notch bands (1.5–2.3 GHz, 2.4–2.8 GHz, 3.2–3.7 GHz, 3.2–4.8 GHz, and 6.4–7 GHz) to mitigate interference in GPR, WLAN, WiMAX, and C-band satellite communication, and (3) an evaluation of the effect of the SRR structures on the radiation pattern and directivity of the antenna. The rest of this paper is organized as follows: the antenna design is described first, followed by the results and discussion of each SRR type, the radiation pattern, and the directivity, and the paper ends with the conclusion.

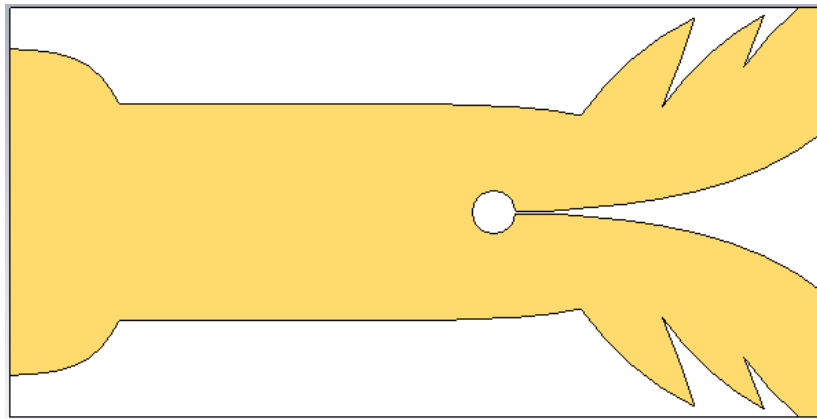


Figure1. Design Antenna M-Vivaldi

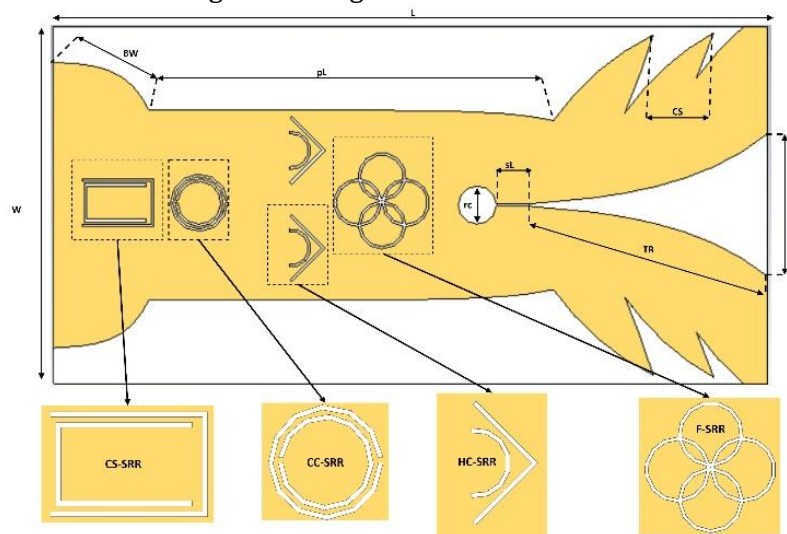


Figure2. Design Antenna AC-Vivaldi

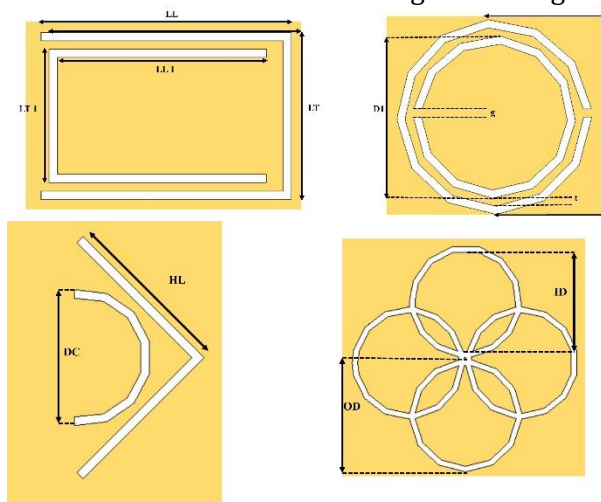


Figure3. Design SRR
CS-SRR, CC-SRR, HC-SRR, F-SRR

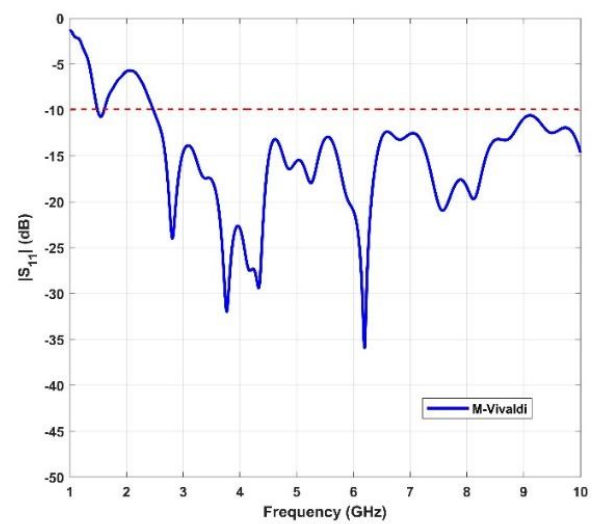


Figure 4. Return Loss M-Vivaldi

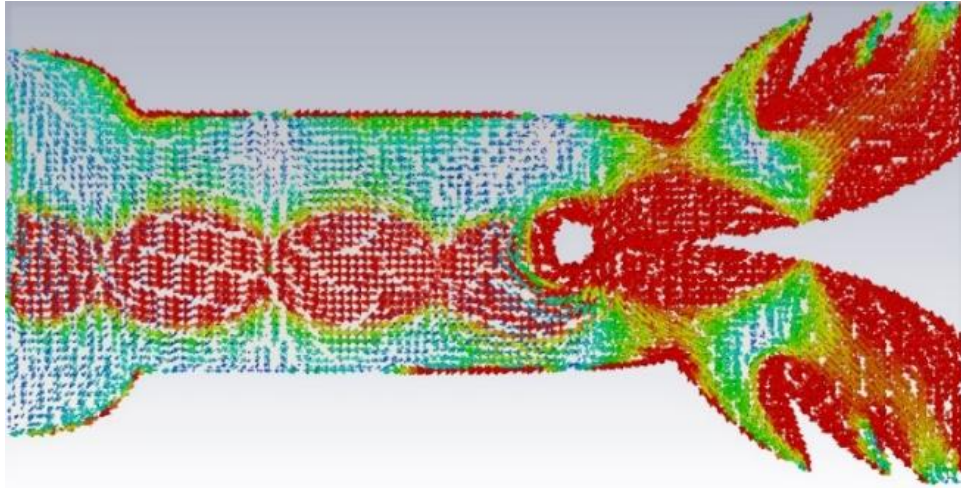


Figure 5. Surface Current M-Vivaldi at Frequency 3 GHz

Table 1. Antenna Dimensions M-Vivaldi

Parameter dimension in (mm)					
Par	Dim	Par	Dim	Par	Dim
L	150	sL	7	D1	6
W	75	R	30	G	0,5
BW	22,36	LL	15	T	0,5
pL	85	LL1	12,5	HL	10
CS	12,7	LT	10	DC	8
TR	52,1	LT1	8	ID	4,5
Rc	4	D	8	OD	5

DESIGN ANTENNA

Antenna design incorporated a modified Vivaldi shape with extended length (pL) to facilitate remote space transmission of electromagnetic fields. Additionally, extra wings were introduced in the taper slot area. The wing shape in the taper slot used Equation (1) expressed below:

$$y = C_1 e^{Rx} + C_2, C_1 = \frac{y_2 - y_1}{e^{Rx_2} - e^{Rx_1}}, C_2 = \frac{y_1 e^{Rx_2} - y_2 e^{Rx_1}}{e^{Rx_2} - e^{Rx_1}} \quad (1)$$

The y-coordinate value of the tapered slot (C_1 and C_2 variables) depended on points x_1 , x_2 , y_1 , and y_2 . These points represented the starting and ending points for manufacturing tapered slots (De Oliveira et al., 2021). The M-Vivaldi design yielded a bandwidth of 2.4–9.1 GHz, with notch band frequency of 1.6–2.4 GHz. The current of the electromagnetic field in Figure 3 was consistent with the center of the M-Vivaldi design. To create band-notch locations, SRR were positioned near the electric field area. The initial SRR types consisted of CS-SSR, CC-SSR, HC-SSR, and F-SSR. These SRR types were later combined to introduce a band-notch effect to the M-Vivaldi design.

RESULT AND DISCUSSION

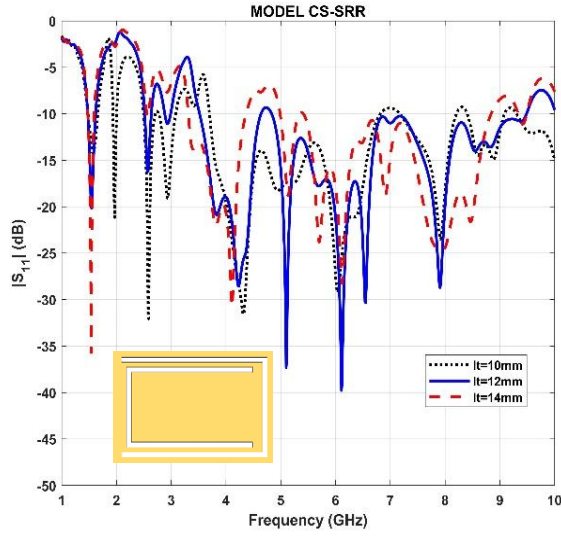


Figure 6. Return Loss Type CS-SRR

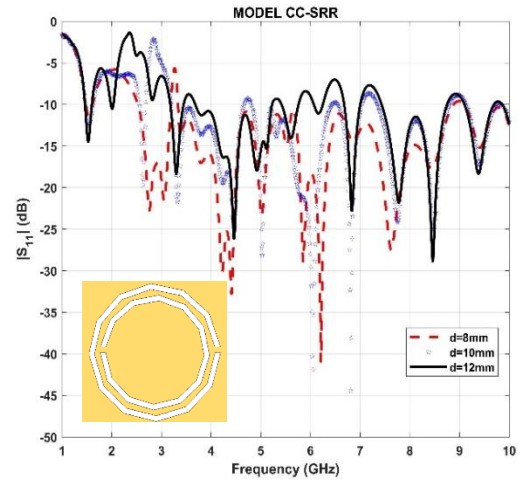


Figure 7. Return Loss Type CC-SRR

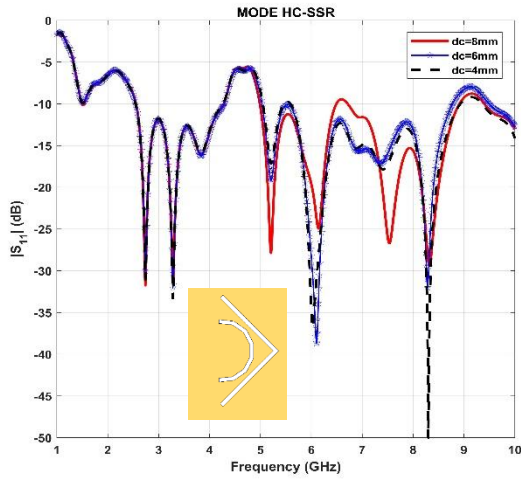


Figure 8. Return Loss Type HC-SRR

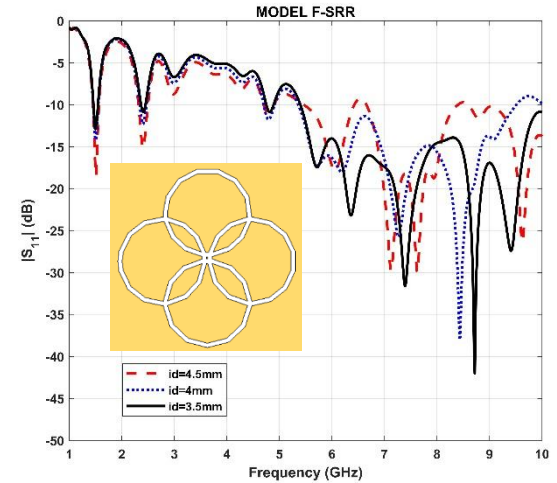


Figure 9. Return Loss Type F-SRR

A. Notch band CS-SRR

For the CS-SRR form in the patch section, the length size was linked to CS-SRR and was determined by Equation (2) (Ramakrishna et al., 2021):

$$fn = \frac{c}{2Ln\sqrt{\epsilon_{eff}}} \quad (2)$$

$$ln = LL + LL1 + LT + LT1 \quad (3)$$

where L_n signified the total slot length for CS-SRR, f_n denoted notch band frequency achieved, ϵ_{eff} equaled $\epsilon_{eff} = \frac{\epsilon_r + 1}{2}$, ϵ_r symbolized the dielectric constant, and c signified light velocity. In this research, FR4 substrates were used, leading to a dielectric constant of 4.4 and ϵ_{eff} with a value of 2.7. Figure 6 showed the return loss of CS-SRR type by altering the length of lt . A selected lt length of 10mm provided a bandwidth of 1.6-1.9 GHz to mitigate interference in GPR applications.

B. Notch band CC-SRR

The CC-SRR shape shown in Figure 7 featured a circular shape with length measurements determined by the basic circle circumference formula expressed in Equation 4

$$fn = \frac{c}{2Lk\sqrt{\epsilon_{eff}}} \quad (4)$$

$$lk = 2\pi r + 2t - g \quad (5)$$

Lk represented the circumference of the outer circle, including t (a gap between inner and outer circles) and g (a gap within each circle, set at 0.5 mm). The outer circle diameter alteration, using $d = 8\text{mm}$, yielded notch band frequency of 3.1-3.3 GHz suitable for C Band applications.

C. Notch band HC-SSR

Notch band produced in the HC-SSR used $dc=8\text{mm}$ for 1.5-2.5 GHz, 4.2-4.9 GHz, $dc=6\text{ mm}$ for 1.5-2.5 GHz and 4.2-5, and $dc=4\text{mm}$ for a bandwidth of 4.2-5. Changes in dc length had a minor impact, where dc represented the outer half-circle diameter length in the HC-SSR type. Figure 8 showed the calculation of circumference size for HC-SSR using Equation (6)

$$kc = \frac{1}{2}\pi d + 2(Hl) \quad (6)$$

the choice of $dc = 8\text{mm}$ corresponded to two notch band at 4.2-4.9 GHz, which matched the WLAN operating frequency.

D. Notch band F-SSR

The next notch band form, Notch band F-SSR, was a combination of several circles with varying diameters ($id=4.5\text{ mm}$, 4 mm , and 3.5 mm). Dimensions $id=4.5\text{ mm}$ resulted in notch band of 1.5-2.3 GHz, 2.4-3.0 GHz, $id=4\text{ mm}$ at 1.5-2.3 GHz, and $id=3.5\text{ mm}$ at 1.5-2.3 GHz. It should be noted that diameter changes within the circuit had minor effects. The circle diameter measurement of $id=4.5\text{ mm}$ produced two notch band, that matched the operating frequency of Wireless Local Area Network. This band, including CS-SSR, CC-SSR, HC-SSR, and F-SSR, showed notch band at respective frequency. When all SSR types were combined, the AC-SSR resulted in S-11 parameter outcomes as shown in Figure 9.

D. Radiation Pattern

The incorporation of SSRs led to the creation of five-notch band. Figure 10 showed the results of paternal radiation type SSR with M-Vivaldi at frequency of 3 GHz, indicating no significant differences. In these results, M-Vivaldi exhibited a main lobe magnitude of 6.89 dBi, a main lobe direction of -5° , and a sidelobe of -8.5 dB. The highest magnitude of the main lobe occurred in the HC-SSR type, measuring 6.94 dBi with a main lobe direction of -5° , and a sidelobe as large as -8.6 dB. Figure 11 showed a comparison of paternal radiations at the 3 GHz frequency, featuring AC-SSR type alongside M-Vivaldi. The magnitude of the play lobe was 6.88 dBi, with a play lobe direction of -5.0° , and a sidelobe of -9.1 dB. The AC-SSR sidelobe level was the highest among all these types due to its combination of all SSR types, resulting in a sidelobe width of -9.1 dB and the production of various notch band. In Figure 12 directivity results were compared for M-Vivaldi, CS-SSR, CC-SSR, HC-SSR, and F-SSR. The HC-SSR type reached the highest point at 10.2 dBi, occurring at frequency of 4.5 GHz. This correlated with the return loss result at 4.5 GHz, which lay in the middle of notch band between 4.2-4.8 GHz. When comparing the AC-SSR type with M-Vivaldi in Figure 12, significantly lower results were obtained. The current directivity output at frequency of 4.5 GHz was 8.07 dBi for AC-SSR, while for the M-Vivaldi type, it was 9.97 dBi. Poor directivity results were not focused on tapperslots in AC-SSR types because certain SSR-type gaps were blocked. In Figure 6, the surface current at frequency of 3 GHz for AC-SSR type underwent electromagnetic field rotation throughout the SSR area before proceeding towards the tapered slot for signal transmission. This field rotation led to a notch band at several frequency. Table 2 presents a comparison of notch bands from other studies.

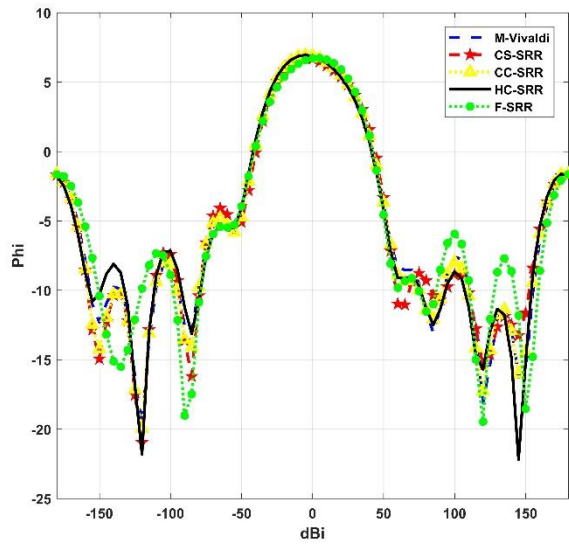


Figure 10. Radiation Pattern between M-Vivaldi, CS-SSR, CC-SSR, HC-SSR, and F-SSR at 3 GHz (theta=900)

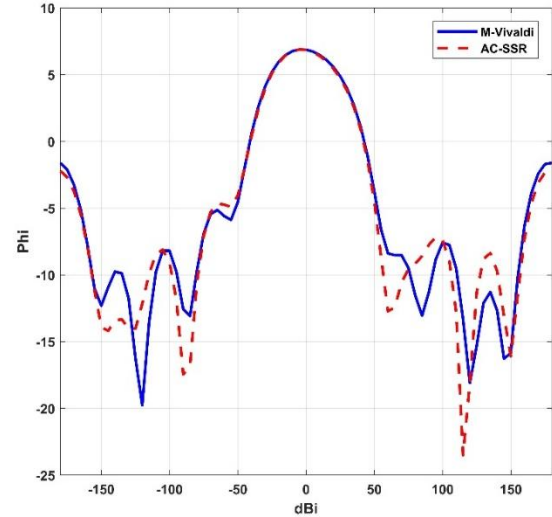


Figure 11. . Radiation Pattern between M-Vivaldi and AC-SSR at 3 GHz (theta=90°)

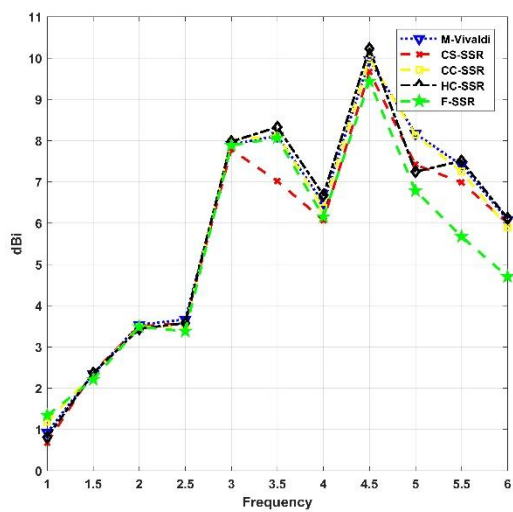


Figure 12. Directivity between M-Vivaldi, CS-SSR, CC-SSR, HC-SSR, and F-SSR

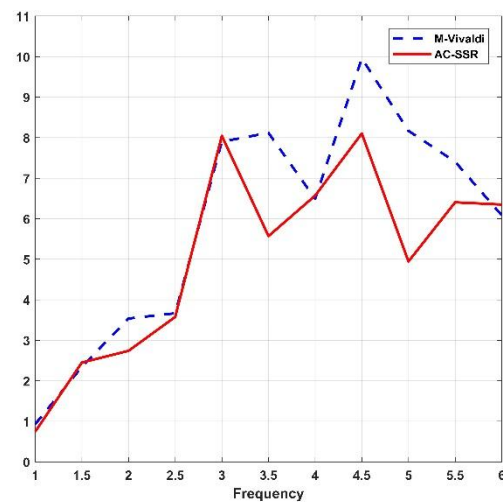


Figure 13. Directivity between M-Vivaldi and AC-SSR

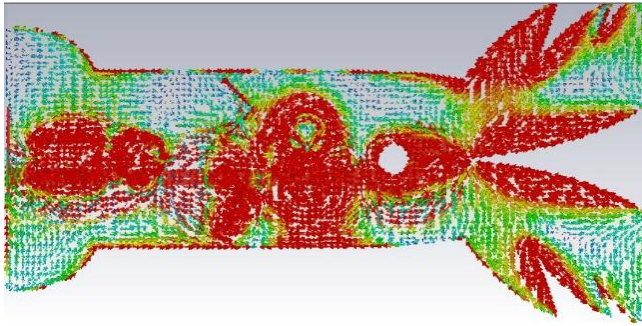


Figure 14. Surface Current AC-SRR 4 at frequency 3 GHz

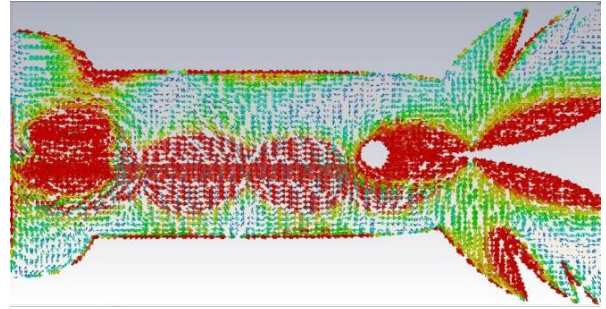


Figure 15. Surface Current CS-SRR 4 at frequency 3 GHz

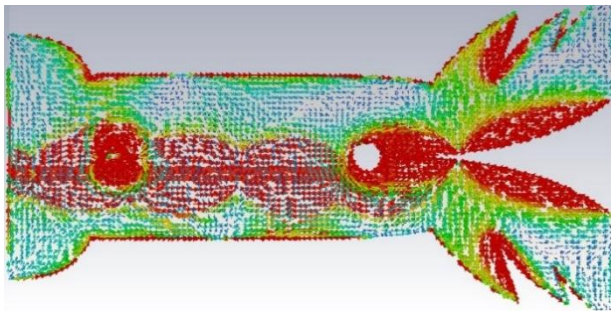


Figure 16. Surface Current CC-SRR 4 at frequency 3 GHz

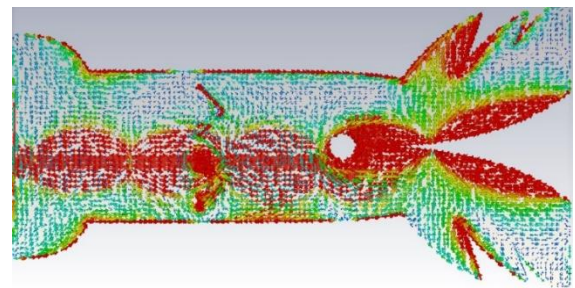


Figure 17. Surface Current HC-SRR 4 at frequency 3 GHz

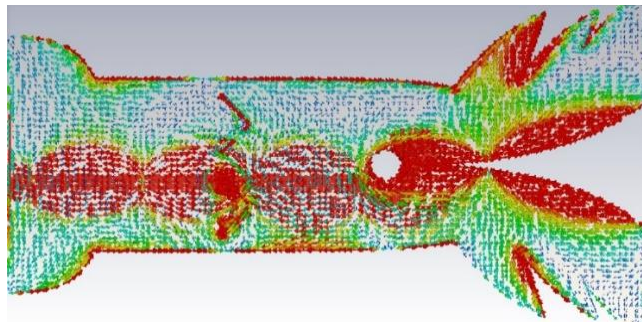


Figure 18. Surface Current F-SRR 4 at frequency 3 GHz

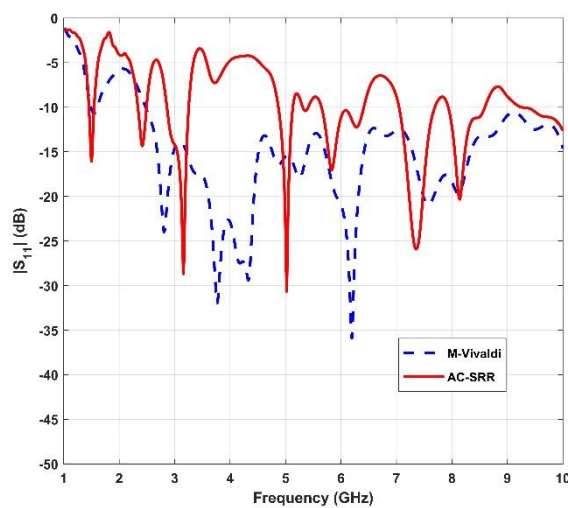


Figure 19. Return Loss between M-Vivaldi and AC-SSR

Figures 14–18 show the surface current distribution of the M-Vivaldi antenna loaded with each SRR type at 3 GHz, where red indicates the strongest current density and blue the weakest. In Figure 14 (AC-SRR), the current is strongly concentrated around the SRR structures in the central part of the patch, in addition to the feed region and the tapered slot. The current circulates around the combined resonators before it continues toward the tapered slot. This rotation of the electromagnetic field traps part of the energy in the resonators, which explains the notch bands produced by the AC-SRR. In Figures 15–18 (CS-SRR, CC-SRR, HC-SRR, and F-SRR), the strong current appears mainly around the feed point and the tapered slot, with a local concentration around each resonator. The local concentration is the cause of the notch effect of each SRR type. The pattern differs between types because of the shape and position of each resonator. Because only one resonator is loaded in each of these cases, the current distribution is closer to that of the original M-Vivaldi than in the AC-SRR. Figure 19 compares the return loss ($|S_{11}|$) of the M-Vivaldi and the AC-SRR from 1 to 10 GHz. The M-Vivaldi (blue dashed line) stays mostly below -10 dB across its operating band, with the deepest resonances reaching about -30 dB. The AC-SRR (red solid line) follows the same overall trend, but its return loss rises above -10 dB at several frequency ranges. These rises are the notch bands, where the antenna rejects the signal instead of radiating it. They correspond to the five notch bands reported in this study (1.5–2.3, 2.4–2.8, 3.2–3.7, 3.2–4.8, and 6.4–7 GHz), which reduce interference in GPR, WLAN, WiMAX, and C-band satellite systems. Outside these bands, the AC-SRR keeps good impedance matching.

Table 2. Comparison Notch Band

Ref	Design Antena	Type SSR	Band-notch (GHz)
Roy et al. (2021)	Horn Antenna	CSSR	9,635-9,95
Sehgal & Patel (2021)	Rectangular	CSSR	3,35-4,5; 5,1-5,6
Ramakrishna et al. (2021)	Monopole	RSRR + H-shaped resonator	3,1-3,6; 4,92-6,12; 7,5-8,4; 10,2-11
This work	Vivaldi	AC-SSR	1,5-2,3; 2,4-2,8 ; 3,2-3,7 ; 3,2-4,8 ; 6,4-7

CONCLUSION

In conclusion, the research described the existence of four distinct types of SRR, including CS-SSR, CC-SR, HC-SR, and AC-SR. When the SSR type was incorporated into the patch section of antenna, it introduced a notch band at multiple frequency. This effect became even more pronounced when combined with AC-SSR type, leading to a unique set of notch band. These band frequency experienced notch at 1.5-2.3 GHz, 2.4-2.8 GHz, 3.2-3.7 GHz, and 3.2-4.8 GHz. This combination led to the creation of five distinct notch band regions, effectively reducing interference for GPR communication, WLAN, WiMax, and C Band Satellite applications.

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