Defence Science Journal, Vol. 74, No. 1, January 2024, pp. 79-84, DOI : 10.14429/dsj.74.19154

A Planar Dual Notched Band Vivaldi Antenna for Wireless Communication Applications

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ABSTRACT

With the aim of realizing a Vivaldi Antenna (VA) with stop bands for wireless communication applications, this paper introduces a novel, uncomplicated, easily fabricated, and compact planar VA featuring two distinctive rejected frequency bands. The designed VA is engraved onto an FR4-epoxy substrate, measuring $0.4243\lambda_0 \times 0.4296\lambda_0 \times 0.01315\lambda_0$ at 2.63 GHz. The integration of dual notched band functionality is ingeniously achieved through the implementation of a simple additional strip and a U-formed slit. A physical prototype of the VA was successfully constructed and meticulously measured with the R&S®ZNB Vector Network Analyser. The measured impedance bandwidth demonstrates that the realised VA operates from 2.63 GHz to beyond 12 GHz while effectively excluding two bands: 3.46-4.16 GHz (18.37 %) and 5.32-6.5 GHz (19.97 %). Simulated results indicate that the designed VA can provide stable unidirectional radiation patterns, reasonable realized gain, and acceptable radiation efficiency across its operating ranges, with notable drops observed at the two notched bands. As a result, these findings highlight the practical value of the designed VA for wireless communication applications, particularly in scenarios where the integration of filtering structures in antennas becomes essential to prevent interference with co-existing systems. The presented VA opens new avenues for enhancing wireless communication performance, catering to the increasing demand for reliable and interference-resistant solutions.

Keywords: Vivaldi antenna (VA); Dual notched band characteristic; Wireless communication applications

1. INTRODUCTION

The interest in wireless communication technology is growing steadily due to the wide range of services it provides in our daily lives[1]. The Vivaldi antenna (VA), introduced by Gibson in 1979 as a new category of Ultra-wideband (UWB) antennas, has emerged as a prominent choice for various applications due to its impressive characteristics. These include wide impedance bandwidth operation, a planar structure, directional radiation patterns, low-cost fabrication, and ease of integration[2-3].

Several VAs having various configurations for UWB application have been proposed in the literature such as those presented in[4-7], where various techniques have been used to enhance their performance such as slots[4], directors[5], embedded pin diodes[6], meta surface[7]. However, UWB systems face a significant challenge in terms of potential electromagnetic interference with other co-existing narrowband systems, such as C-band satellite communication (3.7–4.2 GHz), 5G mid-band (3.4–3.8 GHz), and wireless local-area network (WLAN) upper band (5.725–5.825 GHz), among others. To address this issue, the use of antennas with narrow stop bands becomes crucial for ensuring the efficient operation of compact multi-functional devices[8-11].

Until now, numerous VAs exhibiting notched band characteristics have been proposed in the literature for wireless communication applications, such as those presented in[12-17]. Several techniques have been employed to generate notched band functions, including mushroom-like electromagnetic band gap structures[12], capacitive-loaded loop resonators[13-14], resonant parallel strips[15], split-ring resonators[16-17], and etched slits[18]. Unfortunately, the designs presented in these references feature only one notched band, and many of them utilize complicated techniques to introduce these narrow stop bands.

In this work, we propose a simple planar dual notched VA designed for wireless communication applications. The dual-band rejection is accomplished through the incorporation of a strip into the feed line and the introduction of a U-formed slit on it. A physical prototype of the VA is fabricated and its measurements are conducted using the R&S®ZNB Vector Network Analyzer. The fabricated prototype exhibits operational frequencies from 2.63 GHz to higher than 12 GHz, effectively rejecting two notched bands at 3.55 GHz and 5.57 GHz. Further contributions offered in this study include: 1) the design and realisation of an uncomplicated and low-cost VA optimized for wireless communication applications; 2) The introduction of a dual-band notched function, which effectively evades interference, distinguishing it from most existing structures that feature a single band rejection capability; 3) Experimental validation of the fabricated prototype's ability to reject the specified frequency bands. The main VA parameters will be attentively analyzed employing computer simulation technology (CST) software[19].

Received : 23 May 2023, Revised : 28 July 2023
Accepted : 21 August 2023, Online published : 12 January 2024

Figure 1. Designed VA; (a) front side; and (b) back side.

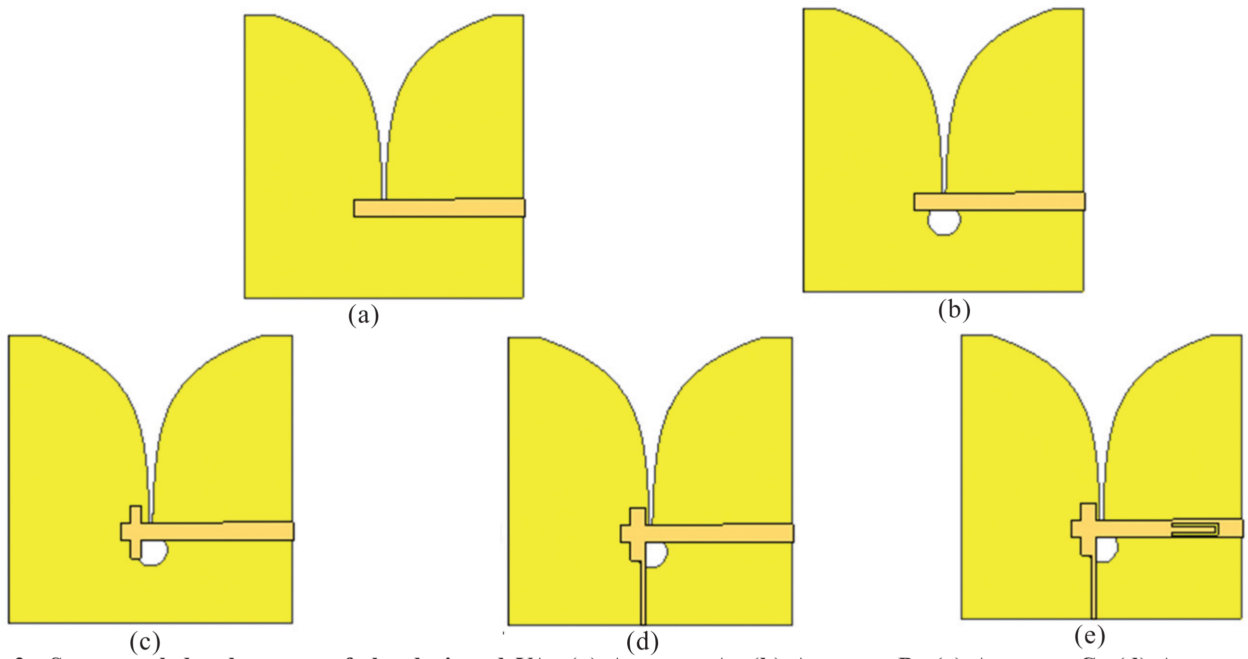


Figure 2. Structural development of the designed VA; (a) Antenna A; (b) Antenna B; (c) Antenna C; (d) Antenna D; and (e) Antenna E.

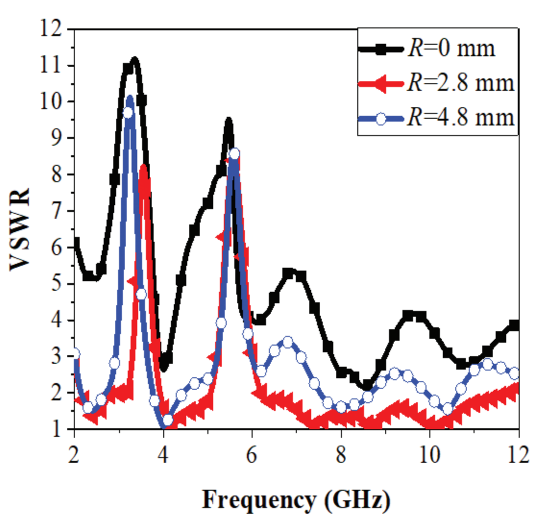


Figure 3. Impact of circular cavity radius on the impedance bandwidth of the VA.

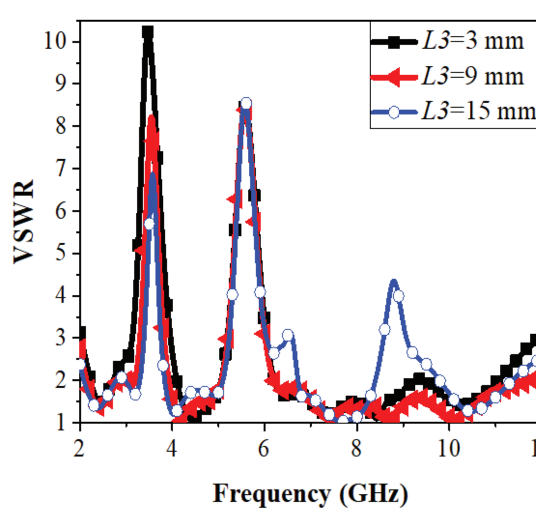


Figure 4. Impact of circular cross strip length on the impedance bandwidth of the VA.

2. ANTENNA DESIGN AND PARAMETRIC STUDY

2.1 Antenna Geometry

The proposed VA consists of three key components, each contributing to the overall enhancement of its performance. The first part features an exponentially tapered opening, gradually widening that act as radiating structures for propagating electromagnetic waves. Additionally, an optimized circular cavity is embedded within this section, resulting in improved impedance matching in the operating band pass. The second part incorporates a 50 Ω straightforward feed line ended by a cross strip, which plays a crucial role in expanding the operating impedance bandwidth. This strategic inclusion ensures the antenna's ability to operate efficiently over a broader range of frequencies. Finally, the third part of the VA design encompasses two notching band structures. These structures are formed by incorporating a parasitic strip line and a U-formed slit, which effectively create frequency notches to suppress interference from specific frequency bands. The designed VA is printed on commercial FR4-epoxy (thickness = 1.5 mm, ε_r = 4.4) measuring $0.4243\lambda_0 \times 0.4296\lambda_0 \times 0.01315\lambda_0$ at 2.63 GHz. Its geometrical structure and dimensions are depicted in Fig. 1. Figure 2 showcases the structural development of the designed VA, depicting five designs that underwent a two-stage design process. In the initial stage, the UWB operation was achieved through the introduced changes in the first three antennas (A, B, and C). Following this, the second stage focused on obtaining the notched band performance by incorporating changes in antennas D and E. The optimised dimensions of the designed VA areas follows: L=49 mm, L_1=12.05 mm, L_2=13.15 mm, L_3=9 mm, L_4=1.75 mm, W=48.4 mm, W_1=3.22 mm, W_2=2.8 mm, W_3=2.5 mm, a=2 mm, b=8 mm, c= 1 mm, e=0.8 mm, f=11 mm, S_1=38.19 mm, S=0.43 mm, R=2.8 mm.

2.2 Parametric Study

In this subsection, we study the main dimensions that significantly influence the operating impedance bandwidth. Specifically, we focus on the dimensions of the incorporated circular cavity and the cross strip. Additionally, we analyse the dimensions that impact the notched band function to gain a comprehensive understanding of the proposed antenna's functionality. Figure 3 illustrates that changing the radius R of the incorporated cavity has a substantial influence on the impedance bandwidth, with an optimal dimension of 2.8 mm. Furthermore, the study of the cross strip dimension L_3 in Fig. 4 reveals that the incorporated cross strip also plays a crucial role

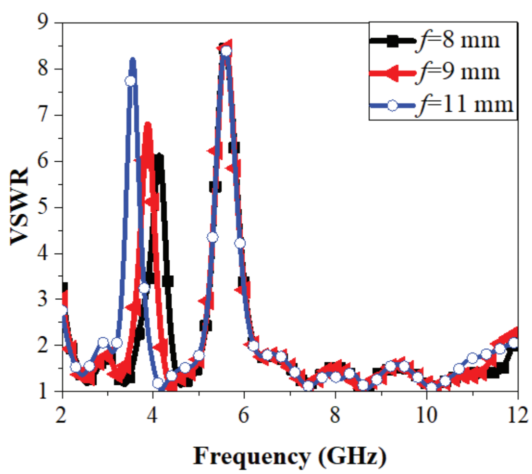


Figure 5. Impact of additional strip length on the impedance bandwidth of the VA.

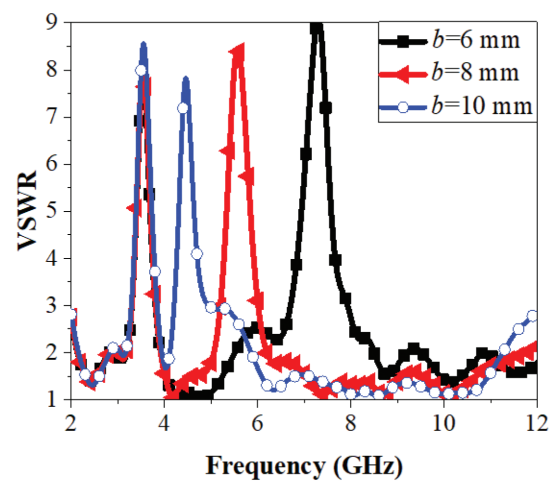


Figure 6. Impact of U-shaped slit length on the impedance bandwidth of the VA.

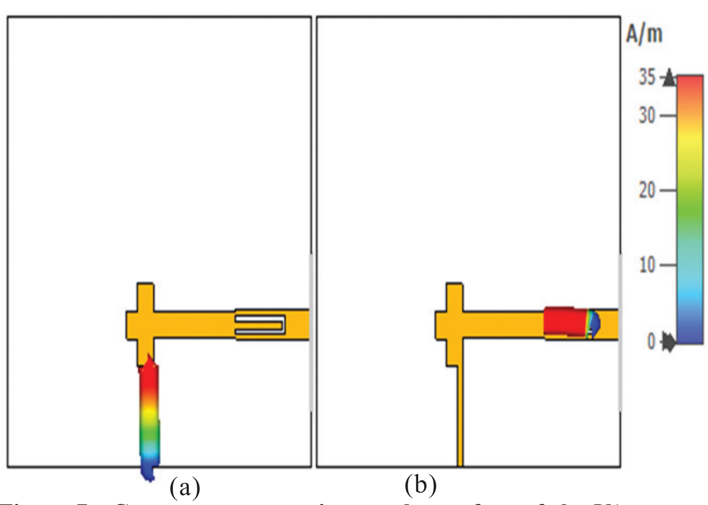


Figure 7. Current concentration on the surface of the VA at: (a) 3.55 GHz, and (b) 5.57 GHz.

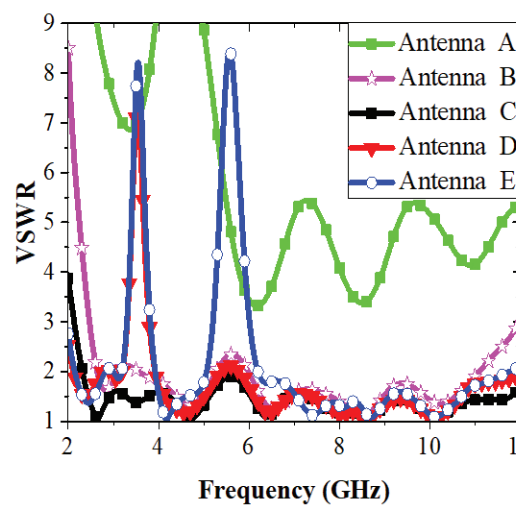


Figure 8. VSWR of the VA and other initial designs.

in affecting the impedance bandwidth, particularly in the upper frequencies of the VA pass band. An investigation was carried out to assess the impact of varying the length of the additional strip and the U-formed slit on the dual-notched band. It is observed that reducing the length *f* of the additional strip from 11 mm to 8 mm, as shown in Fig. 5, results in a shift of the center of the lower rejected band towards higher frequencies. Additionally, Fig. 6 demonstrates that increasing the length *b* of the additional strip from 4 mm to 12 mm causes a shift of the center of the upper notched band towards lower frequencies, while the lower rejected band remains unaffected. This indicates that the lower notched band width is solely determined by the additional strip, whereas the upper notched band is influenced by the U-formed slit. To further understand the structures responsible for the generation of the two notched bands, the current density on the antenna's surface is analysed.

Figure 7 illustrates the current distribution at the lower-rejected resonant frequency, where it is concentrated on the additional strip. In contrast, at the upper-rejected resonant frequency, the current distribution is focused within the etched U-formed slit. These findings align with the results presented in Fig. 5 and Fig. 6 and unequivocally establish the respective contributions of the additional strip and the U-formed slit in achieving the rejection of the two bands at 3.55/5.57 GHz.

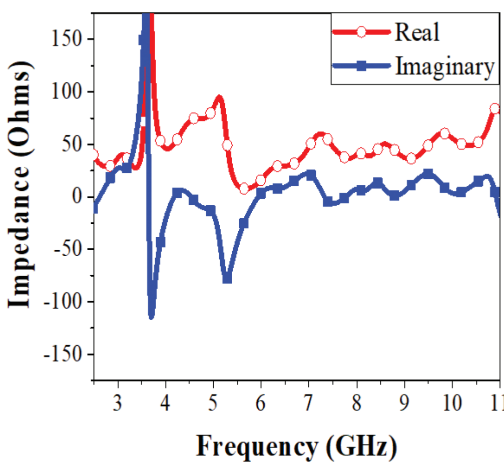


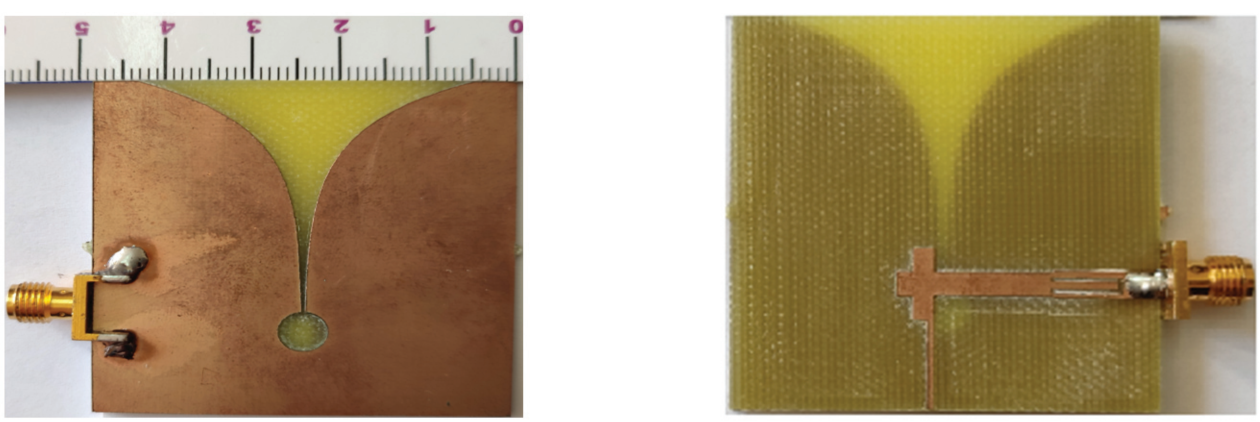
Figure 9. Impedance of the VA.

3. RESULTS

Figure 8 illustrates the calculated impedance bandwidth of the structures depicted in Fig. 2, demonstrating the effectiveness of the introduced changes in each antenna. The results demonstrate that integrating the circular cavity (Antenna B) and the cross strip (Antenna C) has enhanced the impedance bandwidth. Additionally, it is evident that the addition of the extra strip to the feed line in Antenna D allows the rejection of the lower band at 3.55 GHz. Furthermore, introducing the U-formed slit in the feed line (Antenna E) ensures the presence of the second notched band at 5.57 GHz. Figure 9 displays the input impedance, showcasing favorable adaptation for the designed VA, with the exception around the two stop bands at 3.55/5.57 GHz. Figure 10 showcases the physical prototype, which is printed using a laser printer (LPKF S-103).

The impedance bandwidth of the physical prototype is shown in Fig. 11, showcasing its operational band from 2.63 GHz to upper than 12 GHz, with the exclusion of two bands at 3.55 GHz and 5.57 GHz. There is a remarkable agreement between the calculated and measured VSWR, confirming the dual notched band performance. The slight discrepancies between the two results may be attributed to fabrication and measurement process tolerances, as well as losses in the port connections. Figure 12 illustrates the simulated radiation patterns of the designed VA in the H-plane and E-plane at five frequencies within the pass bands: 3.11 GHz, 4.18 GHz, 7.41 GHz, 8.7 GHz, and 10.13 GHz. These plots reveal consistent unidirectional radiation patterns in both planes, highlighting the antenna's directional performance. The simulated realized gain and radiation efficiency are illustrated in Fig. 13. Within the pass bands, the calculated values exhibit reasonable levels of performance. However, in the two stop bands, there are drops of -5.52 dBi/-8.68 dBi in realized gain and 13.21%/8.45% in radiation efficiency, respectively. These findings indicate the effectiveness of the designed VA in rejecting signals within the specified notched bands.

In Table 1, it is evident that the designed VA offers several advantages, including the presence of two stop bands, low dimensions, a simple and uncomplicated structure, and ease of fabrication. These features make the antenna a favorable choice for wireless communication applications, allowing for effective band rejection while maintaining a compact and low cost-design.



(a) (b)

Figure 10. Realised VA, (a) front view, and (b) back view.

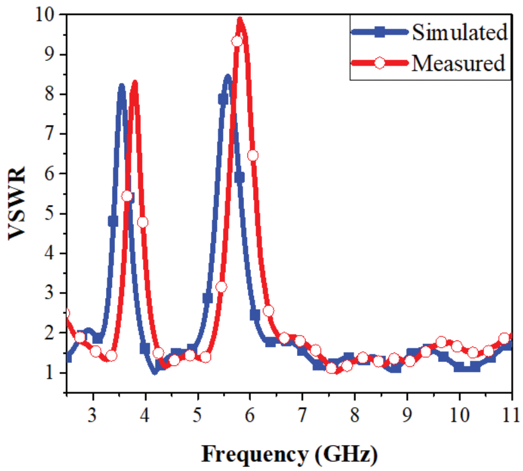
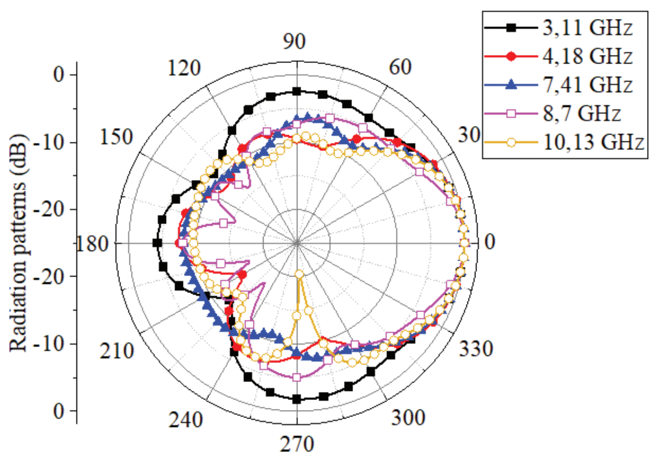
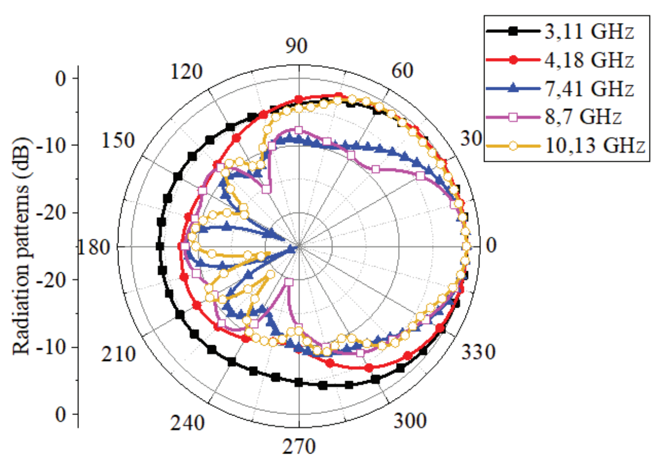


Figure 11. VSWR of the presented VA.



(a)



(b)

Figure 12. Normalised radiation patterns of the VA, (a) H-plane, and (b) E-plane.

4. CONCLUSION

In this study, we have successfully presented a planar dual notched band VA designed for wireless communication applications. The designed VA has an uncomplicated structure etched onto alow-cost FR4-epoxy substrate, measuring $0.4243\lambda_0 \times 0.4296\lambda_0 \times 0.01315\lambda_0$ at 2.63 GHz. The fabricated prototype can operate between 2.63 GHz to upper than 12 GHz and rejects the two bands 3.46-4.16 GHz (18.37%) and 5.32-6.5 GHz (19.97%). Additionally, the designed model provides consistent unidirectional radiation patterns and reasonable values of realized gain and of radiation efficiency with drops at the two rejected bands. Overall, the presented VA provides a practical and effective solution for wireless communication applications requiring filtering structures to avoid interference with other co-existing systems, including C-band satellite communication, 5G mid-band, and WLAN.

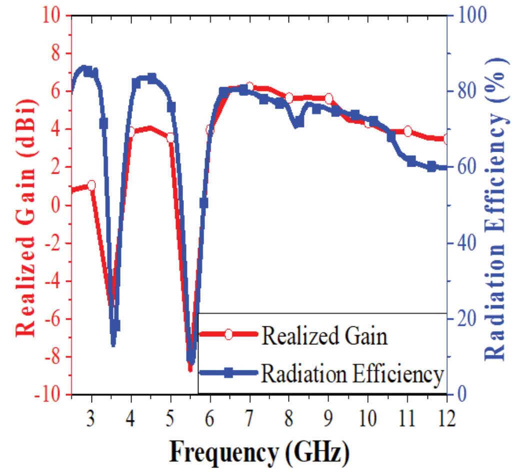


Figure 13. Realised gain and radiation efficiency of the presented VA.

Table 1. Evaluation of VA parameters with those of some other models existing in literature.

Ref.	dimensions (mm²)	No. of notched band	Complexity/ ease of fabrication
[20]	240×152	0	Complex/difficult
[21]	110×66	0	Complex/ difficult
[22]	87.3×70	1	Complex/difficult
This work	48.4×49	2	Simple/easy

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In the current study: He conducted the simulation of the proposed antenna, meticulously collected, analyzed, interpreted, and discussed results, and wrote the manuscript.

Dr Mohammed Guerroui obtained his PhD degree in Telecommunications from the University 8 Mai 1945 of Guelma, in 2022. His research interests include: UWB antennas, and ground-penetrating radar antennas.
In the current study: he contributed to the development of the antenna’s structure.