AIP Conference Proceedings

RESEARCH ARTICLE | MARCH 11 2024

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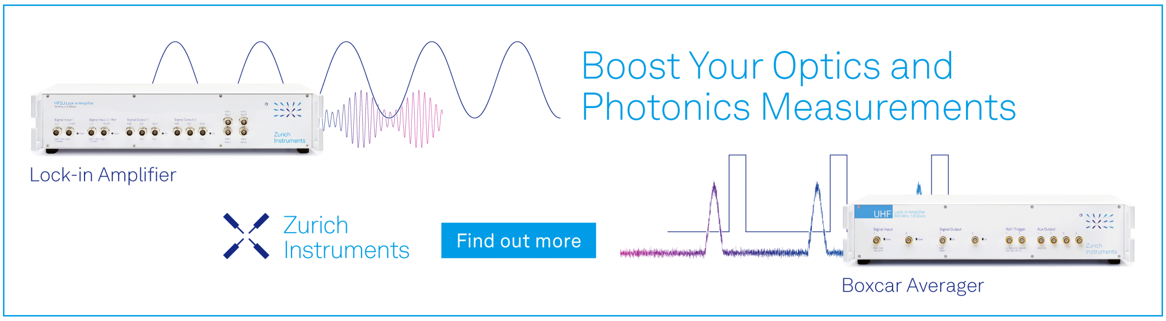
AIP Conf. Proc. 2998, 040007 (2024)
https://doi.org/10.1063/5.0188334



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Design of UWB Antipodal Vivaldi Antenna with Rectangular Corrugated Edges for Through Wall Imaging(TWI) Applications

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Abstract. An Ultra-wideband (UWB) rectangular corrugated edges antipodal Vivaldi antenna (RCE-AVA) designed for through wall imaging applications is demonstrated. In this study, two distinct designs for antipodal Vivaldi antennas are reported: a conventional AVA and a rectangular corrugated edges AVA. In this study, a parametric-based analysis of both antennas is presented. At first, a conventional AVA with an elliptical shaped antenna is designed using FR4 substrate. Additionally, the antenna is modified with Rogers-5880 material by implementing same size rectangular corrugations on the edges of the antenna. Furthermore, the modified antenna provides stable gain and high directivity throughout the UWB band. The proposed antenna worked in the frequency rangefrom 3.1 GHz to 10.6 GHz with improved radiation properties. A maximum gain of around 11.8 dB is achieved with a return loss value of less than -10. Computer Simulation Technology (CST) simulation software was used to verify the design, parametric evaluation, and optimization of RCE- AVA.

INTRODUCTION

Ultra-wideband (UWB) is a cutting edge radio technology that is building a lot of attention in the research community and the industry. It has ability to transmit large volume of data over a wide frequency spectrum with greater bandwidth. In 1893 the first experiments were conducted by Hertz on UWB based wireless communication system [1]. However, the Hertz experiment on UWB technology was dominant about two decades The UWB spectrum was authorized for commercial and research usage by the Federal Communications Commission (FCC) in March 2002. This spectrum allocation for UWB technology attracts lot of attention to research organizations and industry, which opened the doors for innovation in the field of UWB. This technology provides numerous benefits including high data rate, low power utilization, obstacle penetration, low cost-implementation and time resolution. These attributes makes UWB a promising technology for several applications.

UWB technology has gained its popularity in the last few years for use in through wall imaging (TWI) applications. TWI technology works on mechanism of electromagnetic (EM) waves to image objects through the wall[2]. TWI has wide application in rescue, security and surveillance [3]. This promising technology transmitting of EMwaves by transmitter antenna to penetrates through wall. These EM waves strike the target and reflected back with some energy to receiving antenna, Further the reflected energy is processed through signal processing techniques to develop image of target through the walls. For security-related reasons, the TWI applications are extremely desirablefor the detection of metal-based explosive substances in busy public spaces such airports, hospitals, sports stadium parks, and shopping malls.

Research interest in designing UWB antennas for the TWI technology is currently expanding. The UWB antenna serves as a sensor element for the TWI system [4][5]. The system as a whole depends on the antenna's functionality. The most preferred option for through-wall applications is a Vivaldi antenna because it satisfies the majority of requirements. The Vivaldi antenna has many benefits, including its small size, high gain, wide bandwidth, good

The 5th International Conference on Automotive Innovation and Green Energy Vehicle
AIP Conf. Proc. 2998, 040007-1–040007-9; https://doi.org/10.1063/5.0188334
Published by AIP Publishing. 978-0-7354-4793-6/$30.00

directivity, low side lobes, and end-fire radiation [6][7][8]. UWB Vivaldi antenna have been designed as a solution for TWI applications [9].

Vivaldi antenna was first presented by Dr. P. J. Gibson in 1979 [10]. Antonio Vivaldi was a great violin composer of his time and Dr. Gibson was a huge fan of him. In honor of Antonio Vivaldi, Dr. Gibson designed an antenna with violin shape and given Vivaldi name to this antenna. Vivaldi antennas can be group into three classes: Coplanar-VA, Antipodal-VA, and Balanced-AVA [11]. The radiating structure and the feed line, usually a microstrip or strip line, are the two main geometric components of the Vivaldi antenna. The two-layer structure is called the antipodal Vivaldi which was developed by Dr. Gazit in 1988 [12] and provides minimal distortion, high gain, and high directivity.

Antipodal Vivaldi antennas (AVA) use slots structures with various shapes and sizes to improve performance. Additionally, it restricts the lower cut-off frequency, minimizes the side lobe levels and maximizes the main lobe level [13]. The corrugated structure used similarly shaped slots with repeating patterns on the flare edges. Corrugated slots at the edges of AVA improve gain, bandwidth, and return loss. Also, the corrugated edges work as a resistive load, so the maximum field is directed towards the corrugated edges, which improves the radiation characteristics. Antipodal Vivaldi antennas frequently use corrugated structures with slits to boost performance [7]. [14] Presents corrugated AVA with rectangular slots of variable length for imaging purposes. The developed antenna demonstrated that the reflection coefficient parameter (S11) in the entire chosen frequency band is less than -10dB. According to [15], a corrugated structure-based broadband AVA was able to reach gain and bandwidth of up to 9 dBi and 6.37 GHz, respectively.

Vivaldi antenna with flexible polyimide substrate was designed in [16] for through the wall applications. The proposed antenna used a corrugated structure with silver strips to improve performance. Another Vivaldi antenna with corrugation and grating structure was designed on FR4 substrate [17] for through-the- wall applications. The presented antenna has achieved a gain of 8.2 dBi with working frequency range from 1.9 GHz to 12 GHz. In order to provide a wide impedance bandwidth, high gain, and a narrower beam pattern within the working frequency range, the Vivaldi antenna uses a corrugated structure [18]. In [19] a rectangular corrugated antipodal Vivaldi antenna (AVA) was developed to improve the antenna gain. The proposed AVA fabricated on Rogers RO-4003 substrate with a frequency range of 6 GHz to 18 GHz. To improve the gain, another compact size Vivaldi UWB antenna with corrugation and grating elements was reported in [20]. The implementation of a corrugated structure improved the boresight gain in the low and medium frequency range of the UWB band.

This paper is about the designing of an UWB Antipodal Vivaldi antenna by using corrugated structure for TWI applications that can operate across the whole UWB band, from 3.1 to 10.6 GHz. The reason for using UWB is that in a lower frequency band due to at a longer wavelength, more waves can pass through the wall, which can increase the depth of penetration to get a response from targets. While in the higher frequency band due to higher bandwidth, the UWB antenna can carry more information, which can help to obtain better resolution images of detected targets. Another design purpose of an UWB Antipodal Vivaldi antenna is to achieve high gain with stable radiation pattern.

ANTENNA DESIGN

Conventional Antipodal Vivaldi Antenna (CAVA)

The geometric layout and configuration of the CAVA design used in this study are shown in Figure 1. The CAVA is designed and made of low-cost FR4 material (glass-reinforced epoxy laminate material). The substrate specification includes dielectric εr is 4.3, dielectric loss tangent δ is 0.02, and thickness is 1.5 mm. The two elliptic curves of the same dimensions have been used for the development of conventional AVA as indicated in [21][22] and contain two key parts: feed line and radiation wings. The outer curvature of an antenna wings has an elliptical structure to promote good broadband results, achieved due to smooth expansion between the feed line and radiation wings. An antenna design using elliptic curves is satisfactory as the input impedance is matched across the entire UWB band. The higher frequency limit of the Vivaldi antenna should hypothetically be infinite and the low frequency limit typically depends on the width of the antenna and the value of the effective dielectric constant (εeff), which are represented by equations (1) and (2), [21].

$$fmin = \frac{c}{2W\sqrt{\varepsilon_{eff}}} \qquad (1)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+\frac{12h}{w}\right)^{-1/2} \qquad (2)$$

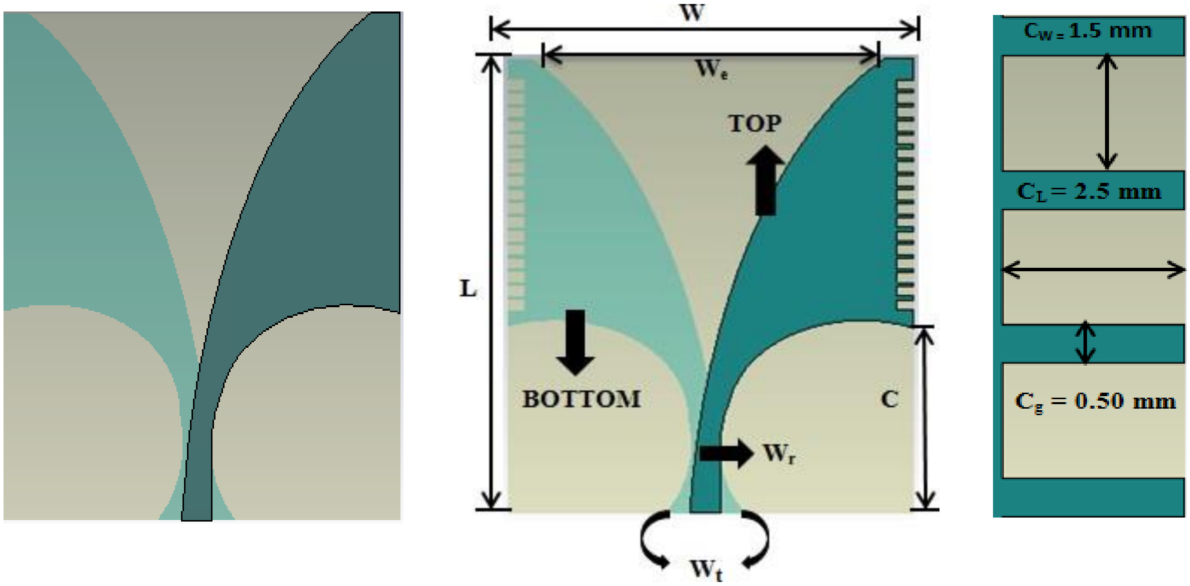
Feed line width is W and comprises the characteristic impedance *Zo*= 50Ω, mathematically it can be calculated by using Equation (3) and (4) [21] as:

$$z_o = \frac{60}{\sqrt{\varepsilon_{eff}}} ln\left(\frac{8h}{w} + \frac{w}{4h}\right) for \left(\frac{w}{h}\right) < 1 \qquad (3)$$

$$z_o = \frac{120\pi}{\sqrt{\varepsilon_{eff}}\left[\frac{w}{h} + 1.393 + \frac{2}{3} ln\left(\frac{w}{h} + 1.444\right)\right]} for \left(\frac{w}{h}\right) \geq 1 \qquad (4)$$

Rectangular Corrugated Edges Antipodal Vivaldi Antenna (RCE-AVA) Design

The proposed antenna is designed on RT/Duroid 5880 material as it's shown in Figure 2. The 50Ω micro-strip line has been used for the excitation of the antenna port. The radiating element has an elliptical shape with seventeen additional rectangular corrugated edges placed on both arms of the antenna together with the parameters [23][24][25]. The corrugation length is C_L = 2.75 mm and the corrugation width is C_W = 1.5 mm with 0.80 mm distance apart from each corrugation. Antenna used Rogers-5880 material to produce better gain due to the influence of tangential loss properties [26]. Table 1 shows the optimized dimension of the design parameters of the RCE-AVA antenna that has been carried out in this work.



(a) (b) (c)

FIGURE 1. (a) CAVA design (b) RCE-AVA design (c) rectangular corrugated edges structure

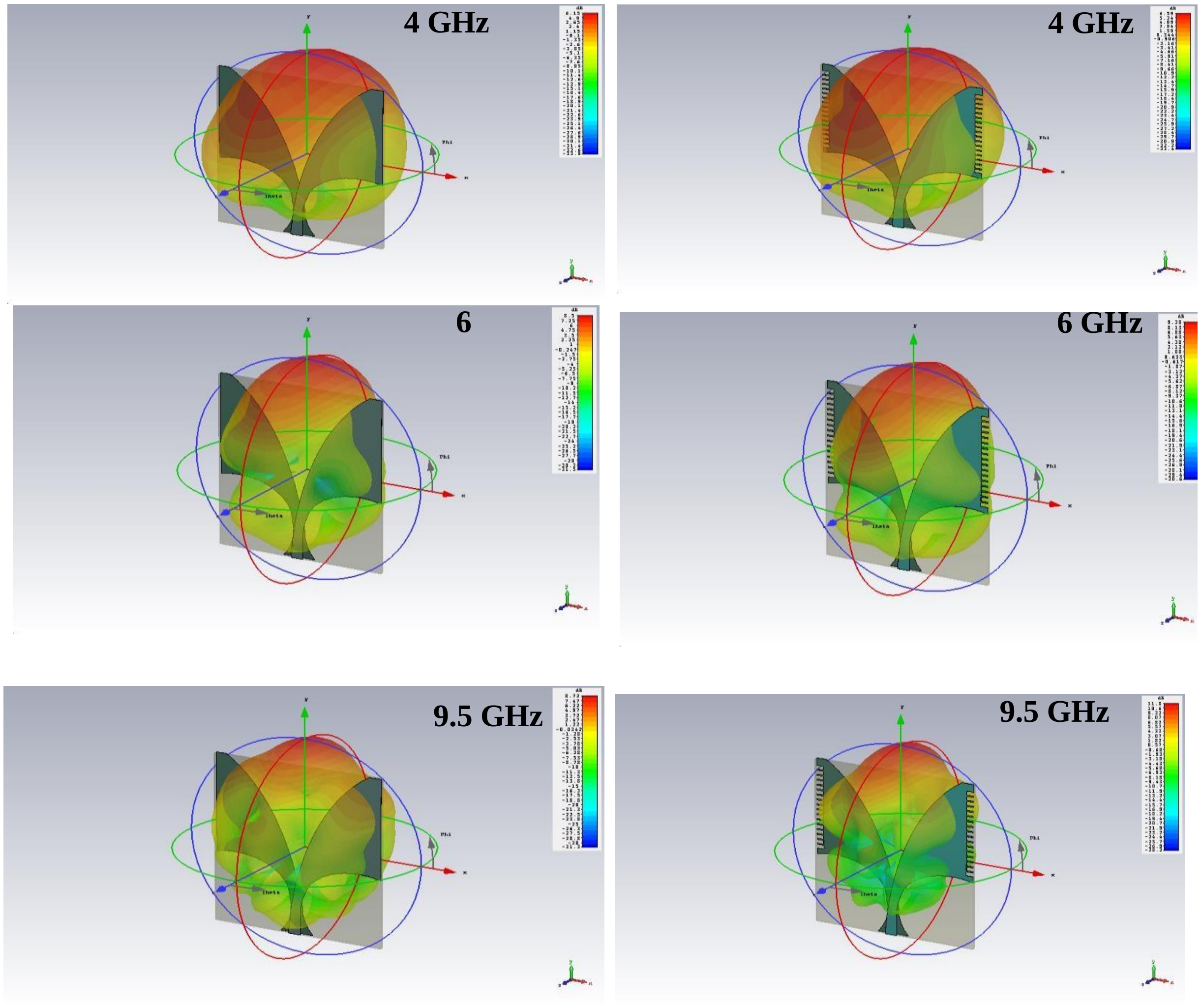
TABLE 1. Optimized dimensions of purposed antenna

Dimensions	Value
W	60.75 mm
L	66 mm
C	14 mm
W_e	54.75 mm
W_t	11.75 mm
W_r	4.56 mm
Cl	2.75 mm
Cw	1.5 mm
Cg	0.5 mm

SIMULATION RESULTS AND DISCUSSION

Far Field Radiation Pattern

Stable gain and directivity of an antenna are considered essential requirements for TWI applications. Figure2 shows the 3D far-field radiation pattern of conventional AVA and RCE-AVA at the frequencies of 4 GHz, 6 GHz and 10 GHz. Both antennas have received good gain and directivity values in the UWB frequency range, showing thatthe proposed antenna could be a possibility for TWI applications.

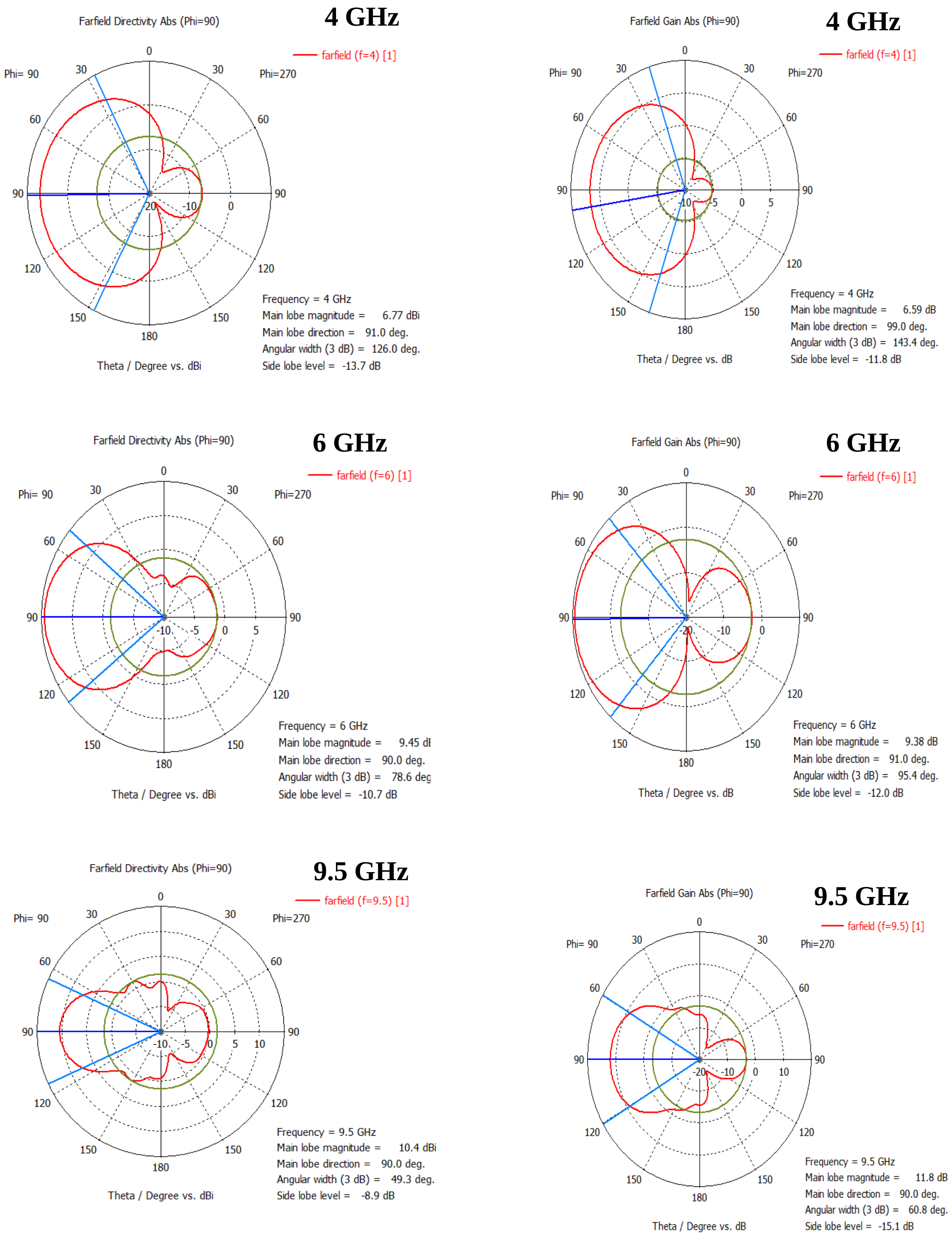


(a) CAVA (b) RCE-AVA

FIGURE 2. Far field radiation pattern at 4 GHz, 6 GHz and 9.5 GHz

Polar Radiation Pattern

The calculated polar patterns of CAVA and RCE-AVA at frequencies of 4 GHz, 6 GHz and 10 GHz are shownin Figure 3. The CAVA has received acceptable values of directivity and side lobe levels in the UWB frequency range. Meanwhile, the RCE-AVA antenna has received good values of directivity, side lobe levels and angular width.



(a) CAVA (b) RCE-AVA

FIGURE 3. Polar radiation pattern at 4 GHz, 6 GHz and 9.5 GHz

Reflection –Coefficient (S11)

The simulated results of the reflection coefficient S_{11} of the CAVA and of RCE-AVA are represented in Figure 4. Based on the results using the CSTMWS software, it is observed that the design antenna reflection coefficient ranging from 6.1 GHz to 6.5 GHz is not linked to the standard reflection value. This frequency range is not considered to obtain adequate reflection results. While the reflection coefficient (S_{11}) of RCE-AVA covers the entire UWB band. The acceptable S_{11} return loss values have been produced by RCE-AVA designed across the UWB band, which is an important requirement for TWI applications.

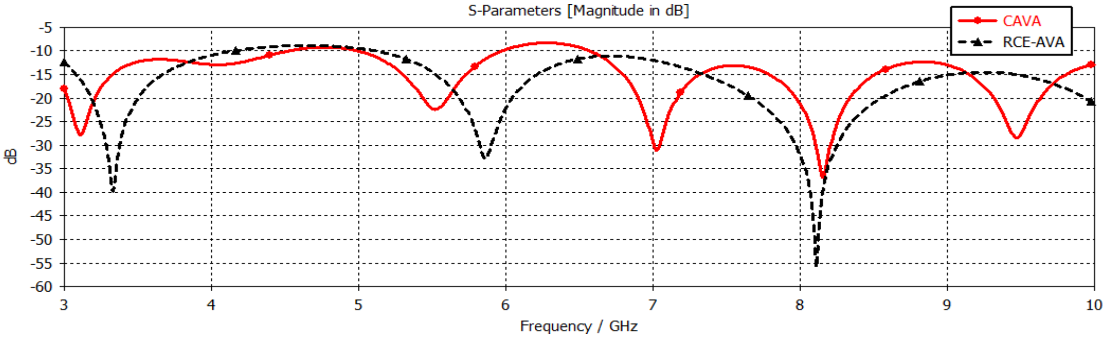


FIGURE 4. CAVA and RCE-AVA reflection-coefficient (S11)

Voltage Standing Wave Ratio

The VSWR of CAVA and RCE-AVA is shown in Figure 5. It is observed that the VSWR of the CAVA design from 6.1 GHz to 6.5 GHz is slightly greater than 2. Meanwhile, the RCE-AVA antenna has acceptable values throughout the UWB band. In general, for best antenna performance, the VSWR should be less than 2.

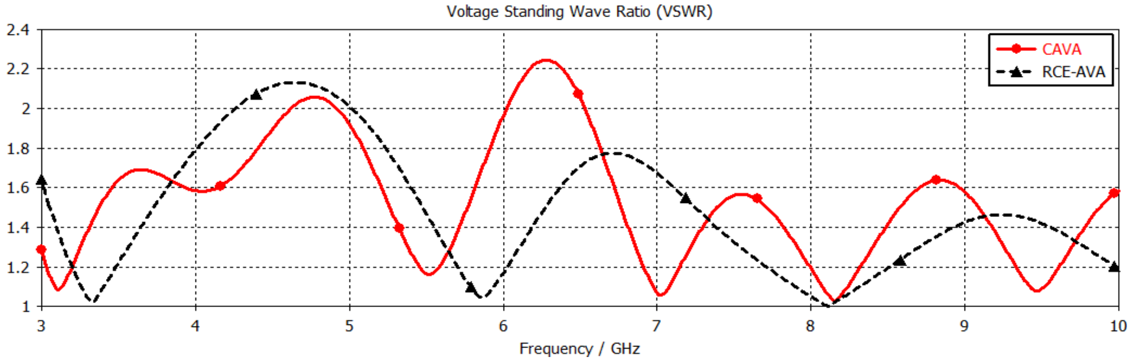


FIGURE 5. CAVA and RCE-AVA (VSWR)

Comparative Analysis

Figure 6 displays the comparative analysis plot of the CAVA and RCE-AVA in gain form. It has been noted that the RCE-AVA antenna has demonstrated more gain over the UWB frequency band than the CAVA.

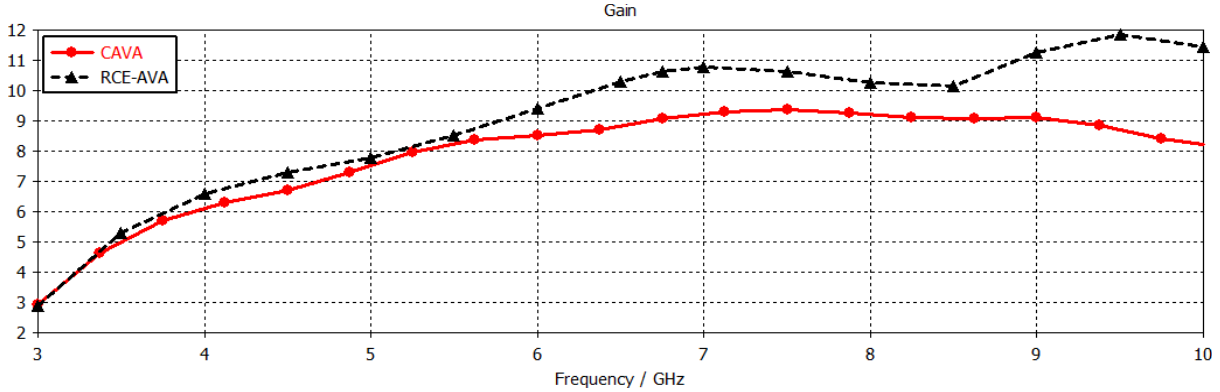


FIGURE 6. Gain comparison of CAVA and RCE-AVA

Table 2 shows the comparison of gain, side lobe levels (SLL) and directivity of CAVA for 4 GHz to 10 GHz. While Table 4 shows the comparison of gain, side lobe levels (SLL) and directivity of RCE- AVA for 4 GHz to 10 GHz**.**

TABLE 2. Gain, Side lobe levels (SLL) and Directivity of CAVA

Frequency	**Gain (dB)**	**SLL (dB)**	**Directivity (dBi)**
4 GHz	6.15	-13.7	6.77
5 GHz	7.53	-10.0	8.3
6 GHz	8.5	-10.7	9.45
7 GHz	9.24	-9.8	10.3
8 GHz	9.22	-11.8	10.5
9 GHz	9.1	-10.8	10.6
10 GHz	8.17	-9.2	9.96

TABLE 3. Gain, Side lobe levels (SLL) and Directivity of RCE-AVA

Frequency	**Gain (dB)**	**SLL (dB)**	**Directivity (dBi)**
4 GHz	6.59	-11.8	6.63
5 GHz	7.76	-10.5	7.87
6 GHz	9.38	-12.0	9.39
7 GHz	10.7	-14.8	10.8
8 GHz	10.2	-14.3	10.2
9 GHz	11.2	-12.4	11.2
10 GHz	11.4	-15.3	11.4

The stable gain and high directivity ensure that the antenna can be used for TWI to detect targets behind the wall.The proposed antenna used the UWB band which provides deep penetration and wide bandwidth for better image resolution. The antenna should produce a better return loss to build the image of the target behind the wall. When S11of the antenna is -10 or better, it produces good reflections, and as a result, the gain, directivity, and penetrating abilityof the antenna will be improved. Table 4 shows the comparison of some related works of the Vivaldi antenna and the proposed work in terms of substrate, max. Gain, operated frequency, antenna structure and applicability. It has been observed that the proposed antenna has achieved the maximum gain among the previous works reported in Table 4.

TABLE 4. Comparison of previous Vivaldi antenna works to proposed antenna design

Reference	Substrate	Max. Gain (dBi)	Frequency (GHz)	Antenna Structure	Application
[9]	FR4	9.6	2.5-11.3	Corrugated	Through Wall Radar Imaging (TWRI)
[14]	FR4	6.61	1.45 - 9.82	Corrugated	Microwave Imaging
[15]	FR4	9	1.67- 6.37	Corrugated	Microwave Imaging
[16]	Polyimide (PI)	9.7	2-8	Corrugated	See through the wall
[17]	FR4	8.2	1.9-12	Corrugated	Through-wall Radar (TWR)
[18]	Taconic RF-35	10.4	1.8 - 9	Corrugated	Microwave Imaging system
[19]	RO4003	8	6 - 18	Corrugated	UWB
[20]	FR4	5	2.9-12	Corrugated	Radar and Microwave Imaging
This work	Rogers 5880	11.8	3.1-10.6	Corrugated	Through Wall Imaging (TWI)

CONCLUSION

In this study, a UWB rectangular corrugated edges antipodal Vivaldi antenna (RCE-AVA) design for through wall imaging (TWI) applications has been investigated. The implementation of rectangular corrugated edges in the proposed design has significantly improved its performance in terms of gain, directivity, return loss, VSWR and side lobe levels. Rogers 5880 and FR4 materials have been tested to improve radiation characteristics. Based on the simulation result, RCE-AVA has achieved the good realized maximum gain value, which is 11.8 dBi at around 9.5 GHz. The reflection coefficient value less than -10 has been obtained and the VSWR value should be less than 2. Therefore, it can be concluded that rectangular corrugated edges antipodal Vivaldi antenna (RCE-AVA) may be a promising candidate for through wall imaging (TWI) application.

ACKNOWLEDGEMENT

This research was supported by the Ministry of Higher Education (MOHE) through Fundamental Research Grant Scheme (FRGS) (FRGS/1/2021/ICT09/UTHM/02/1) and UniversitiTun Hussein Onn Malaysia (UTHM) through Postgraduate Research Assistant Grant (GPPS) (vot H567).

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