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# Palm tree coplanar Vivaldi antenna for near field radar application

**Nurhayati**

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| a revision has been submitted (MOP-19-0572.R1) | ADM: Editorial Office, MOTL<br>• Minor Revision (25-Sep-2019)<br>• a revision has been submitted<br>*Archiving completed on 17-Dec-2019*<br>view decision letter | MOP-19-0572 | Comparison Study of Palm Tree Coplanar and Antipodal Vivaldi Antennas for Near Field Radar Application<br>*Files Archived* | 14-May-2019 | 25-Sep-2019 |

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Microwave and Optical Technology Letters

**Decision Letter (MOP-19-0572)**

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**To:** nurhayati@unesa.ac.id, amanicoba@ifsp.edu.br
**CC:**
**Subject:** Microwave and Optical Technology Letters - Decision on Manuscript ID MOP-19-0572
**Body:** 25-Sep-2019

Dear Mrs. Nurhayati,

Manuscript ID MOP-19-0572 entitled "Comparison Study of Palm Tree Coplanar and Antipodal Vivaldi Antennas for Near Field Radar Application" which you submitted to Microwave and Optical Technology Letters, has been reviewed. The comments of the referee(s) are included at the bottom of this letter.

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Once again, thank you for submitting your manuscript to Microwave and Optical Technology Letters. I look forward to receiving your revision.

Sincerely,

Professor sungtek kahng
Area Editor, Microwave and Technology Letters

Associate Editor's Comments to Author:

Associate Editor
Comments to the Author:
The reviewers have concerns about the authors' manuscript in terms of true contribution and inconsistent points from performances. Though the authors' antenna has a different shape from edge-corrugated Vivaldi antennas, the reviewers and future readers may be so confused that they can come to the conclusion this paper lacks novelty in shape. And there are some unclear points like the cut-off frequency above the expected value despite the leafy edges, and these points should be explained to convince the readers.

Reviewer(s)' Comments to Author:

Reviewing - Phase 2: 1

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3.The captions of the figure 11 and 12 do not correspond to the picture.
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Reviewing - Phase 2: 2

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1. Fig. 5 (b) suggests that generally the coplanar version has lower SLL compared to its antipodal counterpart.Please explain the reasons behind this difference in more detail as it is an important part of the study.
2. The SLL at 3 GHz is around -7 dB as mentioned in the paper. What are the impacts of this high -7dB SLL on the imaging function? Is there any method to reduce it to lower than -10 dB?

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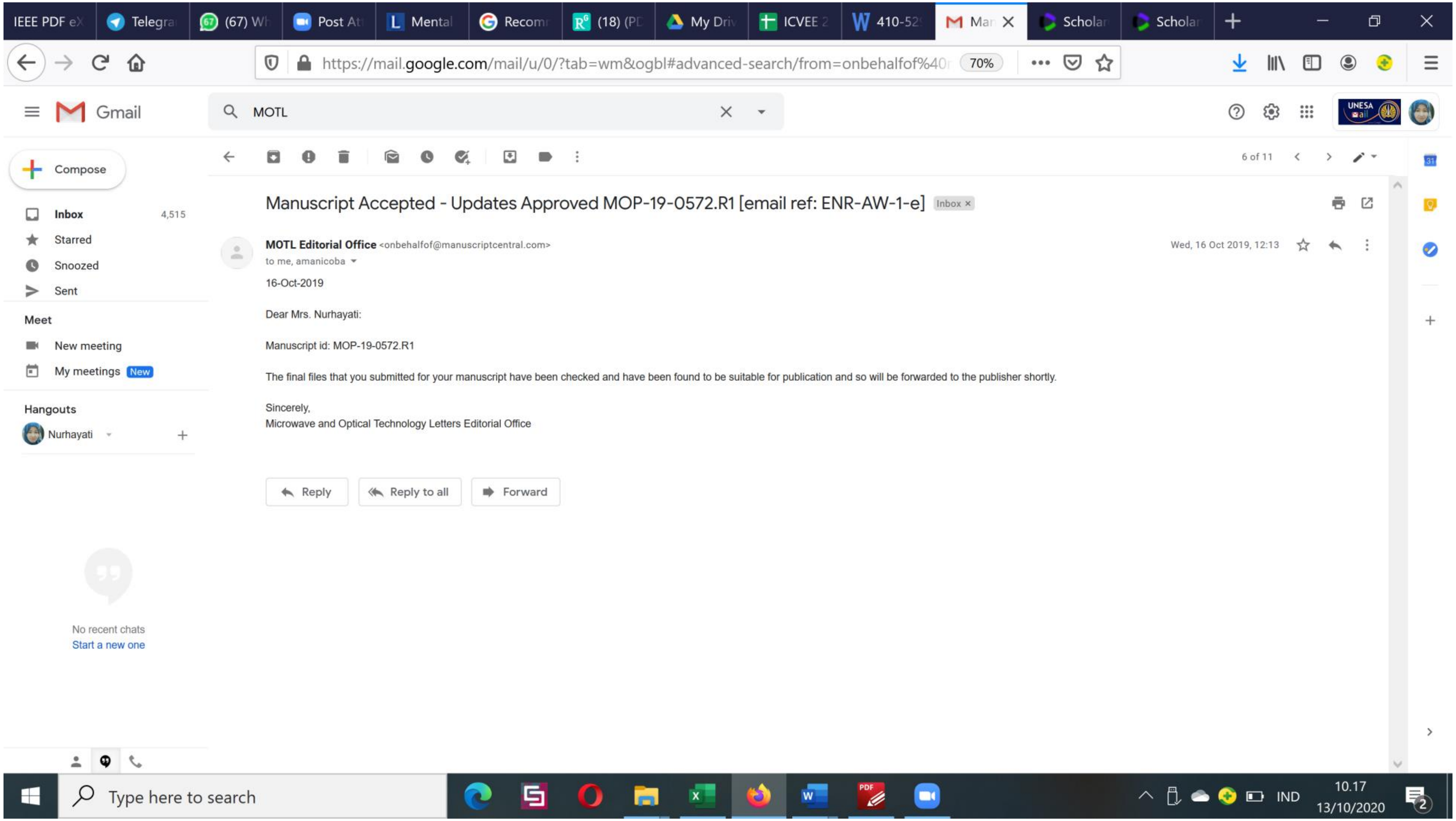

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Reviewer(s)' Comments to Author:

Reviewing - Phase 2: 1

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Reviewing - Phase 2: 2

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2. The SLL at 3 GHz is around -7 dB as mentioned in the paper. What are the impacts of this high -7dB SLL on the imaging function? Is there any method to reduce it to lower than -10 dB?

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**Authors' response:**

Thank you for directing us to improve the paper. We have explained in the paper, in section one in the two last paragraph that we explore the slot edges on both AVA and CVA, i.e : Conventional Coplanar Vivaldi Antenna (C-CVA), Regular Coplanar Vivaldi Antenna (R-CVA), Exponential Slot Edge Coplanar Vivaldi Antenna (ESE-CVA), Regular Antipodal Vivaldi Antenna (R-AVA), and Exponential Slot Edge Antipodal Vivaldi Antenna (ESE-AVA), **by keeping the same dimensions of substrate and similar shape of exponential edge and tapered slot. We also compare the effect the number, height, and opening rate of slot edges** to get the perforance of radiation pattern and current distribution. As far as now mostly paper discussed corrugated slot with **rectangular** slot edge and mostly applied in AVA. **But in our paper we use the exponential slot edge by followed to the equation(1)-(3) in section 2 and** there is no paper uses it yet. **From the simulations and measurements, we find that CVA has better overall radiation pattern performance than AVA in L and S band frequency**.

We have explained in sub section 3.1 about our low end frequency resulted for all antenna and we just optimized our antenna in L and S band frequency as mention in the last paragraph of section one. Our antenna was not optimized to operate below 1.5 GHz although there is possibility that the antenna return loss can cover below 1 GHz in the narrow band. In Figure 2. 9 and 10, we just ploted every 25 data from 1000 data to easier the markpoint of the figure.

# Reviewer(s)' Comments to Author:

**Reviewer: 1**

Comments to the Author

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1. The article lacks novelty. Numerous papers have been published the corrugated edges technology to reduce low end cutoff frequency and improve low frequency radiation performance.

**<u>Authors' response:</u>**

Thank you for the inputs. It has been discussed from the paper on the last paragraph two and three in section one that the corrugated structure has been published in [11]-[19] but just discussed one type on vivaldi element that is Antipodal Vivaldi Antenna (AVA). Our previous research [20] discussed about comparison of vivaldi antenna without the corrugated slot and [21] applied in array but there is no comparable with different types of Vivaldi antenna. Our novelty are making the comparison both types of Vivaldi antenna that is Coplanar Vivaldi Antenna and Antipodal Vivaldi antenna simultaneuously i.e: Conventional Coplanar Vivaldi Antenna (C-CVA), Regular Coplanar Vivaldi Antenna (R-CVA), Exponential Slot Edge Coplanar Vivaldi Antenna (ESE-CVA), Regular Antipodal Vivaldi Antenna (R-AVA), and Exponential Slot Edge Antipodal Vivaldi Antenna (ESE-AVA), by keeping the same dimensions of substrate and similar shape of exponential edge and tapered slot.. We also compare the effect of the number, height, and opening rate of slot edges to the radiation pattern and current distribution. We also designed exponential slot edges follows the equation of exponential tapered slot in (1)-(3) that has never been used before. The Palm Tree Vivaldi concept implies, unlike other corrugated edge techniques, the simultaneous increase of the main lobe level with the reduction of the SLL. The other techniques reduce the SLL without increasing the main lobe. Although there is Palm Tree AVA, the study of Palm Tree CVA is necessary to ensure applicability in different Vivaldis.

2. According to the size of the regular Vivaldi antenna in this paper, the theoretical low end cutoff frequency of the antenna is about 1GHz. However, from the results in Figure 10, the cutoff frequency is larger than 1GHz. In fact, through the corrugated edges, the low frequency cutoff frequency of the antenna should be much less than 1 GHz.

   Authors' response:

   From the theories, to get the low end cut off frequency of vivaldi element, the element width should be set more than equal to cut off its wavelength [22]. In our design we just focussed all simulation and measurement in L and S band (1-4 GHz). However if we set the frequency range less than 1 GHz, it will result some resonance below 1 GHz but only in the narrow bandwidth.

   From the figure we can conclude that ESE-CVA has better bandwidth impedance and radiation pattern in mostly band of frequency than AVA although our low end frequency reached for ESE-AVA at 1.14 GHz, ESE CVA at 1.23 GHz, C-CVA at 1.32 GHz, R-CVA at 1.34 GHz and R-AVA at 1.51 GHz as shown in sub setion 3.1. Bandwidth of antenna also depend on the substrate, feeding and radiator shape.

3. The captions of the figure 11 and 12 do not correspond to the picture.

   **Authors' response:**

   We have changed the caption of FIGURE 11 with " Fabricated antennas: (a) R-AVA front view, (b) R-CVA front view, (c) R-CVA back view, (d) ESE- AVA front view, (e) ESE_CVA front view, and (f) ESE-CVA back view".

4. Some grammar mistakes should be modified.

   **Authors' response:**

   Thank you, We have tried to improve the grammer.

5. The authors should list some similar publications to reveal the advantages of this work.

   Authors' response:

   We have added Table 3 to inform some similiar publication in section 4.3

**TABLE 3** Comparison the proposed and literature studied

| Reference, Type, technic | Size (WxLxh) | Subs. Permitivity | Bandwidth (GHz) | Gain |
|---|---|---|---|---|
| [2] CVA, - | 260x254 | duroid 5880 er=2.2 | 0.7-2.7 | 7.4 dBi |
| [8]AVA,slit edge and trapezoid lens | 40x90x0.508 | Roger RO4003C er=3.38 | 3.4-40 | 14.6 dB (40GHz) |
| [9]DAVA,edge slit, | 70x166x0.762 | RO4350 er=3.48 | 4.7-20 | 15dB(16GHz) |
| [11]AVA,taper slot edge | 48x60 | FR4, er=4.6 | 2.5-15 | 10 dB (7.5GHz) |
| [12]AVA,comb slit edge | 120x202x0.508 mm2 | R04003C er=3.38 | 1.65-18 | 10.3 (3GHz) |
| [14]AVA | 80x60x1.6 | FR4 er=4.3 | 3.1-10.6 | copol/xpol20 dB |
| [16]CVA,side slot | 88x751.57 mm | Duroid 5870 | 1.54-7 | 9.8dBi (6 GHz) |
| [17]AVA,Exponential Slot edge | 36.3x59.8x0.64 | RO3206 er=6.15 | 5.6-11 | 8.3dB(6GHz) |
| [18]AVA, | 40x90x0.508 | RO4003C er=3.38 | 3.4-40 | 14.3 (40GHz) |
| [19]AVA,fren leaf | 50.8x62 | FR4,er=4.4 | 1.3-20 | 10 dBi |
| [23]AVA | 150X150 | FR4 ER=4.3 | 1.5-3.5 | 7.9 dB |
| Our purpose, CVA | 150X150 | FR4 ER=4.6 | 1.23-4 | 10,7 dB or 11,9 dBi (3 GHz) |

**Reviewer: 2**

Comments to the Author

This paper is well-written and provides a comprehensive study about the effects of several parameters on the AVA and CVA performances. The minor concerns are as follows.

Authors' response:

1. Fig. 5 (b) suggests that generally the coplanar version has lower SLL compared to its antipodal counterpart. Please explain the reasons behind this difference in more detail as it is an important part of the study.

   **Authors' response:**

   Fig 5 shows that Coplanar Vivaldi has lower SLL than AVA. It could be happened because AVA has radiator in the different side of substrate and it interferes the shape of SLL and the gain, while coplanar has radiator in one side of substrate. In CVA the feeding shape very influence the matching impedance of antenna element and it can be maximize to get the wider bandwidth and higher gain whereas in AVA only has certein feeding shape.

2. The SLL at 3 GHz is around -7 dB as mentioned in the paper. What are the impacts of this high -7dB SLL on the imaging function? Is there any method to reduce it to lower than -10 dB?

   **Authors' response:**

   High SLL will decrease the antenna gain and it can influence the signal reception quality because it increase interferences of reception of signal. It results false target detection. By modified the corrugated slot, the radiator, feeding shape or adding some structure in openning mouth of antenna element, it can decrease SLL We can see from table 2 that CVA has lower SLL than AVA and by add exponential corrugated slot it can reduce the SLL, in 2.5 GHz as center frequency , antenna element has lowest SLL as -12.71 than in 3 GHz.

Received ; | Revised ; | Accepted

DOI: xxx/xxxx

**ARTICLE TYPE**

# Comparison Study of Palm Tree Coplanar and Antipodal Vivaldi Antennas for Near Field Radar Application†

Nurhayati *[1] | Alexandre M.De Oliveira[2] | João F.Justo[3] | Eko Setijadi[4] | Bagus E.Sukoco[5] | Endryansyah[6]

[1,6]Department of Electrical Engineering, Universitas Negeri Surabaya, Surabaya, Indonesia
[2]Maxwell Laboratory of Microwave and Applied Electromag, Federal Institute of São Paulo, Cubatãoo, Brazil
[3]Department of Electronic Systems Engineering, Polytechnic School of the University of São Paulo, , Brazil
[4]Department of Electrical Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
[5]Lembaga Ilmu Pengetahuan Indonesia, , Bandung, Indonesia

**Correspondence**
*Nurhayati, Email: nurhayati@unesa.ac.id

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**Abstracs**

The Vivaldi antenna is an ultra-wideband device that has high gain and directional radiation pattern. This paper performs a comparison of conventional, regular and exponential edges of a Palm Tree Vivaldi antenna that could operate in L and S band frequencies. The Conventional Coplanar Vivaldi Antenna (C-CVA), Regular Coplanar Vivaldi Antenna (R-CVA), Exponential Slot Edge Coplanar Vivaldi Antenna (ESE-CVA), Regular Antipodal Vivaldi Antenna (R-AVA) and Exponential Slot Edge Antipodal Vivaldi Antenna (ESE-AVA), all with the same dimensions, are compared in terms of reflection coefficient and radiation pattern performance. Gain improvement is achieved as 6.22 dB, 7.64 dB, 7.90 dB, 7.92 dB, and 10.74 dB at 3 GHz respectively for R-AVA, ESE-AVA, C-CVA, R-CVA, and ESE-CVA. The number, height, and opening rate of slot edges predispose current distribution and radiation pattern of CVA. Our results show that the Exponential Slot Edge Coplanar Vivaldi Antenna provides the best gain and derives the best side lobe level, which confirmed the possibility of applying the Palm Tree technique to Coplanar Vivaldi antennas, in addition to the Antipodal ones, as originally proposed.

**KEYWORDS:**
Coplanar, Vivaldi, Antipodal, Radiation Pattern, Exponential slot

## 1 | INTRODUCTION

Vivaldi antenna is a simple and robust planar device, which has been the focus of recent intensive research, mostly due to its superior unique properties, it is compact, easy to manufacture, with small dimensions and high gain, and could be integrated directly in a circuit board[1]. As a result, it is suitable for many ultra-wideband (UWB) microwave applications. There are many applications for L and S bands, such as cell phone and wireless communication[2], ground penetrating radar[3], software defined and cognitive radios[4], medical imaging and on-body telemetry[5][6], astronomy[7], satellite communication, surveillance and amateur radio. All such application needs reliable system mainly for antenna optimization as front end of telecommunication device.

Despite such features, the Vivaldi antenna still carries many shortcomings. The original antenna design has limitations, particularly on directivity and gain, such that a design optimization procedure is generally required for a specific application. Over the last few years, many strategies have been developed to improve those properties, for example by adding trapezoid lens[8], using double antipodal structures[9], and metamaterials[10]. However, all those solutions compromise the main constructive advantage, by increasing the final antenna dimensions and making the design more complex. Therefore, it is important to search for new design strategies, in order to overcome those limitations, but not compromising the original design simplicity. Recently, several investigations have explored the design of the slot edges on Antipodal Vivaldi Antennas (AVA) [11][12] [13][14][15][16], using rectangular and comb structure, exponential, and fractal patterns.

It has been shown that the Exponential Slot Edge for AVA (ESE-AVA) [17], labelled as the Palm Tree antenna, has superior radiation patterns when compared to antennas with other slot edge designs [18][19]. This antenna simultaneously increases the gain, boosts the main lobe, and reduces the Side Lobe Level (SLL), all without making the design more complex or increasing its volume. While investigations have so far explored the design of the slot edge in antipodal configuration, a recent investigation has indicated that CVA could also benefit from slot edge optimization, in order to increase gain and enhance the main lobe of radiation patterns [20][21].

This investigation explores the design of slot edges on both AVA and CVA, and the resulting radiation properties for applications in L and S bands. We compare the reflection coefficient and radiation performance of Conventional Coplanar Vivaldi Antenna (C-CVA), Regular Coplanar Vivaldi Antenna (R-CVA), Exponential Slot Edge Coplanar Vivaldi Antenna (ESE-CVA), Regular Antipodal Vivaldi Antenna (R-AVA), and Exponential Slot Edge Antipodal Vivaldi Antenna (ESE-AVA), by keeping the geometry with the same dimensions. We also compare the effect of the number, height, and opening rate of slot edges to the radiation pattern and current distribution. From simulations and measurements, we find that CVA has better overall radiation pattern performance than AVA in L and S band frequency. Particularly, among all tested designs, the ESE-CVA provides the best gain at 10.74 dB and -7.14 of SLL. We also compare some near field measurement for CVA and AVA in different object. This manuscript is presented as follows: section 2 presents the design procedure of the AVA and CVA, section 3 presents results on the antenna performance, section 4 presents experimental results specifically for the ESE-CVA, and finally section 5 presents some concluding remarks.

## 2 | VIVALDI ANTENNA

We consider five types of Vivaldi antennas with the same dimensions as 1.25 $\lambda$ and 1.25 $\lambda$ at canter frequency, as shown in Figure. 1 and with dimensions given in Table I. Vivaldi antennas are simulated in L and S band frequency from 1-4 GHz with 2.5 GHz as center frequency to get reflection coefficient and radiation pattern performance.

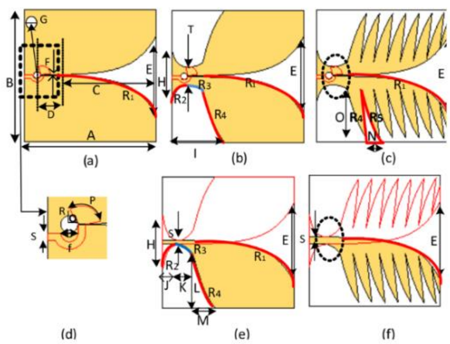


**FIGURE 1** Antenna dimensions of (a) C-CVA, (b) R-CVA, (c) ESE-CVA, (d) feeding shape of CVA and xyz indicator, (e) R-AVA, and (f) ESE-AVA.

The antennas are designed considering a FR4 substrate with permittivity of 4.6, and 1.6 mm of thickness and 0.035 mm of patch thickness. Although the Antipodal and Coplanar Vivaldi antennas have different feeding shapes, they have the same width of transmission line. All the parameters of exponential slot edge for both antennas have the same dimensions except for the transmission line and the part in the circle dash. The exponential tapered slot and exponential slot edge are designed by [15]:

$$y = C_1 e^{R_n x} + C_2 \tag{1}$$

$$C_1 = \frac{y_2 - y_1}{e^{R_n x_2} - e^{R x_1}} \tag{2}$$

$$C_2 = \frac{y_1 e^{R_n x_2} - y_2 e^{R_n x_1}}{e^{R_n x_2} - e^{R_n x_1}} \tag{3}$$

where y is exponential curve and x1, y1 (x2, y2) are the start (end) points of the tapered slot and C1 and C2 are constant. All the exponential shape for tapered slot and slot edge are determined by setting some opening rate (Rn), as indicated in Table I.

**TABLE 1** Antenna parameters (in mm) based on Figure 1.

| Parameter | Dimension | Parameter | Dimension |
|---|---|---|---|
| A | 150 mm | $N$ | 15 mm |
| B | 150 mm | $O$ | 60 mm |
| C | 120 mm | $p$ | 120 deg |
| D | 13 mm | $Q$ | 4 mm |
| E | 90 mm | $R$ | 8 mm |
| F | 0.9 mm | $s$ | 4 mm |
| G | 8 mm | $T$ | 20 mm |
| H | 60 mm | $R1$ | 0.04 |
| I | 60 mm | $R2$ | -0.2 |
| J | 20 mm | $R3$ | 0.1 |
| K | 15 mm | $R4$ | 0.05 |
| L | 60 mm | $R5$ | -0.05 |
| M | 25 mm | | |

## 3 | ANTENNA PERFORMANCE

### 3.1 | CVA and AVA Reflection Coefficient and Surface Current Performance

We compare the reflection coefficient performance of the antennas in coplanar (C-CVA, R-CVA, and ESE-CVA) and antipodal (R-AVA and ESE-AVA) configurations, as shown in Figure. 2. The first reflection coefficient at –10 dB is obtained from CST simulations for ESE-AVA at 1.14 GHz, ESE-CVA at 1.23 GHz, C-CVA at 1.32 GHz, R-CVA at 1.34 GHz, and R-AVA at 1.51 GHz. From the theories, to get the low end cut off frequency of the Vivaldi element, the element width should be set more than equal to cut off its wavelength[22]. In our design, we just focussed in L and S band (1-4GHz) and not optimised to operate below 1.5 GHz. However if we set the frequency range less than 1 GHz, there is posibility antenna will result some resonance below 1 GHz. In this simulation we just ploted every 25 data from 1000 data S11 to easier the markpoint of the figure.

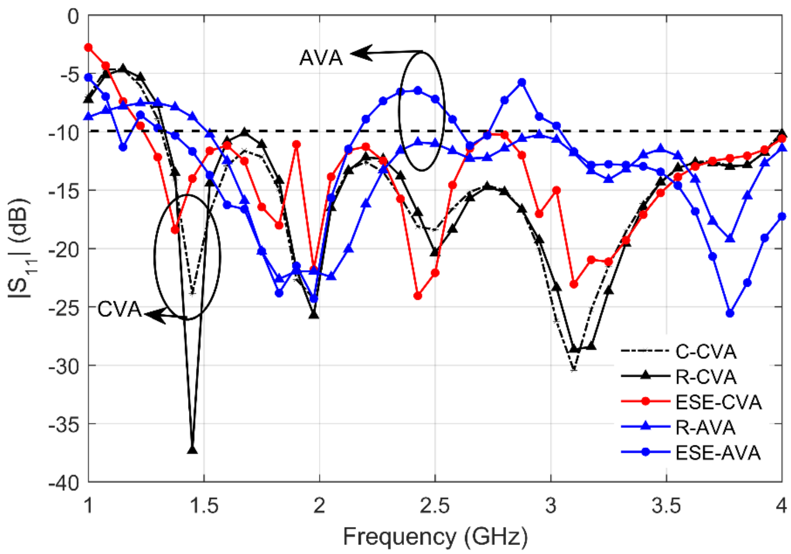


**FIGURE 2** Reflection coefficient performance of CVA and AVA.

CVA and AVA are designed with the same tapered slot value (shown with dash line in the square area in Figure.3) and the same width of transmission line, the ESE AVA antenna provides better performance of reflection coefficient at low end of frequency than the ESE Coplanar. But at 3 GHz, Electric field in the tapered slot is stronger in CVA than in AVA, as shown in the comparison between results in Figures. 3(c) and 3(e).

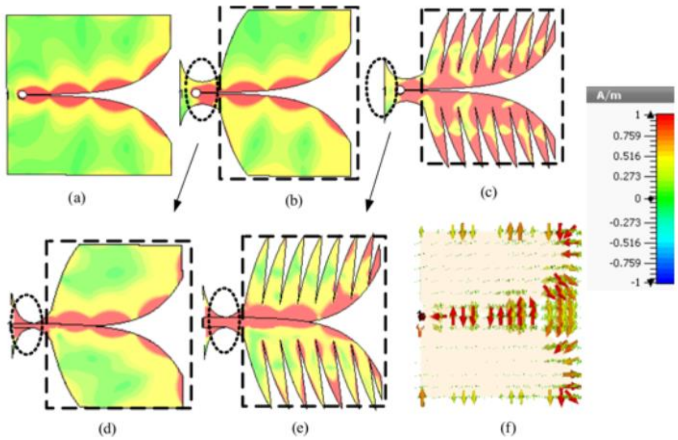


**FIGURE 3** Surface current performance for (a) C-CVA, (b) R-CVA, (c) ESE-CVA, (d) R-AVA, and (e) ESE-AVA and (f). E-Field vector plot of C-CVA.

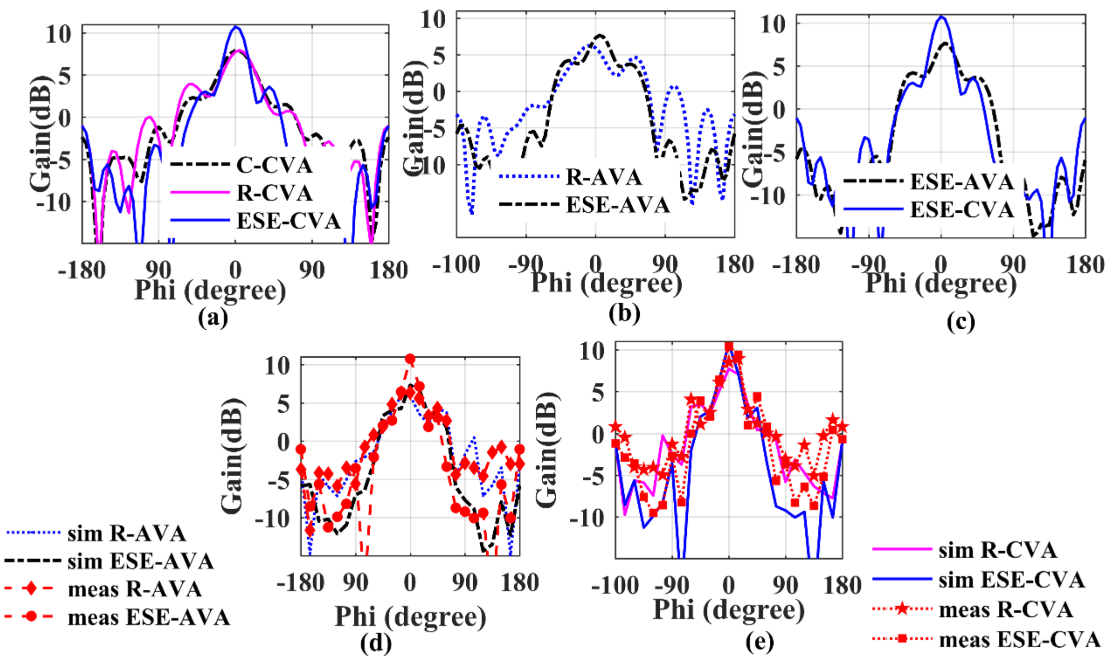


**FIGURE 4** Antenna gain at 3 GHz in the E-plane (XY-plane): (a) simulation results of CVA, (b) simulation results of AVA, (c) simulation results of ESE-AVA and ESE-CVA, (d) simulation and measurement results of R-AVA and ESE AVA, and (e) simulation and measurement results of R-CVA and ESE-CVA.

The intensity of electric field at the beginning of tapered slot indicates good resonance at higher frequencies and in the opening mouth of tapered slot indicates good resonance at lower frequencies. Figure. 3 shows the surface currents at 3 GHz for all antennas, indicating that, despite the same dimensions, the ESE-CVA has the highest surface current. By exciting the feeding of antenna, it yields electric field and produces higher current distribution. The exponential slot edge traps the propagation of electric field and surface current, leading to an antenna with a higher gain than the one without the exponential slot edge.

However, the intensity of electric field depends on an impedance matching from the feeding to slot line and from the tapered slot to free space. In this paper, we emphasize electric field of antenna only in vertical polarization as shown in Figure. 3(f). It is shown by vertical E-Field vector plot of C-CVA between two exponential tapered slot. The polarization of Vivaldi antenna depend on its excited feeding and the structure of the Vivaldi patch.

## 3.2 | CVA and AVA Radiation Pattern Performance

Figure. 4 shows the antenna gain at 3 GHz for the coplanar antennas, indicating that ESE-CVA provided the best gain, followed by R-CVA and C-CVA. For antipodal antennas, the ESE-AVA has a larger gain than R-AVA. However, the ESE-AVA has a more asymmetric radiation pattern than the ESE-CVA, as shown in the lower part of Figure. 4. Figure. 5 shows a comparison of the gain at several frequencies for all antennas, indicating that the best results are obtained with the ESE-CVA. The gains at 3 GHz are 10.74 dB for ESE-CVA, 7.92 dB for R-CVA, 7.90 dB for C-CVA, 7.64 dB for ESE-AVA, and 6.22 dB for R-AVA.

The CVA has two tapered slots in the same side of the substrate and the feeding of CVA is located on the reverse side of substrate. If the feeding has matching impedance with the slot line, it yields resonance between two tapered slots. In CVA, electric field propagates between two tapered slots in the same side of substrate. CVA can be designed with specific feeding shape and it influences the CVA bandwidth. ESE-CVA also has high gain because the electric field is strengthened by the exponential slot edge. In AVA, current from feeding propagates directly from the transmission line in the straight line to the tapered slot, which is located on the opposite side of substrate. In this case, we compare all Vivaldi antennas with the same width of transmission line, and the CVA provides better performance than AVA.

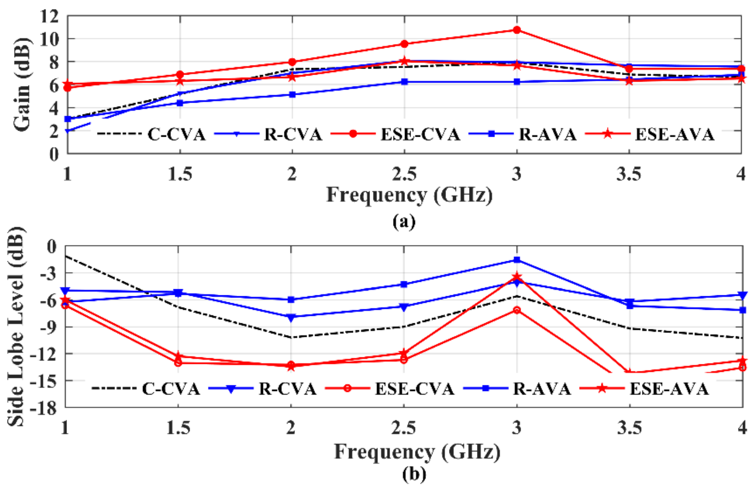


**FIGURE 5** (a) Gain and (b) SLL performance of the antennas.

# 4 | ESE-CVA: OPTIMIZATION AND MEASUREMENT RESULTS

## 4.1 | ESE-CVA Radiation Pattern

ESE-CVA provides the best performance in radiation pattern and bandwidth, as discussed in the previous section. However, there are several parameters to design the slot edge that affect radiation pattern performance. The radiation pattern of the ESE-CVA could be optimized by varying some parameters of the exponential slot edge. The number of exponential slot edges interferes on gain, side lobe level, back lobe, and beam width. From simulation results at 2.5 GHz as the center frequency, as shown in Figure. 6, the ESE-CVA with seven slots has the main lobe of 9.5 dB, SLL of -12.7 dB, and beam width of 39.8 degrees. On the other hand, the antenna with five slots has the main lobe of 9.3 dB, SLL of -12.6 dB, and beam width of 40.7 degrees, whereas for four slots has the main lobe of 9 dB, SLL of -12.5 dB, and beam width of 42.2 degrees. Therefore, more slots can increase the main lobe and reduce SLL, but provide a larger beam width. This occurred because the electric field resonates between slot edges, improving the radiation pattern.

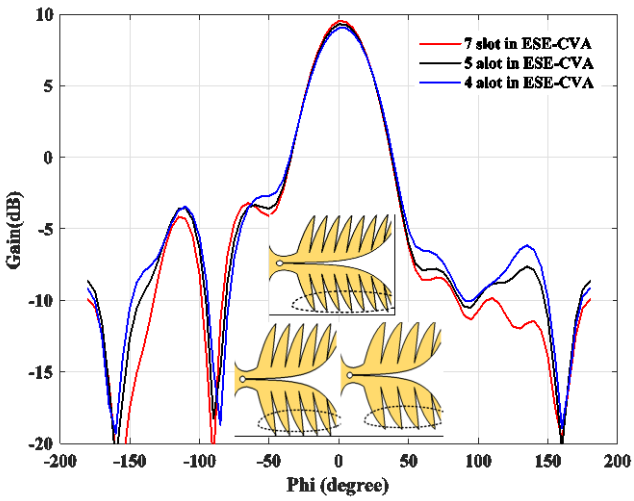


**FIGURE 6** Radiation pattern ESE-CVA with varying the number of slot at 2.5 GHz

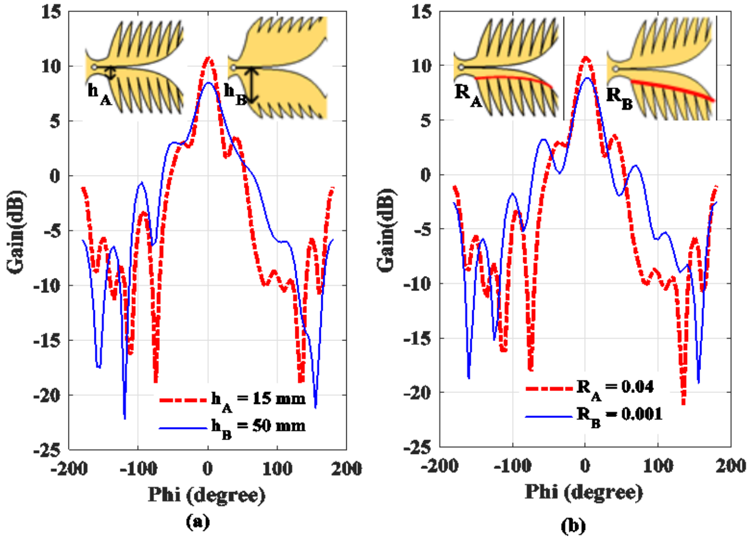


**FIGURE 7** Gain of ESE-CVA by varying depth of slot and slope of ESE at 2.5 GHz.

The height of ESE from the center of tapered slot, shown in Figure. 7(a), and represents the slope of exponential slot edge, shown in Figure. 7(b), interfere with the radiation pattern performance. When the height of ESE ($h_A$) is 15 mm, the antenna gain is 10.7 dB and SLL -7.1 dB. On the other hand, when $h_B$ is 50 mm, the antenna gain is 8.1 dB and SLL -5.4 dB. The shorter the height of slot edge to the center of the opening tapered slot, as shown in Figure 7(a), the more electric field induces the slot edge and enhances the gain. For the antenna with R=0.04, the main lobe is 10.7 dB, SLL is -7.1 dB, and squint is 0 degree, while for R=0.001, the main lobe is 8.8 dB, SLL is -5.6 dB, and the squint is 5 degrees. This indicates that the slope of ESE could control radiation pattern performance. It shows that the shorter height (h) of slot edge from center of tapered slot and higher opening rate (R) of slot edge improve the gain, SLL performance, and the squint performance of the main lobe.

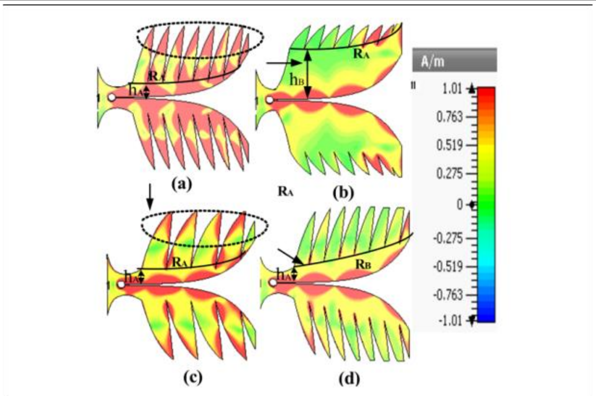


**FIGURE 8** Surface Current of CVA at 3 GHz with; (a). number of slot = 7, depth of slot=15 mm R=0.04, (b). number of slot = 7, ,depth of slot =50mm R=0.04, (c)). number of slot = 4, depth of slot 15 mm R=0.04,, and (d). number of slot = 7, depth of slot 15 mm R=0.01.

## 4.2 | Surface Current of ESE-CVA

The surface current performance for ESE-CVA with different heights of slot edge from the center of the element, different number of slot edge, and different slope of slot edge is shown in Figure. 8. Higher intensity of electric current, represented by surface current distribution, is reached for shorter height (hA) of slot edge, as shown in Figure. 8(a), while higher height (hB) of slot edge yields less surface current distribution, as shown in Figure. 8(b). Higher densities of surface current, which resulted from electric field in the mouth opening of the tapered slot, appears in the slot edge of CVA that has higher depth of slot edge. Higher depth in the slot edges means shorter height (hA) of slot edge to the center of tapered slot. However, for short depth of slot edge only shows a small surface current at the corner of the slot edge, represented in red color in Figure. 8(b).

Figures. 8(a) and 8(c) show a comparison on the surface current for the element with different number of slot edges. CVAs in Figures. 8(a) and 8(c) are designed with the height of slot edge $h_A$=15 mm and slope of slot edge $R_A$=0.04. Those CVA have the same height of slot edge to the center of tapered slot, but they have different number of slot edge.

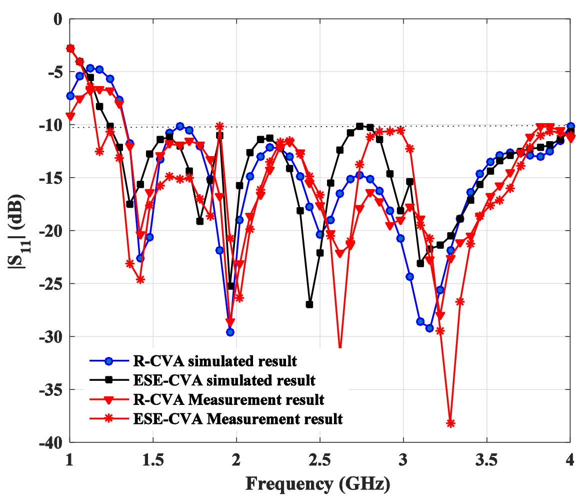


**FIGURE 9** Simulation and measurement results of R-CVA and ESE-CVA on $S_{11}$ as a function of frequency.

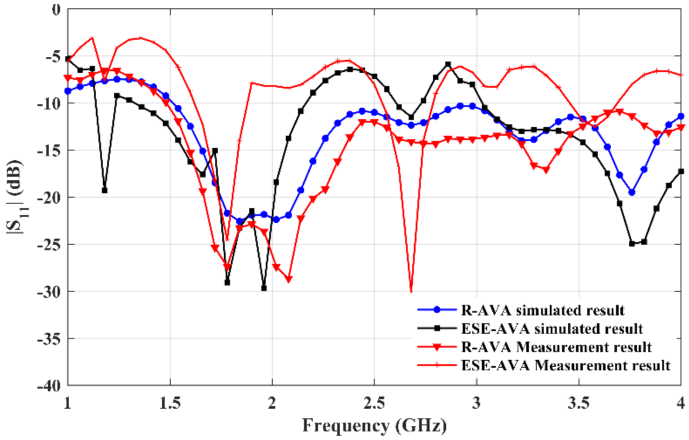


**FIGURE 10.** Simulation and measurement results of R-AVA and ESE-AVA on $S_{11}$ as a function of frequency.

At 3 GHz, the CVA with seven slot edges presents the maximum surface current in the most part of all sections, as shown in Figure. 8(a), while the CVA with smaller number of slot edges presents less portion of surface current, as shown in Figure. 8(c). Therefore, more slot edges lead to more electric field induced in the slot gap and it also yield surface currents trapped in the slot edge. An increase in the number of exponential slots increases surface current in CVA.

Surface current performance for CVA with different slope is shown in Figures. 8(a) and 8(d), designed with $R_A$=0.04 and $R_B$=0.01, respectively. A higher slope of tapered slot edge to the center of the antenna increases performance of surface current. In the midle and towards the end of mouth opening of tapered slot, higher slope ($R_A$) has smaller distance of slot edge from opening tapered slot. It conversely for smaller slope ($R_B$) that has longer distance of slot edge from opening of tapered slot. The slope of slot edge influences the spacing of slot edge to the mouth opening of tapered slot in the middle and in the end of tapered slot and it causes the flowing of surface current to the slot edge.

## 4.3 | Measurement Results of CVA and AVA

Figure. 9 shows a comparison of simulations and measurements of the reflection coefficient (S11) for regular (R) and exponential slot edge (ESE) of CVA, whereas Figure. 10 clarifies simulations and measurements of R-AVA and ESE-AVA. CVA provides better performance in bandwidth than AVA, especially at low end of the frequency band. Table II shows the values of gain, SLL, squint, and the lowest frequency that occupies reflection coefficient performance below -10 dB, between simulations and measurements.

**TABLE 2** Comparison between antennas: gain, SLL, squint from simulations and measurements.

| | Gain(dB) | | SLL(dB) | | Lowest Frequency | | Squint |
|---|---|---|---|---|---|---|---|
| **Fre(GHz)** | **2.5** | **3** | **2.5** | **3** | **Sim. result** | **Meas. result** | |
| R-AVA | 6.2 | 6.2 | -4.31 | -1.58 | 1.52 | 1.48 | -5 |
| ESE-AVA | 8.02 | 7.64 | -11.94 | -3.44 | 1.14 | 1.62 | -5 |
| C-CVA | 7.51 | 7.9 | -9.02 | -5.61 | 1.32 | 1.2 | 0 |
| R-CVA | 8.04 | 7.93 | -6.74 | -4.02 | 1.34 | 1.34 | 5 |
| ESE-CVA(proposed antenna) | 9.52 | 10.74 | -12.71 | -7.14 | 1.23 | 1.16 | 0 |

Table 2 presents about the comparison of R-AVA, ESE-AVA, C-CVA, -CVA and ESE-CVA gain, SLL, squint and the lowest frequency in 2.5 and 3 GHz. It indicates that ESE-CVA gets the best performance of Gain, SLL, and squint at 2.5 and 3 GHz, eventhough the lowest of frequency band is reached for ESE-AVA. High SLL will decrease the antenna gain and it can influence the signal reception quality because it increase interferences of reception of signal. It results false target detection. By modified the corrugated slot, the radiator, feeding shape or adding some structure in openning mouth of antenna element, it can decrease SLL We can see from table 2 that CVA has lower SLL than AVA and by add exponential corrugated slot it can reduce the SLL, in 2.5 GHz as center frequency , antenna element has lowest SLL as -12.71 than in 3 GHz.

Table 3 shows the comparison of our purposed and the literature studied. It shown that mostly reserched only discussed for one type of vivaldi element that is Antipodal Vivaldi Antenna (AVA). Our novelty disscussed the comparison both types of Vivaldi antenna that is Coplanar and Antipodal Vivaldi antenna by keeping the substrate dimensions and similar shape of exponential edge and tapered slot. In specific dimension and frequency [22], shown in the last row of Table 3, our proposed provided a wider bandwidth and higher gain than those.

**TABLE 3** Comparison the proposed and literature studied

| Reference, Type, technic | Size (WxLxh) | Subs. Permitivity | Bandwidth (GHz) | Gain |
|---|---|---|---|---|
| [2] CVA, - | 260x254 | duroid 5880 er=2.2 | 0.7-2.7 | 7.4 dBi |
| [8]AVA,slit edge and trapezoid lens | 40x90x0.508 | Roger RO4003C er=3.38 | 3.4-40 | 14.6 dB (40GHz) |
| [9]DAVA,edge slit, | 70x166x0.762 | RO4350 er=3.48 | 4.7-20 | 15dB(16GHz) |
| [11]AVA,taper slot edge | 48x60 | FR4, er=4.6 | 2.5-15 | 10 dB (7.5GHz) |
| [12]AVA,comb slit edge | 120x202x0.508 mm2 | R04003C er=3.38 | 1.65-18 | 10.3 (3GHz) |
| [14]AVA | 80x60x1.6 | FR4 er=4.3 | 3.1-10.6 | copol/xpol20 dB |
| [16]CVA,side slot | 88x751.57 mm | Duroid 5870 | 1.54-7 | 9.8dBi (6 GHz) |
| [17]AVA,Exponential Slot edge | 36.3x59.8x0.64 | RO3206 er=6.15 | 5.6-11 | 8.3dB(6GHz) |
| [18]AVA, | 40x90x0.508 | RO4003C er=3.38 | 3.4-40 | 14.3 (40GHz) |
| [19]AVA,fren leaf | 50.8x62 | FR4,er=4.4 | 1.3-20 | 10 dBi |
| [23]AVA | 150X150 | FR4 ER=4.3 | 1.5-3.5 | 7.9 dB |
| Our purpose, CVA | 150X150 | FR4 ER=4.6 | 1.23-4 | 10,7 dB or 11,9 dBi (3 GHz) |

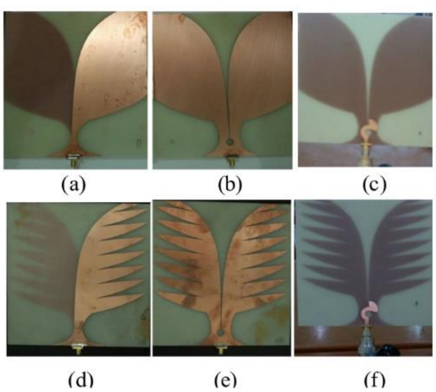


**FIGURE 11** *Fabricated antennas: (a) R-AVA front view, (b) R-CVA front view, (c) R-CVA back view, (d) ESE- AVA front view, (e) ESE_CVA front view, and (f) ESE-CVA back view.*

Fig. 11 shows the AVA and CVA fabricated antennas with regular and exponential slot edges. Figures. 11 (a), (b), and (c) show the front view of R-AVA, R-CVA and ESE-CVA, respectively, while Figures. 11(d), (e), and (f) show their respective feeding in back views.

## 4.4 | Near Field Measurement Application

Fig. 12 displays near field measurement of CVA with four different treatment i.e (a). CVA with thin board, (b). CVA with head phantom made from styrofoam, (c). CVA with thick wood (d) CVA with thin Styrofoam and (e) AVA with head phantom. In Figure 12, the styrofoam has epsilon er=1,1, however the wood has er=2.4. The environment object of measurement can be shown in Figure. 12 (a)-(e) respectively with the target in Figure. 12(f) and (h). The measured S-parameter used Copper Mountain Cobalt series c1220 Vector Network Analyzer which is connected to the CVA antenna in Figure. 12(a)-(d) and (g) whereas in Figure.12 (e) connected to AVA antenna. In the first row of Figure. 13 show different characteristic of S11 with target behind of the object as observed in Figure. 12(a) and (d) and target inside of the object in Figure. 12 (b),(c),(e) and (g). Thin board has thickness 8 mm as shown in Figure. 12(a) and thin styrofoam has thickness 29 mm as displayed in Figure. 12(d). In the first row of Figure 13, the thin board and thin Styrofoam has worse S parameter than head phantom and thick wood for CVA, but the worst S11 is shown for AVA antenna as shown in the first row of Figure 13 (e). Object with thin thickness will have smaller distance between target and the antenna, furthermore it influences S parameter measurement performance.

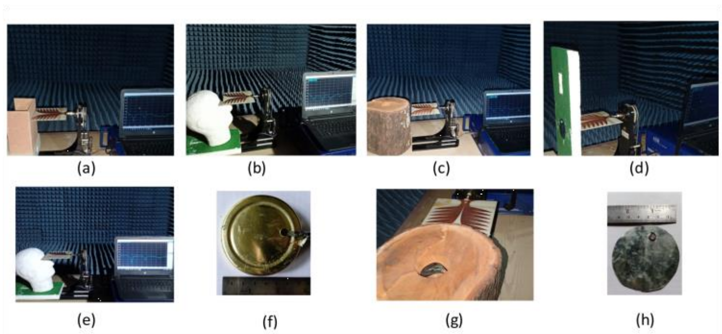


**FIGURE 12** Fabricated antennas: (a) R-AVA front view, (b) R-CVA front view, (c) R-CVA back view, (d) ESE- AVA front view, (e) ESE-CVA front view, and (f) ESE-CVA back view.

The S11 data from VNA have been imported from touchstone block CST Design Studio, and converted to TDR (Time Domain Reflectometry). TDR signal from post processing in CST related to Inverse Fourier Transform and shown in the second row of Figure. 13. The time sampling is set as 30 ns for all the TDR signal. The target in Figure.12 (e) is placed in the object of Figure. 12(a), (b), and (e), while the target in Figure. 12(h) is placed in the object in Figure 12.(c) and (d).It shows different characteristic of signal from object with target in the second row of Figure. 13 and object without target as shown in the third row of Figure 13. The subtraction signal in the second and third row resulted the signal in the fourth row in Figure. 13.

However the absolute of the subtraction signal yields output in the fifth row of Figure.13. It shows that thin board have higher amplitude of target signal than in thin Styrofoam. It also shows that the head phantom can detect target with higher signal than in the thick wood. With the same size of antenna, CVA with head phantom has higher detection of target signal than AVA with head phantom as shown in the last signal in Figure 13 (b) and (e). It happened because CVA has better performance of S11 than AVA as shown in the first row Figure 13(b) and (e). It is also observed that object with board or wood has deployment of signal than object with Styrofoam. Thick wood as shown in Figure. 12(g) has more solid of particle than others. Object with higher dense of particle and further distance of target will have smaller amplitude of signal and higher deployment of target signal.

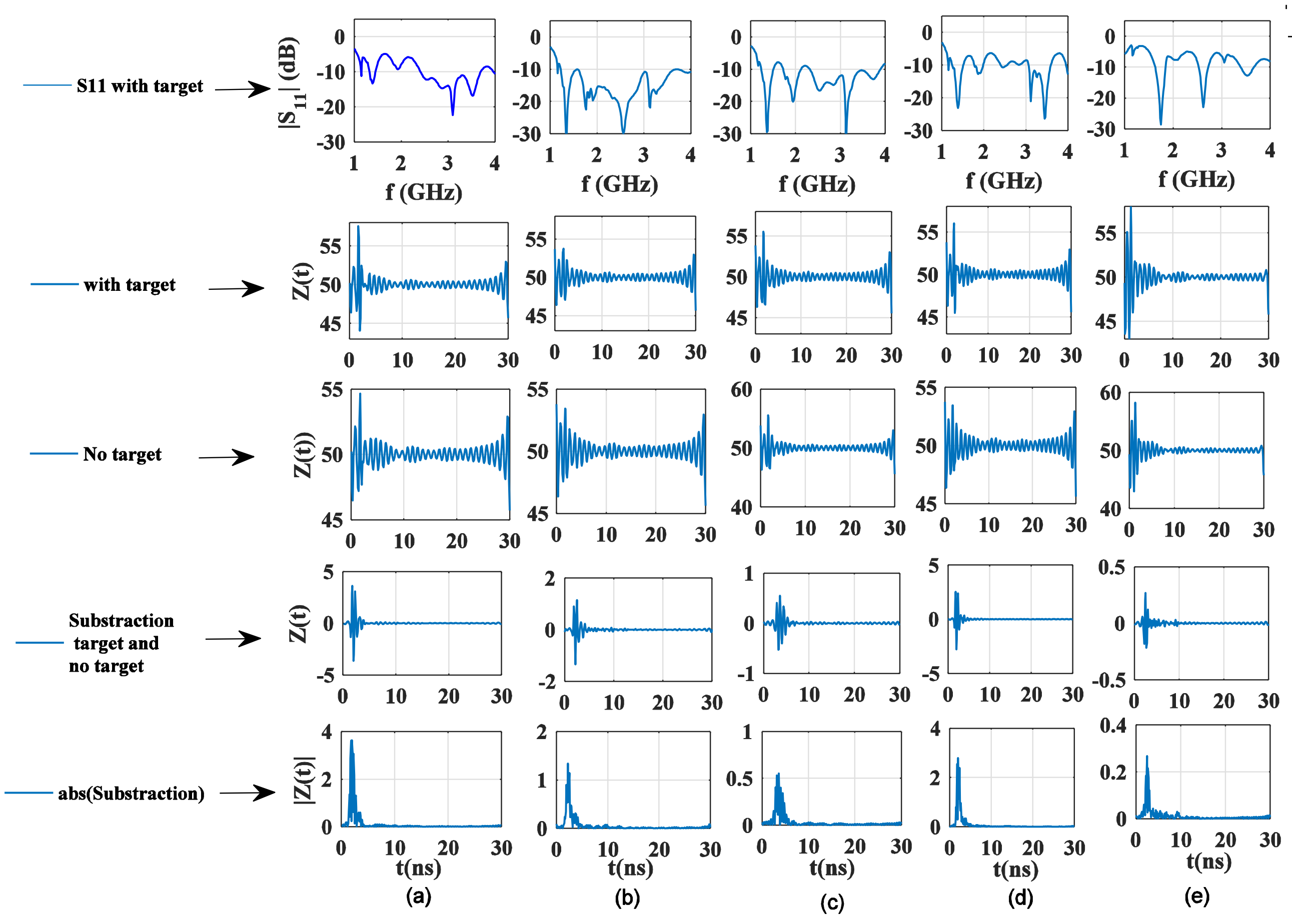


**FIGURE 13** Measurement result of S11 with target in the first row, TDR signal for object with target in the second row, TDR signal for object without target in the third row, Substraction object with target and without target in fourth row and the magnitude of the substraction in the fifth row for object:: (a) CVA with thin board, (b) CVA with head phantom from styrofoam, (c) CVA with thick wood, (d) CVA with thin styrofoam, and (e). AVA with head phantom from styrofoam.

## 5 | CONCLUSION

We compared the properties of Vivaldi antennas consisting of R-AVA, ESE-AVA, C-CVA, R-CVA, and ESE-CVA with the same dimensions of substrate and similar shape of exponential edge and tapered slot. The results indicate that ESE-CVA provides the best performance of gain and side lobe level. Although the width of feeding is designed with the same width for AVA and CVA, the feeding shape influences considerably the performance of resonance frequency and radiation pattern. The number of exponential slot edges, the distance of exponential slot edge to the center of the antenna and the slope of exponential slot edge can control radiation pattern performance. ESE-CVA has better performance of radiation pattern compared to others. Gain improvement is obtained for ESE-CVA of 3.02 dB and SLL of -2.53 dB at 3 GHz when compared to ESE-AVA. Object with higher solid particle and wider distance from the antenna yield worse detection of target signal from near field experimental measurement. With the same size of antenna element and the same object and target, CVA has better performance than AVA.

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