High-Gain Modified Antipodal Vivaldi Antenna for Ultra-Wideband Applications

S. A. Adamu[1], T. Masri[1], W. A. W. Zainal Abidin[1], K. H. Ping[1] and S. A. Babale[2]
[1]*Faculty of Engineering, Universiti Malaysia Sarawak, 94300 K/Samarahan, Sarawak, Malaysia.*
[2]*Wireless Communication Centre, Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia.*
aasaeed2@yahoo.com

***Abstract*—In this paper, the design of a high gain modified antipodal Vivaldi antenna (HG-MAVA) for ultra-wideband applications is presented. The proposed antenna designed on a low-cost FR4 substrate with a thickness of 1.6mm was realized by incorporating a combination of exponential slot edge corrugation on the radiating flare and a high permittivity dielectric director in the flare aperture of a conventional antipodal Vivaldi antenna (CAVA). Compared to the CAVA, the proposed antenna extends the lower end frequency limit of the CAVA to 2.15 GHz. Improvement in realized gain is also achieved throughout the 2.15 GHz to more than 11 GHz operating frequency band of the proposed antenna with the highest improvement of 1.61 dBi at 7 GHz. The surface current distribution and the radiation pattern of the proposed antenna were studied to further characterize the performance of the antenna.**

***Index Terms*—Corrugation; Dielectric Director; Surface Current; Ultra Wideband.**

I. INTRODUCTION

Since the commercial licensing of the ultra-wideband frequency (UWB) spectrum by the federal communications commission (FCC) was introduced in February 2002 [1], different types of UWB antenna designs [2], [3] have been proposed. Recently research attention in both academia and industry has beamed more search light on the Vivaldi antenna due to increase in the demand of commercial and military mobile wireless systems.

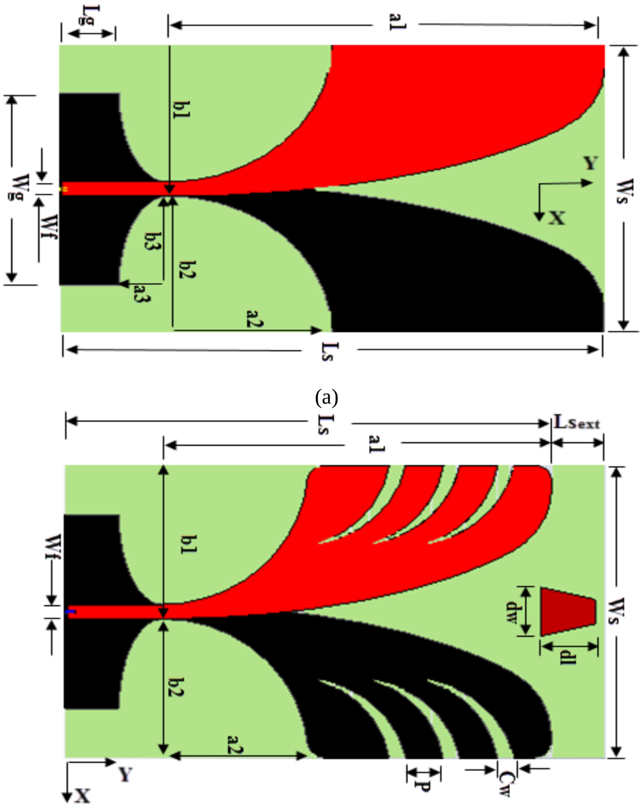
The Vivaldi antenna also known as the Vivaldi notch or the tapered slot antenna was first discussed by P. J. Gibson in 1979 [4]. Its unique feature is a microstrip to slotline transition feeding technique whose design was improved upon in 1988 by E. Gazit [5] using the antipodal Vivaldi antenna to broaden the operation frequency and later by J.D.S. Langley et al. [6] in 1996 for improved cross-polarization.

However the antipodal Vivaldi antenna despite its many advantages [7]–[9], still suffers from drawbacks such as tilted beam, low or inconsistent directivity and gain. Several techniques have being proposed in literature for improving the gain and directivity of the antipodal Vivaldi antenna including the use of high permittivity dielectric director [10]–[13], zero index and negative index metamaterials (ZIM/NIM) [14]–[16], as well as using array structures [17]–[20] among others.

In this paper, a new method of improving the performance of the antipodal Vivaldi antenna based on incorporating a combination of exponential slot corrugations on the radiating arm of the antenna and a high permittivity dielectric director is proposed.

II. ANTENNA GEOMETRY AND DESIGN

A low-cost FR4 dielectric substrate with dielectric permittivity constant ε_r = 4.4, thickness h = 1.6mm, and dielectric loss tangent δ = 0.02 respectively has being used for the design of the antenna whose geometry is as shown in Figure 1(a). The antenna includes three main parts: feed line, feed transition and the tapered radiating flare sections. The shape of the radiating flares is designed in the form of elliptical curves because of its simple structure, offers wide impedance bandwidth and presents a smooth transition between the feeding line and the radiation flares. The arms are flared in opposite directions and symmetrically rotated around the antenna aperture axis.



(b)

Figure 1: Structure of (a) Conventional AVA and (b) Proposed AVA

The upper-frequency limit of a Vivaldi antenna is theoretically infinity while the lower frequency limit depends mainly on the width of antenna (*W*) and the effective dielectric constant (ε_{eff}) and is calculated from [21].

$$f_{\min} = \frac{c}{2W\sqrt{\varepsilon_{eff}}} \tag{1}$$

where;

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

For this design, the radii of the inner and outer edges of the radiating flares are governed by the quarter ellipses defined according to the following equations:

$$a_1 = \frac{L_s - L_g}{2} + k \tag{3}$$

$$a_2 = 0.375a_1 \tag{4}$$

$$a_3 = 0.37a_2 \tag{5}$$

$$b_1 = \frac{W_s + W_f}{2} \tag{6}$$

$$b_2 = \frac{W_s - W_f}{2} \tag{7}$$

$$b_3 = \frac{W_g - W_f}{2} \tag{8}$$

The width of the feed line (W_f) is designed to have a characteristics impedance of Z_o= 50Ω which is calculated from [21]:

$$Z_o = \frac{120\pi}{\sqrt{\varepsilon_{eff}}\left[\frac{W}{h} + 1.393 + \frac{2}{3}\ln\left(\frac{W}{h} + 1.444\right)\right]} \tag{9}$$

$$for\left(\frac{W}{h}\right) \geq 1$$

To obtain improved performance the conventional antipodal Vivaldi antenna was modified by incorporating exponential slot corrugations on the radiating flares and a high permittivity dielectric director in the flare aperture as shown in Figure 1(b). The corrugation is designed by cutting exponential slots of equal length from the copper of exponential radiating arms on both sides. The width, length and distance between the exponential slots of the corrugation remain the same. The slot corrugation enabled the electrical length of the inner taper profile to be lengthened thereby extending the lower end cutoff frequency. Likewise the dielectric director made up of a high permittivity dielectric material work as a directive element that enhances the radiation in the end-fire direction. Thus, the gain of the proposed antenna increases significantly due to the combined effect of both the corrugation and the dielectric director. The optimized parameters of the conventional and proposed antennas are as given in Table I.

Table 1
Proposed Antenna Dimension Values

Parameter	Value (mm)	Parameter	Value (mm)
Ws	60.00	b1	31.50
Ls	90.00	b2	28.50
Lg	18.00	b3	18.50
Wf	3.00	C1	16.00
Wg	40.00	Cw	3.00
a1	78.00	dd	2.00
a2	25.00	dw	10.00
a3	10.00	dh	10.00

III. Result and Discussion

A. Reflection Coefficient

Figure 2 illustrates the simulation results of variation of reflection coefficient (S_{11}) with frequency for the designed antennas. As can be observed from the figure, the reflection coefficient of the conventional antipodal Vivaldi antenna is below -10 dB for the frequency range of 2.82 GHz to more than 11 GHz. Application of the corrugation for the proposed antenna enabled the lower end frequency limit to be extended to 2.15 GHz. Thus the modification applied to the conventional antipodal Vivaldi antenna miniaturized the size of the antenna by lowering the minimum operating frequency.

B. Surface Current Distribution

To further study the behavior of the designed antenna structures, surface current distribution at 4 GHz and 7 GHz are illustrated in Figure 3 (a) and (b). Unwanted surface current can be observed towards the outer edges of the conventional AVA which limits the total radiation in the end fire direction as observed from Figure 3(a). However, as can be seen from Figure 3 (b) the combined effect of loading the slot corrugations on the edges of the radiating arm and the dielectric director in the flare aperture of the proposed antenna causes a significant current to be observed along the slot edges which indicate that the effective length of the current path is lengthened leading to improved radiation in the end fire direction.

C. Realized Gain

The plot of the variation of realized gain against frequency is shown in Figure 4. As can be observed from the figure, the loading of the conventional AVA with the edge corrugation and the dielectric director suppress the surface current at the back edges thus resulting in a significant improvement in gain performance throughout the operating frequency band of the proposed antenna. Similarly, the increase in the effective length of the proposed antenna due to the modification leads to a more directive beam in both the E-plane and H-plane. The realized gain of the conventional AVA is found to be 3.64 dBi to 7.67 dBi over the 2.85 to 11 GHz bandwidth while the realized gain of the proposed antenna is between 3.85 dBi to 8.48 dBi. Increase in gain can be observed throughout the operating band of the antenna with the highest increase of 1.61 dBi realized at 7 GHz due to the combined effect of the modification.

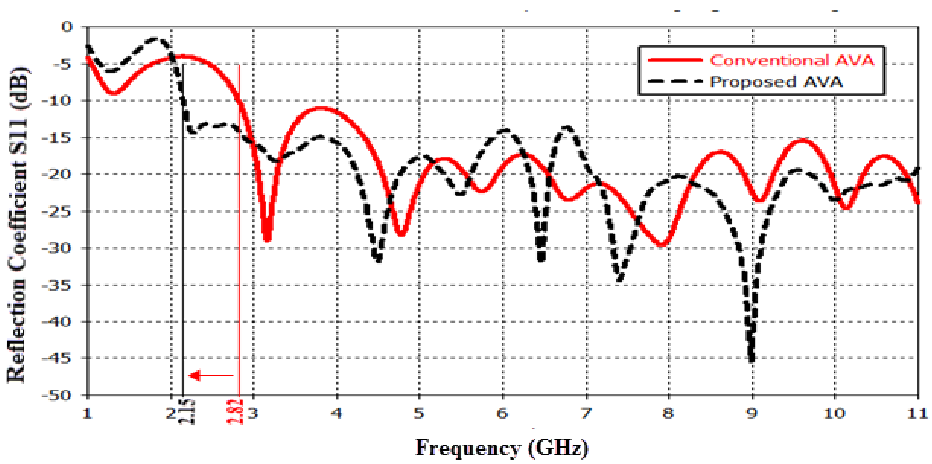


Figure 2: Reflection Coefficient (S_{11}) for the CAVA and Proposed AVA

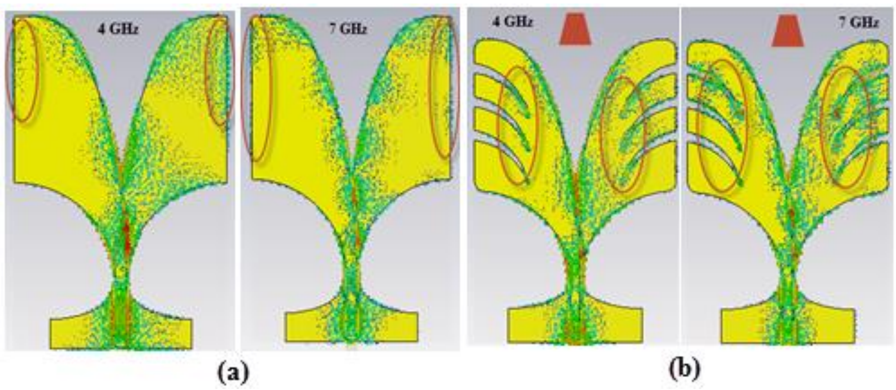


Figure 3: Surface Current Distribution of (a) Conventional AVA and (b) Modified AVA

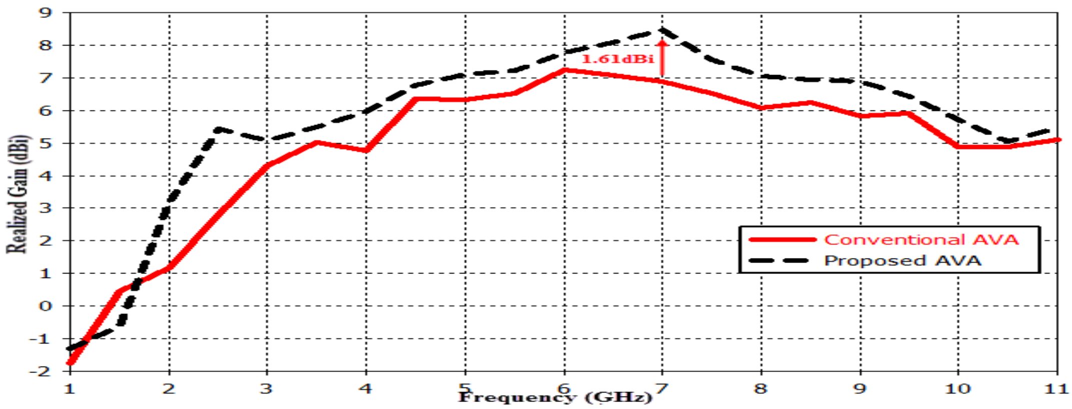
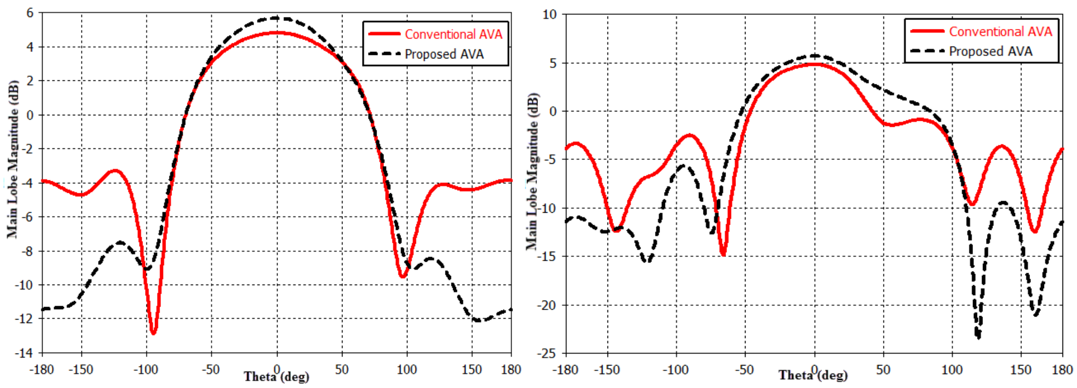
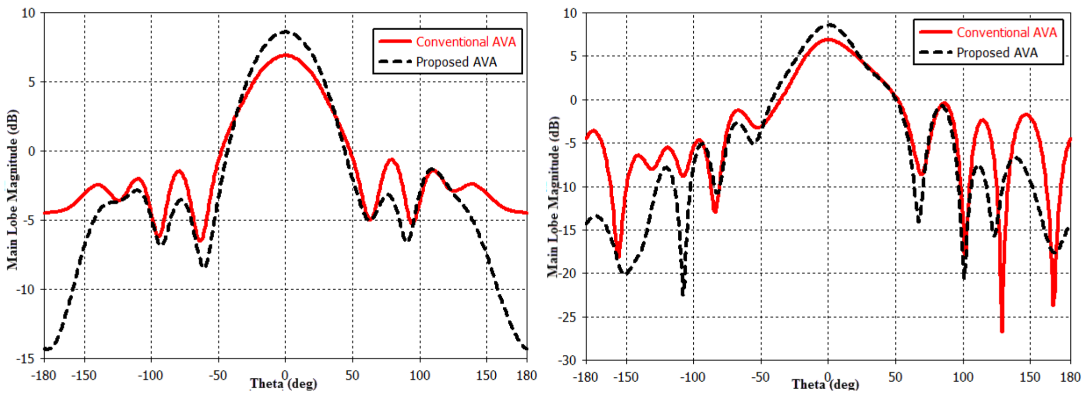


Figure 4: Realized Gain for Conventional and Proposed AVA



(a)



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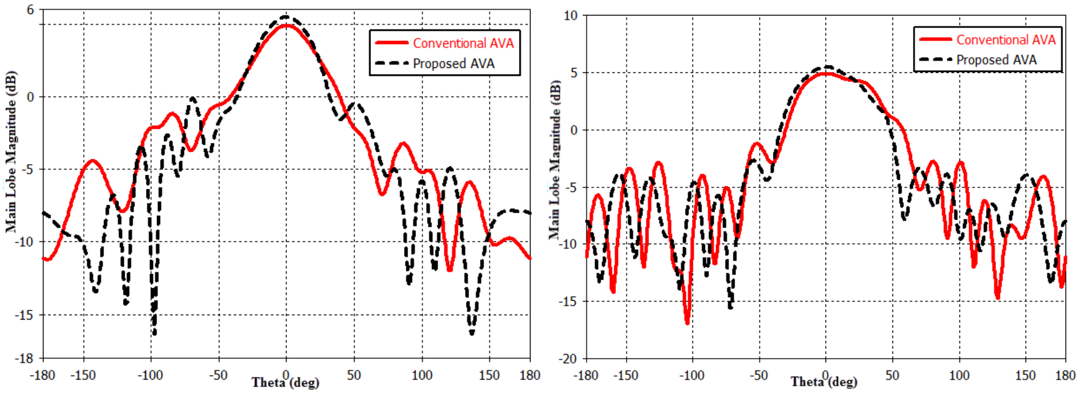

(c)

Figure 5: E-Plane and H-Plane Radiation Pattern of Conventional and Proposed AVA at (a) 4 GHz, (b) 7 GHz and (c) 10 GHz

D. Radiation Patterns

Figure 5(a), (b) and (c) above depict the radiation patterns of the conventional AVA and the proposed antenna in both the E-Plane and H-Plane at 4 GHz, 7 GHz and 10 GHz respectively. As observed from the figure, the modification on the proposed antenna results in low side and back lobe levels as well as increase in the main lobe magnitude. The directivity and gain of the proposed antenna thus improves due to increase in directivity in the bore sight direction.

IV. CONCLUSION

A modified Antipodal Vivaldi Antenna is presented by incorporating exponential shaped slot corrugations on the radiating arm and a high permittivity dielectric director in the flare aperture of the conventional antipodal Vivaldi antenna. This structural modification resulted in an increase in electrical length of the radiating arm thereby reducing the lower operating frequency from 2.82 GHz to 2.15 GHz, and correspondingly improving the realized gain throughout the operating band without altering the overall size of the antenna. The magnitude of E-plane and H-plane directivity was also improved with a corresponding reduction in side and back lobe levels. The proposed antennas will be fabricated and measured next to validate the simulation results.

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