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

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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 \( \varepsilon_r = 4.4 \), thickness \( h = 1.6\text{mm} \), and dielectric loss tangent \( \delta = 0.02 \) 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.

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 \((\varepsilon_{\text{eff}})\) and is calculated from [21]:

\[
f_{\min} = \frac{c}{2W \sqrt{\varepsilon_{\text{eff}}}} \tag{1}
\]

where:

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

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:

\[
a_i = \frac{L_i - L_g + k}{2} \tag{3}
\]

\[
a_2 = 0.375a_i \tag{4}
\]

\[
a_3 = 0.375a_2 \tag{5}
\]

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

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

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

The width of the feed line \((W_f)\) is designed to have a
characteristics impedance of \(Z_0 = 50\Omega\) which is calculated from [21]:

\[
Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{\text{eff}}} \left[\frac{W}{h} + 1.393 + \frac{2}{3} \ln \left(\frac{W}{h} + 1.444\right)\right]} \tag{9}
\]

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>
<thead>
<tr>
<th>Parameter</th>
<th>Value (mm)</th>
<th>Parameter</th>
<th>Value (mm)</th>
</tr>
</thead>
<tbody>
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<td>b1</td>
<td>31.50</td>
</tr>
<tr>
<td>Ls</td>
<td>90.00</td>
<td>b2</td>
<td>28.50</td>
</tr>
<tr>
<td>Lg</td>
<td>18.00</td>
<td>b3</td>
<td>18.50</td>
</tr>
<tr>
<td>Wf</td>
<td>3.00</td>
<td>C1</td>
<td>16.00</td>
</tr>
<tr>
<td>Wg</td>
<td>40.00</td>
<td>Cw</td>
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</tr>
<tr>
<td>a3</td>
<td>10.00</td>
<td>dh</td>
<td>10.00</td>
</tr>
</tbody>
</table>

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.
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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 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.

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.

REFERENCES


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