Design and Analysis of a Corrugated Antipodal Vivaldi Antenna for Ultra Wideband Applications

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Abstract: - In this paper, a new Corrugated Antipodal Vivaldi (CAV) antenna is proposed for Ultra Wideband (UWB) applications. The proposed antenna is structured to provide an acceptable gain in the endfire direction over a wideband of the frequency range of interest within a limited size to be compatible with handsets and portable wireless devices. This is achieved by forming a corrugated Vivaldi of certain steps mounted in the complimentary direction from the substrate to move the skew surface waves to the endfire direction. The proposed antenna consists of three main layers including the copper wings (patches) separated by an FR4-Epoxy substrate and an L-shaped transmission line feed. The substrate dimensions are 50×38 mm². The wings are etched with dimensions of 50×19 mm² on the opposite side to the each other with the complementary direction. It is found that such antenna shows a first frequency mode at 1.58 GHz with return loss value equals to -16.85 dB. A wide band, $S_{11} < -10$ dB, of operating frequency has been achieved to start from 5 GHz to 20 GHz with endfire radiation patterns of different gain values varying from 3.7 dB to 6.6 dB. The performance of the proposed design is tested using HFSS and validated with CST. Finally, the antenna performance in terms of $S_{11}$ is measured and compared to their simulated results to achieve an acceptable agreement.

Keywords: CAV, HFSS, CST, bandwidth, endfire.

I. Introduction

Nowadays, a fast revaluation in the wireless communication systems is observed in a wide range of industrial and academic aspects in different frequency bands. Therefore, the research started to investigate antennas to cover most of the essential bands with considering antenna size reductions, high efficiency, acceptable gain, and easy to fabricate with low cost. Vivaldi structures were proposed as microstrip antennas with unlimited bandwidth, low profile, easy to fabricate, light weight, small size, with low cost [3]. Moreover, the Vivaldi antenna provides an acceptable gain proportional to the antenna length and curvature shape [1].

The first Vivaldi prototype was developed as a tapered slot structure of a traveling wave antenna by P. Gibson [6] that was consisted of a substrate, feed line and radiating structure. The feeding technique used was an electromagnetic coupling microstrip slotted transition line launched to the radiating structure based exponential curved shape to create a smooth transition from slot line to the open space. After Gibson’s design many improvements were proposed such as an antipodal Vivaldi antenna which was invented by E. Gazit [5] in 1988 as a solution of the feeding problem. The antipodal Vivaldi antenna consists of a dielectric substrate with two metallic wings. The two wings are arranged in the opposite complementary back to back direction. The feeding technique is based on a microstrip line followed by a balanced strip line transition. Such design showed many advantages over the original one such as easy to design and fabricate. The twin line feed increases the high operating frequency because there is no slot line width limitation [4]. The disadvantage of the antipodal Vivaldi design is the cross-polarization where it is usually significantly frequency dependent [8]; which it is caused by the skew of the slot field. The skew is changes along the length of the taper which starts with the highest value at the closed end, while, it is usually negligible at the open end of the antenna. Balanced Antipodal Vivaldi antenna was designed in 1996 by Langley and et al as the next improvement to the original design [8]. In this design, the cross polarization problem was solved by adding extra metallization and substrate
layers where the function of the extra layer was to create two E-field vectors that start from the middle layer. The first vector goes to the top layer while the second one goes to the bottom layer and the sum of these vectors gives E-field vector parallel to metallization and as result reduces the cross polarization significantly [1].

In this paper, the design of a CAV antenna is proposed. The antenna performance in terms of $S_{11}$ and radiation patterns is tested experimentally and numerically for the frequency range from 300 MHz to 20 GHz. The rest of the paper is organized as follows. In Section 2, the antenna design and the geometrical details are presented. The numerical results and the design methodology are discussed in section 3. The antenna performance measurements are characterized in section 4. Finally, we conclude the paper in Section 5.

II. Antenna Geometry and Steps of Design

The design steps of the proposed CAV antenna of a miniaturized structure that are followed to arrive to the optimal design is discussed as following: First of all, design a vivalde antenna based on rectangular wings spaced by the substrate to be called as model 1, as shown in figure 1(a). The rectangular wings is changed to be Diamond-shaped to neglect the unnecessary radiation and the power loss through it where this shape is called model 2, as shown in figure 1(b). The diamond shape and with the same declivity angle became a corrugated to increasing the impedance of antenna and achieve a matching between the antenna and the medium where this matching will allow to the wave to propagating from the antenna to the medium with lowest wave’s reflection from the medium to the antenna and this shape called model 3, as seen in figure 1(c). Add a straight line in the bottom of the corrugated wings to re-directing the current distribution path in order to reduce the back lobes that appear in the radiation pattern and this shape is called model 4, as seen in figure 1(d).

![Figure 1](image.png)

Finally, the reached antenna design is consistent of three main structures: substrate, wings, and feeder. The substrate is picked as FR4-Epoxy with relative permittivity $\varepsilon_r=4.4$, and dielectric loss tangent ($\tan\delta=0.02$). The substrate dimensions of 50×38 mm$^2$ with thickness of 5 mm. The wings are designed to be the radiating patch structures based coriguated copper layers as seen in figure 2.
An electromagnetic coupling feed line based on L-shape, see figure 3, is invoked in the middle of the substrate which is easy to design and match to the antenna.

III. Simulation Result
To reach the optimal antenna design, in Figure 2, HFSS software package based FEM is conducted to test the performance of the four proposed models in terms of $S_{11}$, radiation patterns, and gain. The criterion for judging the best antenna model, in this paper, is the bandwidth and gain only as will be seen in the following:

A- Antenna performance
The performance of the proposed models based Vivaldi structures are tested numerically in terms of $S_{11}$ spectra as seen in Figure 4. It is found the all proposed antenna models provide the first frequency mode around 1.5 GHz. While, the rest frequency bands are found to be as following: The first antenna model shows multiple bands, return loss is less than -10 dB, from 6.1GHz to 7.9GHz, 8.6GHz to 9.3GHz, 10.1GHz to 11.1GHz and from 13.1GHz to 15.7GHz. The second one shows matching from 6GHz to 7.7GHz, 8.3GHz to 9.4GHz, 10.1GHz to 11.1GHz, 12.1GHz to 16GHz and 18.1GHz to 20GHz. The bandwidth of the third model enhanced in comparison to the previous two models. Finally, it is found the last model shows a significant bandwidth enhancement to start from 5 GHz to 20 GHz.
The gain spectra of the four proposed models are presented in Figure 5. The first three models characterized by a split in the radiation pattern with back lobe occurred and gain changing from 2.289dB to 6.437dB. The last model shows endfire radiation patterns with gain changing from 3.7dB to 6.602dB.

**B- Parametric study**

The antenna performance, including $S_{11}$, would be affected by changing the geometrical dimensions of the antenna. This study is conducted to find the effects of both of the antenna substrate thickness and feed line dimensions on the antenna performance. The parametric study has been followed to arrive to the optimum design is shown below:

1- **Effect of the substrate thickness**

The effect of substrate height (H) on the $S_{11}$ spectrum is studied by fixing the length at 50 mm and width at 38 mm while H is changed from 1 mm up to 6 mm, with step of 1 mm. Figure 6
shows the $S_{11}$. It is found that the antenna shows the best matching bandwidth when the thickness is 5 mm.

The reason of the antenna has the best matching at 5 mm thickness is back to, the quality factor at this thickness has the lowest value compare with the other thickness and as a result the low-quality factor mean high bandwidth because there is an opposite relation between the bandwidth and the quality factor.

2-Effect of Feed Line Dimensions ($L$, $W$)

The second parameter that studies the effective of it on the antenna performance is the feeder. In this study, focusing on the length and width of the feeder with considering the optimum dimension of the substrate is 50x38x5 mm$^3$. The figure 7 shows the simulation results of the corrugated flat antenna with multiple length values of the feeder where the optimum length of feeder is found at 14 mm that seen in red curve.

After the parametric study of the feeder length, the effective of the feeder width will be studying too. The paramedic study of the feeder width is will be done by considering the optimum feeder
length is 14 mm and substrate thickness is 5 mm. Figure 8 shows the simulation results of multiple width which the optimum width is found at 2 mm.

![Figure 8](image)

**Figure 8**: The $S_{11}$ spectra with respect to changing feed line width.

Finally, after completed the paramedic study on the feeder dimensions and saw the effective of the feeder on the antenna performance, it was concluded that the optimum feeder dimension is found at $L=14$ mm and $W=2$ mm because at this dimensions the best matching with the lowest reflection was been achieved.

IV. **Antenna Results Validations and Measurement**

In order to validate the antenna performance, the antenna was fabricated and then measured by used vector network analyzer to test the antenna performance for check and as seen in figure 9. In additional to the fabrication, the CST MWS is invoked too for more results accuracy. From this test, it is found that the obtained results from CST MWS and HFSS show excellent matching with their identical from measurement as seen in figure 10.
Figure 9: The fabricated CAV antenna.

Figure 10: The simulated and measured $S_{11}$ results of CAV antenna.

After testing the $S_{11}$ experimentally, the 3D radiation patterns are evaluated numerically using CST and HFSS software packages at 5GHz, 8.5GHz, 10GHz, 12.5GHz, 15GHz, 17.5GHz and 20GHz as seen in Table 1.

Table 1: The radiation pattern of Corrugated Antipodal VA at different frequencies

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<tr>
<th>Frequency</th>
<th>3D Radiation Pattern (HFSS)</th>
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V. Conclusions

A novel CAV antenna of a miniaturized size is proposed in this paper for UWB applications. The proposed antenna size is reduced enough to make it possible to be compacted with handheld and portable wireless and electronics devices. The antenna is designed to provide an acceptable matching over a wide range of frequencies by using a corrugated geometry and L-Shaped feed transmission line. The antenna radiation patterns are enhanced in the most frequencies of interest to provide endfire radiations with enough gain for short and medium communication ranges. This is achieved by moving the skew surface waves at the endfire direction through adding the corrugation steps to the Vivaldi structure. The numerical simulation to evaluate the performance of the proposed antenna is carried out using two different numerical software packages based CST and HFSS formulations. A parametric study is invoked to realize the optimum antenna dimensions before the fabrication and the measurement steps. The antenna with optimal dimensions is fabricated and tested. The antenna shows the first resonance mode around 1.58 GHz and another matched band starts from 5 GHz and continues to 20 GHz. Nevertheless, the radiation patterns of the antenna are found in the endfire with gain varying between 3.7 dB to 6.6 dB.

References


