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Design and Development of a Tapered Slot Vivaldi Antenna for Ultra-Wide Band Application

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Abstract— Ultra Wideband (UWB) has a number of applications that make it attractive for a variety of applications such as microwave imaging, wireless communications, ground penetrating radars, remote sensing and phased arrays. This paper offered the design of a tapered slot Vivaldi antenna for ultra-wideband application using FR4 substrate which has relative permittivity of 4.4. The Vivaldi Antenna is designed to cover ultra-wideband (UWB) from 3.1 to 10.6 GHz by using CST Software. In order to improve the bandwidth and the return loss characteristics of the emitted signal, UWB is discovered. The simulation results show that the return loss is better than -10dB within the preferred frequency range. Therefore the designed antenna will be useful for ultra-wideband application.

Keywords— UWB, Microwave imaging, wireless communications, Ground Penetrating Radar, Remote Sensing, Phased Arrays, Tapered Slot Vivaldi Antenna.

I. INTRODUCTION

The Vivaldi antenna is the most popular directive antenna for commercial UWB applications due to its simple structure and small size. The Vivaldi antenna was first introduced by Gibson in "The Vivaldi aerial" [1] which comes under the Tapered Slot Antenna (TSA) with an exponentially tapered profile etched on a thin metallization [2,3]. Since then, it is widely used in different applications such as microwave imaging, wireless communications and ground penetrating radars.

In Vivaldi traveling wave propagate on the inner edges of the flares which is the main mechanism for radiation. A traveling wave propagating along the surface of the slot with a phase velocity less than the speed of light (i.e., $v_{ph} \le c$) results in an end fire radiation [3]. The dual exponentially tapered slot antenna DETSAs have wider bandwidth and improved radiation pattern characteristics compared to TSAs.

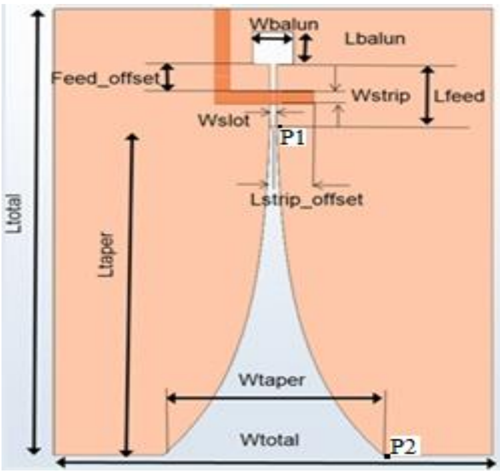

Figure 1: Tapered Slot Vivaldi Antenna

But the major drawback is typical DETSA dimensions which are generally greater than 10 cm, than those of other compact UWB antennas [4]. Although Vivaldi antennas have been extensively used in many applications, especially in ultra-wideband systems [5-8], the original layout has suffered from several design problems mostly related to poor and inconsistent gain, limited operational bandwidth and large dimensions.

Several design approaches have been proposed in the literature in order to improve the bandwidth, directivity and to obtain more compact dimensions. These have been recently widely investigated and developed by many researchers and institutions. A micro strip-to-slot transition adopting a quarter-wave circular slot and a quarter wave radial strip line stubs was introduced in order to achieve a wider bandwidth than the one obtained with the straight stubs [9, 10], Vivaldi antenna arrays for see through dry wall and concrete wall UWB applications [11], and miniaturization of antenna [12-14]. In [13] the traditional micro strip-to-slot line feed transition of a Vivaldi antenna was replaced with a micro strip-to-parallel strip line. The Antipodal Vivaldi Antenna (AVA) obtained this way overcomes the practical limitations of a conventional Vivaldi antenna exhibiting a very wide operation bandwidth. However, the antipodal nature of the antenna gives rise to not only very high levels of cross-polarization, but also severe polarization tilt as the frequency of operation is increased.

To overcome these problems, by adding another dielectric layer and an extra layer of metallization, the electric field in the slot region is oriented parallel to the metallization, namely balanced antipodal Vivaldi antenna is formed, which has smaller cross- polarization level of -15 dB for 6 GHz-18 GHz [11,12]. Recently, several approaches have been suggested in improving end-fire radiation pattern of balanced Vivaldi antenna, i.e., introducing a dielectric director in radiation aperture [16].

Various AVA and BAVA designs with more compact size and better radiation properties have been proposed in the literature [15].Compared to other wideband antennas, the TSAs have moderately high directivity, planer structure, low profile, and symmetric beam in both E- and H-plane. Also, it is inexpensive to fabricate and easy to integrate. All those characteristics make the TSA a good candidate for phased array, remote sensing, and short-rage communication. The aim of this paper was to design an ultra-wideband Vivaldi antenna that was lightweight, compact and conformal, with approximately constant gain characteristics from 3.1-10.6GHz.

II. VIVALDI ANTENNA DESIGN

The parametric study and design of single element Vivaldi antenna is calculated in three different models: stripline model, stripline-slotline model and antenna model. Stripline model contains the selection of the substrate material, substrate thickness and the stripline width. Stripline stub length, slotline stub length, slotline width, antenna length, antenna width and backwall offset are the factors to be determined in the stripline-slotline model. At last, the antenna model is built identifying the uniform slotline length, taper length and taper rate, mouth opening and the edge offset.

As the electrical length of the antenna increases with frequency the gain increases. The length of antenna will be the addition of taper length, balun length, feed length, backwall offset and width must be equal to λ0, where λ0 is the free space wavelength at the low frequency. The exponential taper profile is determined by the opening rate and two points p1(x1, y1) and p2(x2, y2) shown in Figure 1.

The resulting exponential relation explains the taper section

$$\mathcal{Y} = \mathcal{C}_1 e^{\mathcal{R}\mathcal{X}} + \mathcal{C}_2 \qquad (1)$$

Where,

$$\mathcal{C}_1 = \frac{y^2 - y^1}{e^{\mathcal{R}x^2} - e^{\mathcal{R}x^1}} \qquad \mathcal{C}_2 = \frac{y^1 e^{\mathcal{R}x^2} - y^2 e^{\mathcal{R}x^1}}{e^{\mathcal{R}x^2} - e^{\mathcal{R}x^1}}$$

c1, c2 are constants and R the opening rate of the exponential taper. Note that (x1, y1) and (x2, y2) are the coordinates of the origin and end of flare curve, respectively and the taper length L = x2 - x1. An exponentially tapered slot line rather than an elliptically antipodal tapering structure was exploited to make the antenna simulation easier.

The selection of a dielectric substrate is one of the most essential features of the design of a Vivaldi antenna. The important features of a substrate material are its dielectric constant, loss tangent, and the thickness of the dielectric. The FR4 substrate with a dielectric constant of 4.4 is selected. Effective thickness of the dielectric substrate (*teff*) need to be defined as follows [17]

$$\frac{teff}{\lambda_o} = (\sqrt{\varepsilon_r} - 1)\frac{t}{\lambda_o} \qquad (2)$$

Where, λ0 is the free space wavelength at the center frequency, t is the thickness and εr is the dielectric constant of the substrate. The essential criteria for a TSA to possess travelling wave antenna characteristics is [17]

$$0.005 \leq \frac{teff}{\lambda_o} \leq 0.03 \qquad (3)$$

In order to achieve a transition that has low return loss over a wide frequency band, the impedances of the micro strip line and the slot line must be matched to each other to reduce the reflections. The characteristic impedance of a slot line increases with increasing slot width, so the width of slot line must be selected to be as small as possible to achieve an impedance value close to 50Ω. The width, characteristic impedance and guided wavelength of slotline are calculated with procedures suggested in [18].

The stripline feed used in a Vivaldi antenna is either connected directly to the transmitter/ receiver circuitry or is fed by a coaxial cable attached to a connector. The stripline width and guided wavelength is calculated using formulas given in [19]. Hence the antenna parameters calculated are given in Table I.

Table I: Calculated Antenna Parameters All Units are in: mm

PARAMETER	FR4 SUBSTRATE
Low Frequency (GHZ)	3.1
High Frequency (GHZ)	10.6
Total Length	123.51
Total Width	96.77
Taper Length	96.77
Taper Width	48.39
Strip Length	5
Strip Width	1.3068
Slot Width	0.4113
Offset of Strip Length	7.38
Backwall Offset	5
Balun Length	7.38
Balun Width	7.38
Substrate Thickness	1.6

III. SIMULATION AND RESULTS

An optimum antenna design is achieved by the adjustment of the following parameters: flare angle and throat width to reduce the antenna ringing as much as possible.

For the 3.1–10.6 GHz operation, a tapered slot antenna design was developed. The design parameters of the proposed TSA and the fabricated parts are shown in Figure 1. The manufactured TSA was fabricated on FR4 material with a relative dielectric constant of 4.4, thickness of 1.6 mm and a loss tangent of 0.025. The top layer shows the microstrip line used for feeding the tapered slot antenna. The bottom layer indicates the exponential taper profile which is defined by the opening rate *R* and it is determined by the first and last point of the antenna.

The validity of the proposed design methodology is verified using CST simulator which is based on finite differential time domain and method of moments.

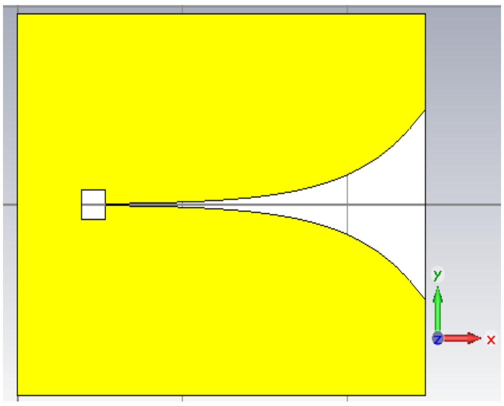

Figure 2(a): Front View of Vivaldi antenna

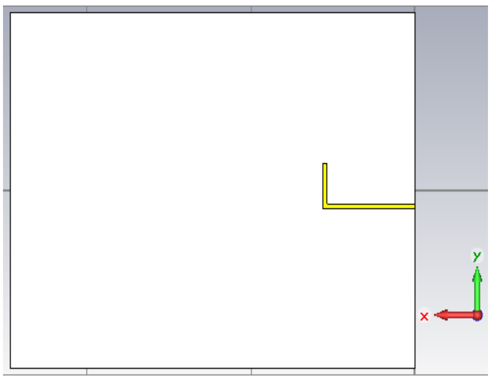

Figure 2(b): Back view of Vivaldi antenna

Figure 3 displays the simulated return loss versus frequency for the Vivaldi antenna. A return loss less than or equal to -10 dB is acceptable for operation. It is this -10 dB threshold that determines the operational bandwidth. For the Vivaldi antenna, the operational bandwidth extends from 3.5 GHz to 10.6 GHz and the return loss is above -10 dB.

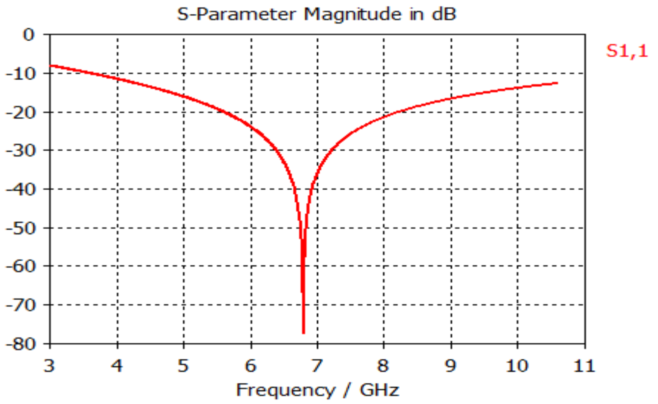

Figure 3: Simulated Return Loss of Tapered Slot Vivaldi Antenna

By further fine-tuning flare angle and throat width the bandwidth and return loss characteristics can be improved.

Then figure 4 displays the simulated voltage standing wave ratio (VSWR) versus frequency for the Vivaldi antenna. A VSWR must be less than 2.1in the specified frequency bands for the acceptable operation of an antenna. For the designed antenna VSWR is less than 2.1 for the frequency range of 3.5 to 10.6 GHz.

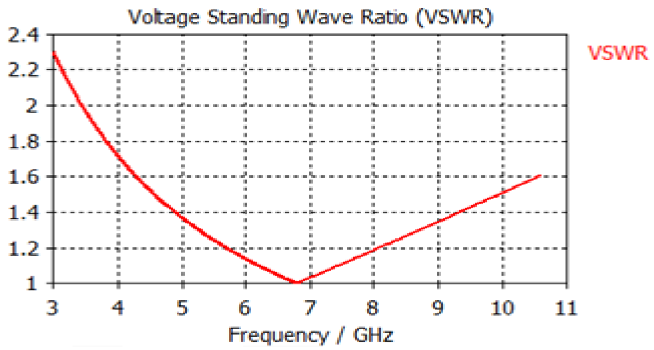

Figure 4: Simulated VSWR of Tapered Slot Vivaldi Antenna

IV. CONCLUSION

In this paper the design of tapered slot antenna for use in ultra-wideband applications has been given. A small tapered slot Vivaldi antenna is designed on a FR4 substrate with a dimension of 123.51 mm (L) * 96.77 mm (W). The designed antenna operates across the entire UWB spectrum with few locations that might cause problems if the dimensions were not precisely tuned. Backwall offset is the extra metallization fixed at the opening of the slotline. An increase or decrease in the backwall offset parameter result in abrupt changes in the return loss characteristics of the antenna. But the above condition is true only for certain values of backwall offset parameter. Antenna length must be greater than a free space wavelength at the lowest frequency of operation. This condition assures equally well gain and beamwidth performance.

The width of an antenna must be greater than the half wavelength. Any change in width results a change in the bandwidth of an antenna. Also the width controls the lower frequency of operation.

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