Antenna Design For Ground Penetrating Radar System

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Abstract - An optimised Vivaldi antenna is designed for lower band Ultra Wide Band (UWB) (0.5-1.5 GHz) to be used in ground penetrating radar system. In order to increase the penetration depth and minimize the interference of the radiated signal, lower band of UWB is explored. An exponentially tapered slot Vivaldi antenna was designed and simulated using Ansoft HFSS. Parameters of the Vivaldi antenna were varied and simulation results were measured and compared. A directive radiation performance with a peak gain which is more than 9dB and return loss below -10 dB in the desired band was achieved. Hence the developed antenna will be effectively used in detection of landmines.

Keywords: UWB, GPR, Tapered Slot Antenna, Slotline, Stripline, etc

I. INTRODUCTION

It is widely believed that the main breakthrough in Ground Penetrating Radar (GPR) hardware can be achieved in the antenna system. The family of tapered slot antennas (TSAs) are useful because they have a wide 10dB return loss bandwidth, are easy to fabricate on a variety of substrates, and have good radiation pattern characteristics with moderate gain of approximately 8 dB.

The Vivaldi is a tapered slot antenna characterised by an exponential flare shape. The flare radiates at different points along its length for different frequencies, determined by the flare width. The conventional flare design has theoretically unlimited bandwidth. In practice, the bandwidth is hard-limited by the physical dimensions of the antenna. The width at the start of the flare defines the upper frequency and the width at the mouth of the flare defines the lower frequency. [1]

The traditional form of Vivaldi antenna is fed from a strip line or microstrip circuit a transition is required. Such transitions can take a number of forms, but typically include quarter-wavelength sections. These limit overall antenna performance to a few octaves because of the frequency dependent nature of the transition. Vivaldi antenna is a plane directive antenna that is well known in literature due to its broad bandwidth, low cross polarization, and highly directive radiation performance. It is well suited for the UWB radar applications because of its ability of distorting the transmitted pulse shape as little as possible. The cost of producing a Vivaldi antenna is low because of its planar profile as it is a small flat antenna.

II. DESIGNING OF VIVALDI ANTENNA

The parametric study and design of single element Vivaldi antenna is studied in three different models: stripline model, stripline-slotline model and antenna from a strip line or microstrip circuit a transition is required. Such transitions can take a number of forms, but typically include quarter-wavelength sections. These limit overall antenna performance to a few octaves because of the frequency dependent nature of the transition. Vivaldi antenna is a plane directive antenna that is well known in literature due to its broad bandwidth, low cross polarization, and highly directive radiation performance. It is well suited for the UWB radar applications because of its ability of distorting the transmitted pulse shape as little as possible. The cost of producing a Vivaldi antenna is low because of its planar profile as it is a small flat antenna.

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 0.5-1.5GHz.

Fig.1 Vivaldi Antenna

The traditional form of Vivaldi antenna is fed from a slotline. To feed the slotline of the Vivaldi antenna
model. Stripline model includes the choice 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 parameters to be determined in the stripline-slotline model. Finally, the antenna model is constructed specifying the uniform slotline length, taper length and rate, mouth opening and the edge offset. As the electrical length of the antenna increases with frequency the gain increases. The length of antenna should be greater than $3\lambda_0$ and width should be greater than $\lambda_0$, where $\lambda_0$ is the free space wavelength at the center frequency. Taper design is described by opening rate, $R$, and end points of the taper, $P_1(x_1, y_1)$ and $P_2(x_2, y_2)$ shown in Figure 1. The following exponential relation defines the taper section. \[ x = c_1 e^{Ry_1} + c_2 \] \[ y = c_1 e^{Ry_1} + c_2 \]

Where,

\[ c_1 = \frac{x_2 - x_1}{e^{Ry_1} - e^{Ry_2}} \]
\[ c_2 = \frac{x_1 e^{Ry_1} - x_2 e^{Ry_2}}{e^{Ry_1} - e^{Ry_2}} \]

The choice of a dielectric substrate is one of the most important aspects of the design of a Vivaldi antenna. The key characteristics of a substrate material are its dielectric constant, loss tangent, and the thickness of the dielectric. Two different substrate materials were chosen, one with lower and higher dielectric to study their effect on antenna performance. Thus substrate FR4 with dielectric constant 4.4 and Roger Duroid 5870 with dielectric constant 2.33 are used to study their effects. Effective thickness of the dielectric substrate ($t_{eff}$) need to be defined as follows [3]

\[ \frac{t_{eff}}{\lambda_0} = (\sqrt{\varepsilon_r} - 1) \frac{t}{\lambda_0} \]

(2)

Where, $\lambda_0$ is the free space wavelength at the center frequency, $t$ is the thickness and $\varepsilon_r$ is the dielectric constant of the substrate. The necessary condition for a TSA to possess travelling wave antenna characteristics is [3]

\[ 0.005 \leq \frac{t_{eff}}{\lambda_0} \leq 0.03 \]

(3)

In order to obtain a transition that has low return loss over a wide frequency band, the impedances of the microstrip line and the slot line should be matched to each other to minimize the reflections. The characteristic impedance of a slot line increases with increasing slot width, so the width of slotline should be chosen to be as small as possible to obtain an impedance value close to 50Ω. The width, characteristic impedance and guided wavelength of slotline are calculated with formulas proposed in [4] for each substrate material.

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 [5]. Hence the antenna parameters calculated are given in Table I.

### Table I

<table>
<thead>
<tr>
<th>Parameter</th>
<th>FR4 (mm)</th>
<th>Roger Duroid 5870 (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna length</td>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td>Antenna width</td>
<td>400</td>
<td>300</td>
</tr>
<tr>
<td>Slotline width</td>
<td>1.5</td>
<td>0.45</td>
</tr>
<tr>
<td>Stripline width</td>
<td>1.4</td>
<td>2.5</td>
</tr>
<tr>
<td>Taper length</td>
<td>390.31</td>
<td>531</td>
</tr>
<tr>
<td>Mouth opening</td>
<td>385</td>
<td>150</td>
</tr>
<tr>
<td>Substrate thickness</td>
<td>3.2</td>
<td>3.15</td>
</tr>
</tbody>
</table>

### III. SIMULATION AND RESULTS

The antenna was designed using values that have been calculated above. First, the effect of changes in antenna length on the wideband return loss performance of Vivaldi antenna was observed. Three different antenna lengths of 595 mm, 600 mm and 605 mm were considered for both substrate materials. In case of Rogers, antenna length of 600 mm possesses the best overall wideband return loss performance in the given frequency range while in case of FR4 it came out to be 595 mm.
Fig. 3 Varying Antenna Length in Roger

Secondly, the effect of change in antenna width also affects the return loss performance of the antenna. Hence the antenna width was varied and the performance of antenna was observed.

The optimised value for Antenna width for FR4 came out to be 430mm while the same for Roger is 300mm.

The slotline width was also varied to achieve proper impedance matching with stripline. The slotline widths considered in FR4 substrate based antenna were 1.5, 2 and 2.5 mm while 0.45, 1.45 and 2.45 mm were considered for the Roger Duroid 5870 substrate based antenna.

So, slotline for FR4 should be taken as 2mm while for Roger it comes out to be around 1.45mm.

The effect of Backwall offset on the return loss of antenna was observed. Backwall offset can be varied by varying the Taper length of the antenna. Three different values of Taper length were considered for both substrate materials. The antenna was simulated and the results obtained are shown in figure 8 and 9.
Mouth opening is the maximum width of the tapered slotline section. Three different values of mouth opening were considered for both substrate materials. The antenna was simulated and the results obtained are shown in figure 10 and 11.

The optimised values of the antenna parameters for both the substrate were obtained. They are as shown in the Table II.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>FR4 (mm)</th>
<th>Roger Duroid 5870(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna length</td>
<td>595</td>
<td>600</td>
</tr>
<tr>
<td>Antenna width</td>
<td>430</td>
<td>300</td>
</tr>
<tr>
<td>Slotline width</td>
<td>2</td>
<td>1.45</td>
</tr>
<tr>
<td>Stripline</td>
<td>1.4</td>
<td>2.5</td>
</tr>
<tr>
<td>Taper Length</td>
<td>390.31</td>
<td>531</td>
</tr>
<tr>
<td>Mouth opening</td>
<td>400</td>
<td>150</td>
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<tr>
<td>Substrate thickness</td>
<td>3.2</td>
<td>3.15</td>
</tr>
</tbody>
</table>

IV. CONCLUSION

Backwall offset is the extra metallization planted at the beginning of the slotline to prevent the currents in this section coming across an abrupt end. Backwall offset is a parameter to be optimized which means any change (increase/decrease) from the optimum value ends up with deterioration in return loss response of the antenna.

An increase in the backwall offset results in an improvement in the lowest operating frequencies of the band. This effect is significant only up to a certain value, after which additional increments have no significant improvement on the return loss of a given Vivaldi antenna.

Antenna length should be greater than a free space wavelength at the lowest frequency of operation. This requirement guarantees fairly well gain and beamwidth performance.
The mouth opening shall be of the order of one-half wavelength, at least, in order to improve radiation efficiency through the antenna. It was observed that the bandwidth of the antenna was increasing with increase in the mouth opening.

Antenna width shall be greater than one-half wavelength at the lowest frequency of operation, so as to accomplish the desired radiation performance. Decreasing antenna width below this value decreases the lowest frequency of operation, thus the antenna bandwidth considerably.

V. REFERENCES


[4] R. Janaswam, Student Member, D.H. Schaubert, Senior Member “Characteristic Impedance of a Wide Slot Line on Low Permittivity Substrates” Department of Electrical and Computer Engineering University of Massachusetts Amherst, MA 01003.