Design and Development of a wide band Vivaldi Antenna Element for GPR

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Abstract:
The objective of this paper is to design and develop a wide band Vivaldi antenna element for Ground Penetrating Radar applications. The antenna is required to operate from 450 MHz to 3000 MHz. Element consists of an exponentially tapered slot, which radiates the wave by traveling wave principle and a microstrip feed line. The transition from microstrip feed line to slot transmission line has been done with microstrip open stub and slot line short stub. The suitable exponential taper has been employed to get proper radiation and good impedance matching. The proposed antenna has been designed and optimised for its electrical performance and dimension by means of electromagnetic solver HFSS based on finite element method (FEM). The simulated results of the Vivaldi antenna element are in excellent agreement with the required ones, with a return loss better than –10 dB over the whole frequency band of 2550 MHz.

I. INTRODUCTION
Ultra-wide-band (UWB) antennas have an increasing demand in communication, radar, and EMI/EMC measurement systems. The antennas for such systems must be compact and lightweight for portability. Besides the requirement on their compact size, gain stability, low cross polarization and broad bandwidth must be considered. This paper presents, Vivaldi element antenna because of its favorable characteristics for UWB application, and specifically they have relatively simple structure, light weight, and small lateral dimensions, wideband, high efficiency, and high gain characteristics. Vivaldi antenna provides a smooth transition between the guided wave travelling in the slot transmission line and the plane wave, which is radiated. This transition has been done by a gradual tapering of the slot line. Desired impedance and pattern band widths have been achieved by optimizing length, width and the tapered shape of aperture.

II. VIVALDI ANTENNA ELEMENT

Vivaldi antennas designed using thin substrates with high dielectric constant would result in smaller size. But this also decreases the efficiency and bandwidth. Therefore, there must be a design trade-off between antenna size and good antenna performance. There are basically two types of losses that occur in this type of antenna, the conductor and the dielectric losses, both of which increase with frequency. Dielectric loss is related to the fact that all dielectrics contain polarized molecules that move in the presence of EM fields. High frequency fields oscillate very quickly and as the polar molecules move in sync with the field, they begin to heat the dielectric material. There is only one possible source for the heat i.e. the energy of the signal itself. It turns out that dielectric loss increases relentlessly with higher frequencies and in direct proportion to signal frequency. Hence, to keep the dielectric losses low at the frequency of operation, FR4 epoxy material of thickness 2.4 mm with a relatively low-dielectric $\varepsilon_r = 4.4$ and low loss-tangent (0.009) was chosen for this design. Proposed antenna has been designed and optimized in HFSS for required antenna characteristics. The HFSS model is shown in figure 2. The bottom layer shows the microstrip line and the series radial stub used for feeding the tapered slot antenna. The top layer indicates the exponential tapered profile radiating element.

The exponential taper is defined by the opening rate $R$ and starting point $P_1(x_1, z_1)$ and end point $P_2(x_2, z_2)$ of the taper as given in equation below. This is shown below in figure 1

$$x = C_1e^{Rz} + C_2$$

where

$$C_1 = \frac{x_2 - x_1}{e^{Rz_2} - e^{Rz_1}}$$

$$C_2 = \frac{x_1 e^{Rz_2} - x_2 e^{Rz_1}}{e^{Rz_2} - e^{Rz_1}}$$

The length and the width of the tapered slotline to achieve the traveling wave mode of radiation generally need to be greater than $\lambda_0$ and $\lambda_0/2$ respectively at lowest frequency of operation.
To achieve a broadband transition, the microstrip open stub and the slot line short stub are to present a virtual short and a virtual open at the point of transition, respectively. To that end, the radius of the radial microstrip stub and the diameter of the circular slot stub may be approximated by $\frac{\lambda_m}{4}$ and $\frac{\lambda_s}{4}$, respectively. The $\lambda_m$ is the effective wavelength of the microstrip and $\lambda_s$ is the effective wavelength in the slot line.

In the proposed design initially the following dimensions were taken as design parameters.
- Flared slot line length is $30 \text{ cm/} 0.45 \text{ GHz} = 667 \text{ mm}$.
- Flared slot line width is $0.5 \times 30 \text{ cm/} 0.45 \text{ GHz} = 333 \text{ mm}$.

But these length and width have been optimized further to make it compact and are 430 mm and 282 mm which are much less than $\lambda_0$ and $\lambda_0/2$ at 450 MHz The simulation model and photograph are shown in figure 2 and figure 3 respectively.

Figure 1: Schematic of Vivaldi Antenna

Figure 2: Simulation model of Vivaldi Antenna

Figure 3: Photograph of Vivaldi Antenna
RESULTS

The simulated and measured results are shown here for the proposed design. The simulated return loss is better than -10 dB over whole frequency band of 2550 MHz. The 3dB beam widths in E and H plane at centre frequency are 48° and 65° respectively. The measured return loss is better than -10 dB from 450 MHz to 3 GHz and 3dB beam widths in E and H plane at centre frequency are 53° and 68° respectively. The gain was measured in an anechoic chamber from 450 MHz to 3 GHz and it is 6.5 dB at centre frequency of operation.

Figure 4: Simulated Return Loss

Figure 5: Measured Return Loss

Figure 6: Simulated E and H Plane Pattern

Figure 7: Measured E Plane Pattern

Figure 8: Measured H Plane Pattern
CONCLUSION

A wide band Vivaldi element has been designed which meets all the design goals. The measured VSWR < 2 from 450 MHz to 3 GHz, the broadside gain 6.5 dB at centre frequency and E & H plane HPBW 53° and 68° respectively have been achieved. Hence this element may be suitable for Ground Penetrating Radar applications.

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BIO-DATA OF AUTHORS

V S Gangwar was born in 1978 and obtained his Bachelor of Engineering degree in Electronics & Communication engineering from the Dr. B R Ambedkar University Agra in 2003. From 2004 to 2005 he was lecturer in E & C Engineering Department at BMAS Engineering College Agra. In 2005 he joined DRDO, LRDE Bangalore as a scientist and started carrier in the area of RF and Microwave sub-Systems. He is currently involved in design, development, evaluation and calibration of active and digital phased array antenna systems for various kinds of Radars. For his significant contribution in establishing active array calibration technique, DRDO conferred upon him Technology Group Award in the year 2008.

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Dr. A K Singh obtained his Ph.D. in 1991 in electronics engineering from Banaras Hindu University, Varanasi (INDIA). He joined Electronics & Radar Development Establishment (LRDE), Bangalore in November 1991 and presently heading the R&D group involved in the design & development of 3D Low Level Active Aperture Radar and Antenna / Array Antenna systems for various radar applications which includes medium range / long range 3D / 4D radar systems, airborne fire control radar systems, naval combat control radar, remote sensing, SAR for UAVs and antenna systems for LIC radars.

He has served as a chairman of technical program committee of International Radar Symposium (India) (IRSI-2007), Co-chairman, technical program committee of IEEE International Symposium on Microwaves in 2008, international correspondent & member of IEEE Radar conference (France) in 2009 and member of various other international & National conference. He has authored more than 90 research papers in different international / national journals and symposiums. He has 3 copyrights and 3 patents to his credit. For his novel invention & significant contributions, he has been awarded NRDC (National Research Development Corporation) meritorious invention award in 1997, DRDO National Science Day commendation in 2005, DRDO Technology Group Award in 2006, DRDO performance excellence award in 2008 and IETE-IRSI award in 2009. He is member of society of electronics engineers and a Fellow of IETE.