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Radiating Flare Design of Tapered Slot Loaded Vivaldi Antenna Using Fourier Series Approach

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Abstract*— Federal communication commission has allocated a band from 3.1 GHz to 10.6 GHz for ultra wide band (UWB) applications. An antenna designed for UWB applications should be capable of offering a higher bandwidth, with minimum distortion of signals. One such antenna that satisfies this criterion is the Vivaldi antenna. The gain offered by a conventional exponentially tapered Vivaldi prototype is less, particularly at a lower giga hertz of frequencies. As the gain is dependent on the geometry of the radiating flare, an improvement in the gain is achieved by removing the restriction on the geometry of the flare. An antenna designed using Fourier series takes an optimized shape, such that the condition of maximum gain and minimum return loss is achieved corresponding to the design frequency. Antenna performance obtained from the simulation result and hardware prototype measurements shows a good agreement thereby verifying the design concept.

***Index Terms*— Ultra wide band, Vivaldi Antenna, Fourier series, gain, Radiation flare.**

I. INTRODUCTION

Any radio technology which uses a band that is 20% of the center frequency or which uses a bandwidth greater than 500MHz comes under ultra wide band electronic system. An antenna designed for UWB applications should radiate and receive pulses with minimum distortion. Tapered slot antennas (TSAs) are the best candidates for UWB applications. These antennas offer a wider bandwidth, significant gain and symmetrical patterns. TSAs are efficient light weight and appreciably simple in geometry making them more advantageous. The main three types of TSAs are linearly tapered slot antenna (LTSA), constant width slot antenna (CWSA) and exponentially tapered slot antenna referred to as Vivaldi antenna. As a member of class of TSA, Vivaldi antennas provide broad bandwidth, less cross polarization and directional propagation at microwave frequencies. Vivaldi antenna consists of a gradually widening slot etched on a metallic plate which in turn is supported by a substrate material. In a conventional Vivaldi prototype, the metallic flare takes the shape of an exponential profile. When the permittivity is very large or when the slot width is very small the wave will be confined within the metallic flare and as the slot width widens the permittivity value gets reduced resulting in radiation along the end fire direction.

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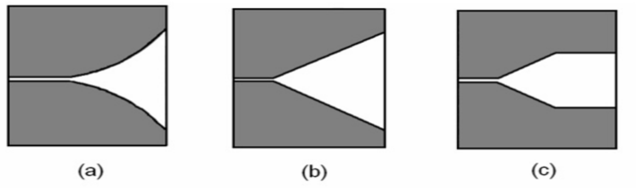

Figure 1. Types of TSA; (a) Exponentially tapered (Vivaldi), (b) Linearly tapered (LTSA) and (c)constant width slot antenna (CWSA)

One of the main advantages of this antenna is that almost all antenna parameters are completely dependent on the geometry of the radiating flare. Unlimited bandwidth is provided by continuous scaling and gradual widening of the taper. The lower cut off frequency that can be radiated is determined by the wider end of the slot and the upper cut off by the slot width at the taper throat end. The gain of the antenna is decided by the length of the taper. Vivaldi antenna comes under the class of planar travelling wave antenna which radiates along the end fire direction that is from the wider end of the slot. Many works have been reported on the Vivaldi antennas which includes the study on, methods to enhance antenna parameters like gain, bandwidth, return loss etc and some application specific works[2-5]. Even though many works have been reported, most of them are restricted to the one having an exponential profile. In this paper the design of radiating flare of a Vivaldi like antenna is dealt so as to achieve an objective of maximum gain and minimum return loss for a design frequency of 2.8GHz. Work is carried out using high frequency structure simulator (HFSS) software using the scripting environment where a visual basic script is used for modeling and simulations. The organization of the paper is as follows. Introduction on the Vivaldi antennas. Section II focuses on the design details of a conventional exponentially tapered slot Vivaldi antenna. Proposed methodology, antenna flare optimization and simulation results are discussed in section III , IV and V respectively. Hardware prototype and corresponding measurements made are focused on section VI. Finally the paper is concluded in section VII.

II. EXPONENTIALLY TAPERED VIVALDI ANTENNA

As the name suggest the variation of the taper follows an exponential profile. The design equation for the radiating flare is given by

$$y = Ae^{px} + B \qquad (1)$$

where A, B and p represent constant values. Maximum value of x determines the total length of the antenna and y represents the distance of the inner portion of the flare from the centre of the slot.

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The rate at which exponential flare tapers is given by the value of p.

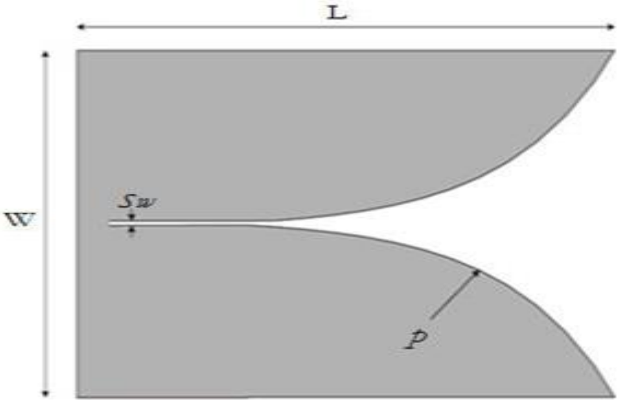

Figure 2. Schematic of the tapered slot Vivaldi antenna design and variables

Figure. 2 shows an exponentially tapered slot Vivaldi antenna for the values of A, B and p as 0.55, 0.45 and 0.09 respectively [1]. The effective thickness of the substrate material should lie within the range [6]

$$0.005\lambda_0 \le t_{eff} \le 0.03\lambda_0 \qquad (2)$$

where t_{eff} is given by

$$t_{eff} = (\sqrt{\varepsilon_r} - 1)t \qquad (3)$$

Where t is the thickness of the substrate and ε_r the relative permittivity of the substrate. When the effective thickness becomes less than the lower bound, the antenna structure becomes mechanically fragile and when it crosses the upper bound the dielectric loss starts to increase. With this geometry the gain offered by the antenna is very less particularly at lower giga hertz of frequencies. This drawback of the conventional structure can be overcome by the proper selection of flare geometry. As the gain of the antenna is dependent on the geometry of the profile, a much improved gain could be realized by removing this restriction on the geometry of the flare. That is, instead of restricting the geometry to an exponential profile, it could take any shape that can provide maximum gain and minimum return loss, corresponding to the design frequency. This paper presents a new design methodology, where the restriction on the shape of the geometry is removed.

III. PARAMETRIC MODELING OF RADIATING FLARE USING FOURIER SERIES APPROACH

The restricted design geometry of an exponentially tapered radiating flare can be overcome by the use of Fourier series approach. In general radiating flare is a closed contour and any complex closed structure can be easily represented using Fourier series approach. The parametric modeling of the radiating flare as a function of r and θ is given by

$$x(\theta) = r\cos(\theta) \qquad (4)$$

$$y(\theta) = r\sin\theta \qquad (5)$$

$$r = \sqrt{x_\theta^2 + y_\theta^2} \qquad (6)$$

$$x_\theta = \sum_{k=0}^{n} a_k \cos(kd\cos\theta) - b_k \sin(kd\cos\theta) \qquad (7)$$

$$y_\theta = \sum_{k=0}^{n} b_k \cos(kd\cos\theta) + a_k \sin(kd\cos\theta) \qquad (8)$$

Where a_k and b_k represent Fourier series coefficients, θ can be varied from –π/2 to π/2, d can take any value which is a multiple of π and n is the total number of Fourier series coefficients considered. It should be noted that as the value of n increases the complexity of the flare increases. The flare must take a shape such that, corresponding to the design frequency, returns loss is minimized and gain is maximized. The gain considered is the gain along the end fire direction, that is along the direction θ =π/2 and Φ=π2. Hence the Fourier coefficients must take a value such that the above mentioned objectives are satisfied.

IV. ANTENNA FLARE GEOMETRY OPTIMISATION

The objective of using Fourier series approach for the design of the radiating flare is that, the gain along the end fire direction [θ=π/2, Φ=π/2] is maximized. The gain and return loss values are dependent on the geometry of the profile and it is designed using Fourier series approach. The factor which determines the shape of the profile is the Fourier series coefficients. Hence the aim is to find all sets of Fourier series coefficients which can result in a shape which in turn can provide maximum gain and minimum return loss, corresponding to the design frequency. Hence the problem of optimization is to optimize the parameters a_ks and b_ks such that it results in a shape that can satisfy the above mentioned objectives. Optimization is carried out using the optimetrics tool of high frequency structure simulator software (HFSS) and the optimization algorithm chosen is the genetic algorithm. Genetic algorithm is a search method used to find true and approximate values of an optimization problem. It is a tool which uses the concept of evolutionary biology like selection, crossover and mutation to find the optimized values. For the simulation purpose a solution frequency of 2.8GHz is set with a total of four coefficients considered. The substrate material used is FR4_Epoxy whose permittivity value is 4.4 and loss tangent is 0.002. Table I gives the final optimized values of the Fourier coefficients the use of which results in an antenna flare as shown in the Figure. 3. Optimized antenna structure has an overall dimension of 79 by 126 mm with a substrate thickness of 4.5mm.

Table 1: Optimized Fourier series coefficients of simulated antenna

Fourier coefficients	Optimized Values
a_0	0.004692
a_1	0.001370
a_2	0.002922
a_3	0.003194
b_0	0.002065
b_1	0.065409
b_2	0.009054
b_3	0.005240

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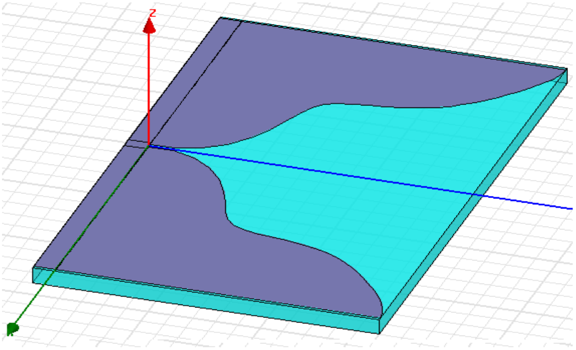


Figure 3. Simulated Vivaldi like antenna using Fourier series approach

V. SIMULATION RESULTS

To check the validity of the proposed concept a set of simulations were carried out using Ansys HFSS and various parameters like return loss, gain and radiation patterns were studied. Solution frequency was set at 2.8GHz and the source model considered is delta gap source model. In delta gap source model the voltage applied is assumed to be a delta function and it is applied to a small gap, at the taper throat end between the two metallic flares. Application of voltage results in an impressed field connecting the two metallic flares resulting in accumulation of charges.

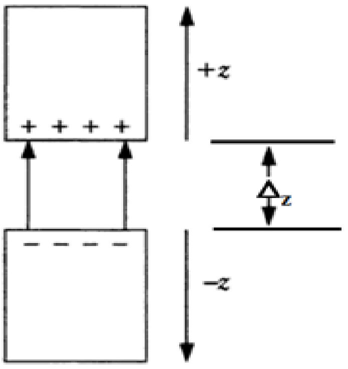


Figure 4. Delta gap source model used for the simulation of antenna

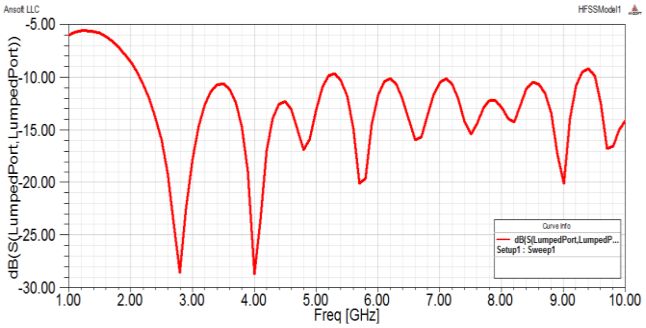


Figure 5. Simulated return loss plot of optimized antenna structure

For the better performance of the antenna the return loss value should be less than -10dB over the entire band of frequencies and should have a minimum value corresponding to the design frequency. In this case a return loss value of less than -10dB is achieved over a range of frequencies from 2.1GHz to 9.2GHz thereby offering an impedance bandwidth of 7.1GHz which is well suited for UWB applications. Also a minimum is achieved at a frequency corresponding to 2.8GHz which is the design frequency. From the figure 5 it is clear that antenna is resonating at multiple points thereby satisfying the requirements of a travelling wave antenna.

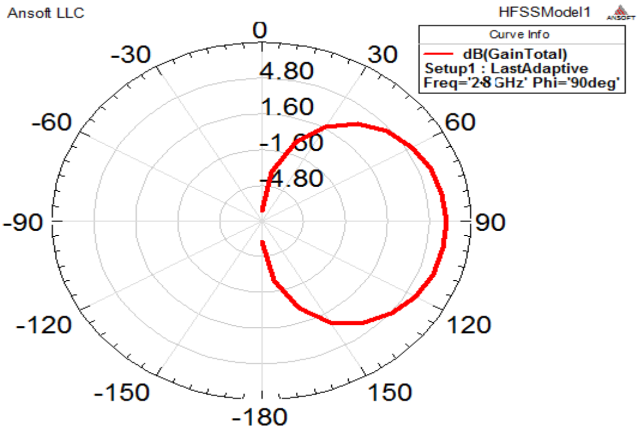
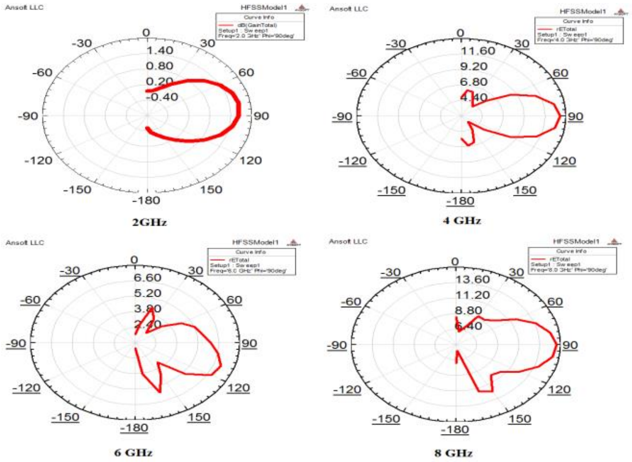


Figure 6. Simulated two dimensional radiation pattern showing gain at theta and phi equal to π/2 corresponding to a frequency of 2.8 GHz



2GHz 4 GHz

6 GHz 8 GHz

Figure 7. Simulated 2-D radiation pattern (Electric field) of the antenna

Figure. 6 shows the two dimensional radiation pattern plot of the antenna at a design frequency of 2.8GHz. Here the antenna is having a maximum radiation along the direction θ=π/2 and Φ=π/2 thereby satisfying the end fire radiating property of the Vivaldi antenna. Figure. 7 shows the radiation pattern corresponding to 2, 4, 6 and 8GHz. At these frequencies also the antenna is having peak radiation along the end fire direction.

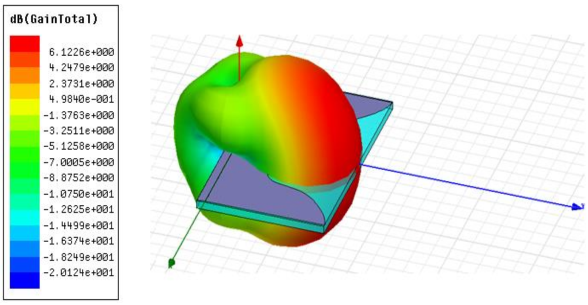


Figure 8. Simulated 3-D polar radiation pattern (gain) of the antenna

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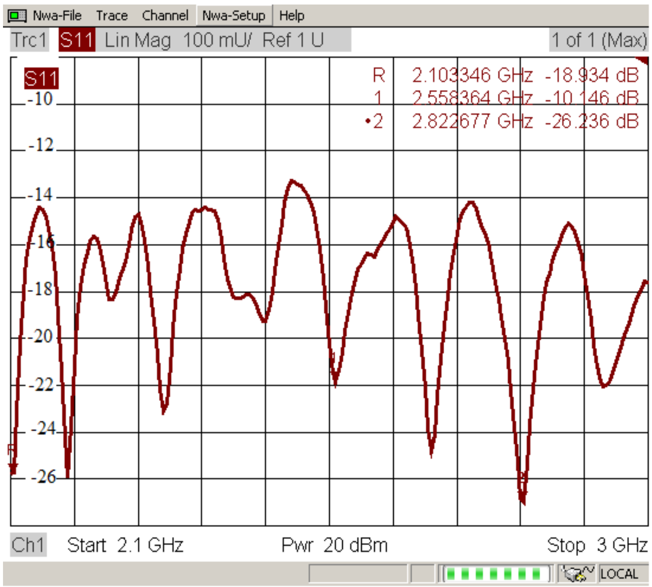
Figure. 8 shows the three dimensional polar radiation pattern plot of the antenna along with the optimized antenna structure. Antenna is radiating along the end fire direction from the wider end of the slot with a peak gain of about 6.1226dB. Conventional exponentially tapered antenna designed for a solution frequency of 2.8 GHz could offer a gain of only 2.5dB. Thus the antenna designed using Fourier series resulted in an improvement in gain by a factor of 4dB.

VI. HARDWARE PROTOTYPE

To check the agreement of the practical antenna structure with the simulation results a hardware prototype was made. Figure. 9 shows the hardware prototype made.

Figure 9. Hardware prototype of the optimized antenna structure

Parameters like return loss and radiation pattern were measured with a network analyser which again serves as the signal source. Source frequency is set at 2.8GHz and the signal is fed to the antenna using a coaxial cable.



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R   2.103346 GHz  -18.934 dB
1   2.558364 GHz  -10.146 dB
•2  2.822677 GHz  -26.236 dB
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Figure 10. Return loss characteristics of the optimized antenna prototype

Figure. 10 shows the return loss characteristics measured. It can be noted that minimum value of return loss is achieved over a frequency corresponding to 2.8GHz which is almost same as that of the one achieved in the simulation result. Also the antenna is resonating at multiple points thereby showing an agreement between the simulation results and the hardware prototype.

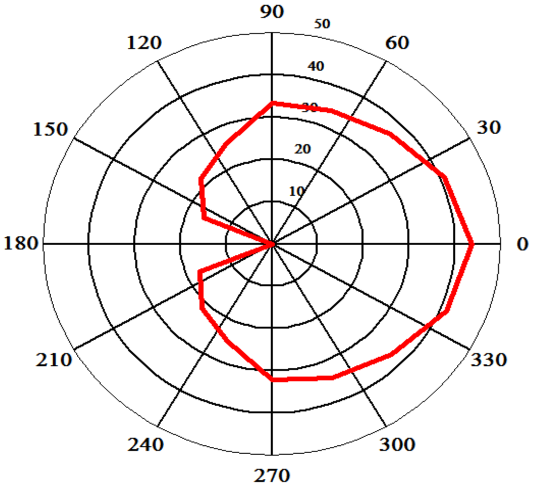

Figure 11. Two dimensional radiation pattern plot

The radiation pattern of the antenna measured is shown in Figure. 11. Two similar antennas were used as transmitting and receiving antenna, and the radiation pattern is measured varying the angle of alignment between the transmitting and receiving antenna. It is clear from the figure that antenna is having maximum radiation along endfire direction thereby satisfying the requirement of Vivaldi antenna. Thus simulation result and hardware prototype shows a good agreement thereby verifying the design concepts.

VII. CONCLUSION

This paper presents the design of a radiating flare of Vivaldi like antenna using the concept of Fourier series. Here the geometry of the antenna is not fixed and it can take any shape which can provide a maximum gain and minimum return loss corresponding to the design frequency. With the design frequency set at 2.8GHz the antenna was capable of providing a bandwidth of 7.1GHz with a peak gain of 6.1226dB along the end-fire direction, thereby making it a best candidate for the use in UWB applications. Simulation results and hardware prototype measurement shows a good agreement thereby verifying the design concepts

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REFERENCES

1. D.Ziani Kerarti, F.Z Marouf and S.M. Meriah, “New Tapered Slot Vivaldi antenna for UWB Applications in,” *24th International Conference on Microelectronics (ICM)}*, 2012.
2. Li Tianming, Rao Yuping and Niu Zhongxia, Analysis and Design of UWB Vivaldi Antenna, in *IEEE International Symposium on Microwave, Antenna, Propagation, and EMC Technologies For Wireless Communications*, 2007
3. Aaron Zachary Hood, Tutku Karacolak and Erdem Topsakal, A small antipodal Vivaldi antenna for ultra wide band application, in *IEEE Antennas And Wireless Propagation Letters*, vol. 7, pp. 656--660, 2008.

4. Satoru Sugawara, Yutaka Maita, Kazuhiko Adachi, Koji Mori and Koji Mizuno, Characteristics Of A MM-Wave Tapered Slot Antenna With Corrugated Edges, in IEEE MTT-S Digest, WE2A--5, 1998.
5. Dalia M. Elsheakh and Esmat A. Abdallah, Novel Shapes of Vivaldi Antenna for Ground Penetrating Radar (GPR), in *7th European Conference on Antennas and Propagation,* 2013
6. Jeremy B. Muldavin and Gabriel M. Rebeiz, Millimeter-Wave Tapered-Slot Antennas on Synthesized Low Permittivity Substrates, in *IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, , vol. 47, pages 1276--1280,* July 15--17, 2009.

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