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Some Parametric studies on Vivaldi Antenna

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Abstract

Purpose of this paper is to study parametrically the impedance and radiation characteristics of a Vivaldi Antenna [1]. Usually, the performance of Vivaldi is sensitive to the parameters, the effects of major geometry parameters of the radiators and feeding transition on antenna performance are investigated across the frequency range of 3.1 to 10.6 GHz. The Vivaldi elements are fed by broadband microstrip-to-slotline baluns. A 2:1 bandwidth (3.4 to 7 GHz) was achieved for VSWR, gain and cross-polarization isolation. The design iteration, simulations results are presented. The information derived from this study provides guidelines for the design and optimization of the Vivaldi antenna which are widely used for UWB applications.

Keywords: *TSA, Vivaldi, Ultra wide band antenna, HFSS Simulation software*

1. Introduction

The co channel interference and multipath effects of wireless communication systems can be reduced by using directional antennas. Some of the current point-to-multipoint systems are using horn antennas for this reason, but the horn antennas are too bulky to be integrated with the rest of the wireless packages and suffer high cost of fabrication. Tapered slot antennas (Vivaldi antenna) have been widely used in phased and active arrays for radar systems. They are good candidates for multifunction communication applications because of their stable directional patterns and consistent impedance matching over a very broad operating frequency range without any tuning elements as well as low profile and unobtrusive planar structures. Therefore, they have been proposed for emerging UWB wireless communications and radar applications.

2. Antenna Geometry

Briefly, the traveling wave mode Vivaldi antenna provides a smooth transition between the guided wave traveling in the slot transmission line (slotline) and the plane wave, which is radiated. This transition is achieved by a gradual tapering of the slotline. Since the slot-line is a balanced transmission line, a wide-band balun is an important component in the antenna design. Vivaldi with a microstrip feed is provided in Fig. 1. The microstrip line is printed on a substrate and the tapered slotline is etched on the ground plane below the microstrip. A few parameters are considered to be of great importance for satisfactory wideband performance: The length and the width of the tapered slot line: to achieve the traveling wave mode of radiation, the slot length and width generally needs to be greater than λ_0 and $\lambda_0/2$, respectively. The opening rate of the tapered slot line: the Vivaldi antenna employs an exponential taper. The coordinates of the tapered slot are defined by:

$$x = C1\, e^{Rz} + C2$$

Where

$$C1 = \frac{(x2 - x1)}{(e^{Rz2} - e^{Rz1})}$$

$$C2 = \frac{(x1 e^{Rz2} - x2 e^{RZ1})}{(e^{Rz2} - e^{RZ1})}$$

The points (x1,z1) and (x2,z2) are the end points of the flare and R is the variable that changes the rate of the opening. The performance of the antenna is very dependent on R.The dimensions of the microstrip-to-slotline (M-S) transition: To achieve a broadband transition, the microstrip open stub and the slotline 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 (Rrad) and the diameter of the circular slot stub (Ds) may be approximated by $\lambda_m/4$ and $\lambda_s/4$, respectively. The λ_m is the effective wavelength of the microstrip and λ_s is the effective wavelength in the slot line.

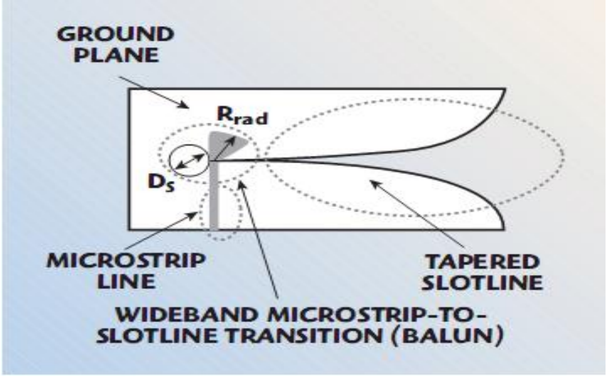

Figure 1. Schematic of a Typical Vivaldi

3. Design Goal and Procedure

The goals for this design are as follows: VSWR less than 2 from 3.4 to 6 GHz. Broadside pattern with gain greater than 4 dBi from 3.4 to 6 GHz. Broadside cross-polarization isolation greater than 10 dB from 3.4 to 6 GHz. Determine the antenna length and width based on the traveling wave design requirements: Recall that the slot line length and width generally needs to be greater than λ_0 and $\lambda_0/2$ at the lowest frequency, respectively. Select a board material: A treatment of the effect of the dielectric on the performance of the Vivaldi antenna is given in Kasturi, et al.[4]. Design the microstrip-to-slotline transition for the required frequency range with S_{11} less than –15 dB. The characteristic impedance Z_0 of the slot line and the port impedance may be varied for best S_{11}. Connect the M-S transition to the tapered slot line, Vary the opening rate until the VSWR,gain and cross-polarization specifications are met [2]. Re-optimize the M-S transition if necessary. Design a microstrip tapered line to match the Z_0 of the microstrip to 50 Ω.

4. Design Process and Simulation Results

Following the design procedure, the following dimensions were determined: Flared slot line length, f_l =30 cm/3.4 GHz = 8.8 cm. Flared slot line width, f_w = 0.5 • 30 cm/3.4 GHz = 4.4 cm. The antenna width (aw) was set at 4 cm. The f_w was set at 3.6 cm such that the ends of the taper are 0.2 cm away from the top and bottom edges. A Rogers RO4003C (εr = 3.38, tanδ= 0.027) board, 60-mil thick, was selected [4]. Next, the M-S transition was designed on a RO4003C board. A pair of M-S transitions was simulated in HFSS and the results were found to be satisfactory. Fig. 2 shows the configuration of a pair of M-S transitions. The dimensions were as follows: D_s = 1 cm, R_{rad} = 0.8 cm (90° radial stub), slot line gap (S_g) = 0.1 cm. The result of the simulation shows that the S_{11} of the pair of the M-S transition is below –14 dB in the 3.4 to 7 GHz range, as shown in Fig.3.The next step was to integrate the M-S transition with the tapered slot[3]. The opening rate R was varied until the VSWR was found to be less than 2 in the frequency range of interest. The gain and cross-polarization isolation were then verified at a few frequency points. It was decided that R = 2 is the optimum opening rate [5]. The effect of R on the antenna VSWR is shown in Fig.4. A properly tapered microstrip line was designed for a 50 Ω nominal input impedance. The resulting Vivaldi element is shown in Figure 5.

5. Radiation Characteristics

The simulated far field radiation patterns, co- and cross-polarization for both planes E-plane and H-plane, are shown in Figure 9 to Figure14.

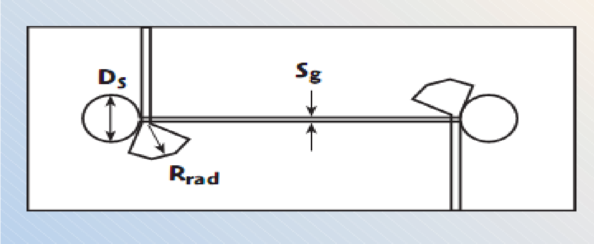

Figure 2. A Pair of M-S Transition

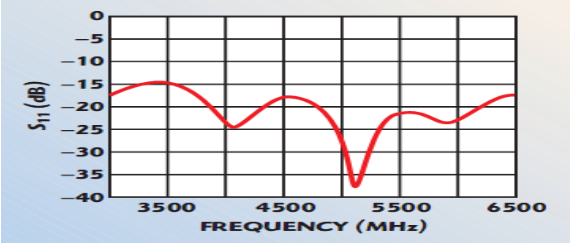

Figure 3. Return Loss of a Pair of M-S Transitions

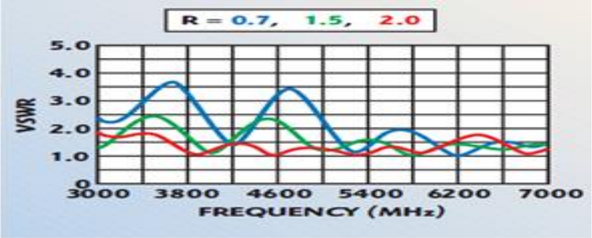

Figure 4. Dependence of a Vivaldi antenna VSWR upon R

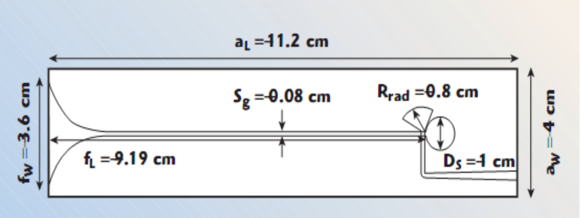

Figure 5. Vivaldi Antenna Element

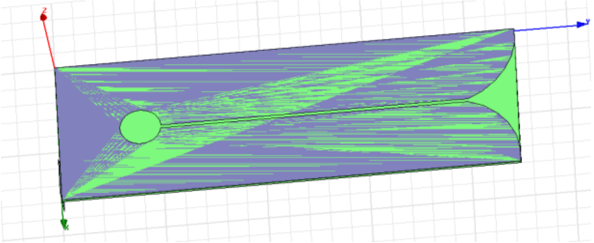

Figure 6. Top View of Simulated Vivaldi Antenna

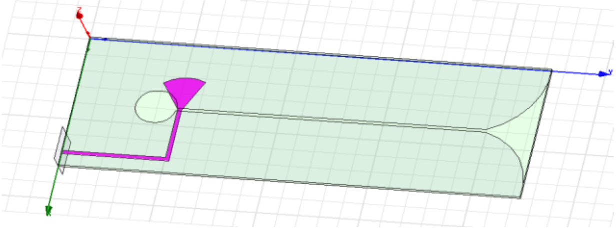

Figure 7. Fed Arrangement of Simulated Vivaldi

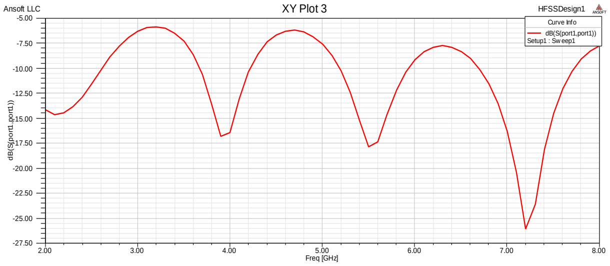

Figure 8. Return Loss of Vivaldi Antenna

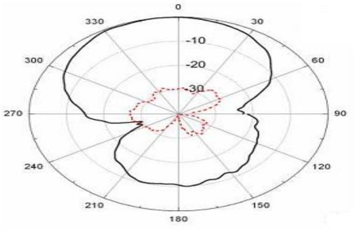

Figure 9. E-plane Pattern at 4 GHz

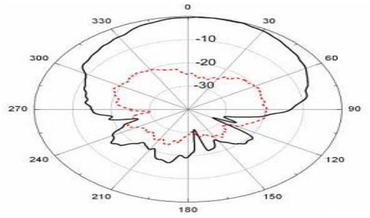

Figure 10. E-plane Pattern at 5.5 GHz

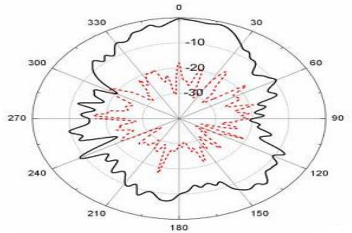

Figure 11. E-plane Pattern at 7 GHz

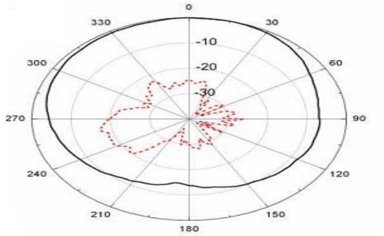

Figure 12. H-plane Pattern at 4 GH

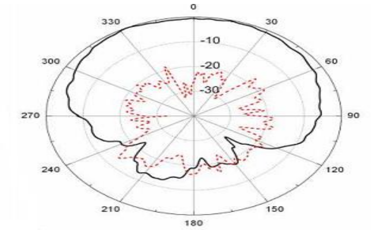

Figure 13. H-plane Pattern at 5.5 GHz

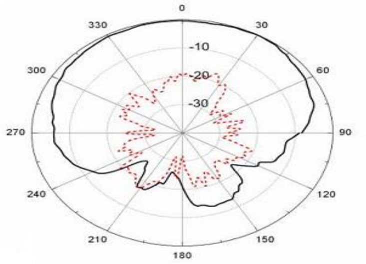

Figure 14. H-plane Pattern at 7 GHz

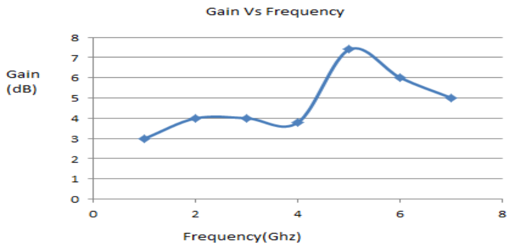

Figure 15. Gain Vs Frequency

The measured radiation patterns at 4GHz, 5.5GHz and 7GHz are shown in Figures. It is obviously from the figure that the cross-polarization levels are all below 18 dB. The antenna shows good end fire radiation property in the entire band. Generally, the E-plane patterns show narrower HPBW while the H-plane patterns exhibit better stability, which is reasonably in accordance with the nature of TSA. Besides, the antenna shows better than 10 dB front-back ratio at the measured frequencies except the little degraded performance in the 7 GHz E-plane pattern. Fig.15 plots the realized gain variation versus frequency. According to the figure, the realized gain achieves the peak value of 7.4 dB as frequency increases to 7 GHz, and drops after that. The decline of the gain in high frequencies is possibly due to the dielectric loss and the surface-wave propagation along the antenna.

6. Conclusion

In this paper, a compact tapered slot UWB antenna is designed. The antenna consists of a tapered slot structure and a microstrip to slotline transition. The tapered slot structure is connected to the slotline. The antenna is investigated for its impedance matching properties, radiation performance characteristics. Obtained results show that the antenna can achieve a wide bandwidth. The results demonstrate that the proposed antenna has wide operating band, reliable directional radiation characteristics, and moderate gain. In addition, the obtained results demonstrate that the antenna has a good directional radiation .Therefore, the antenna can be well applied to ultra-wideband system. All this properties make it a good candidate for UWB detection and imaging applications.

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