Study on Vivaldi Antenna Design

MARDHIAH BINTI MOHAMED ZAID
Faculty of Electrical Engineering,
MARA University of Technology Malaysia,
40450 Shah Alam, Selangor, Malaysia
Email: mardhiahmz86@gmail.com

Abstract – **This paper summarizes a detailed computational study of behavior of Vivaldi antenna. The design, construction and characterization of the Vivaldi antenna implemented by using two (2) different substrates which is RT/Duroid 5880 and FR4. Generally, Vivaldi antenna is usually constructed on copper films on low permittivity low loss substrates such as RT/Duroid. [1] There were some modifications towards the antenna was carried out to improve its performance. At the end of project, a tapered slot Vivaldi antenna that operates from 2 to 10.6 GHz is produced which is fulfill the UWB frequency range. The simulation has been conducted to study the effect of the different substrate towards its performance and also find the most optimized substrate and characteristic of the antenna. Simulation reveals that the antenna has satisfactory operating frequency band which acceptable amplitude of S-Parameter. The simulated results are presented.**

Keyword – UWB (Ultra-Wideband)

1. INTRODUCTION

In recent years, ultra-wideband (UWB) antennas have been developing for many applications and usage includes in medical, military and mostly for communication system that tends to be more extensive, whilst its requirement of ultra-wideband antenna are brought forward. Antennas are essential to high frequency communications and electronic systems for radiating or receiving electromagnetic (EM) energy. Although there are many types of antennas, they all operate according to the same basic EM principles. The tapered slot antenna (TSA), which was introduced by Gibson in 1979, is well suited to meeting these requirements. [1]

Many of early TSA experiments were conducted with CST Microwave Studio from CST Studio Suite software. For all this research, there has been insufficient study of a practical TSA design, a high frequency single-sided exponential Vivaldi antenna, as will be presented here. [2]

In general, the development of Vivaldi antenna is divided into three stages which begins with one-layer structure called tapered slot Vivaldi antenna also known as conventional Vivaldi antenna which will its offer small dimensions and provides a sufficient return loss and a sufficient distortion. The development was followed by a two-layer structure which is called as the antipodal Vivaldi antenna that will offer minimum distortion in exchange for a larger antenna structure. Lastly, the three-layer structure which is called as balanced antipodal Vivaldi antenna. This antenna structure can reduce the cross-polarization of the antipodal structure. [3] In addition, the main characteristic of Vivaldi antenna is influence by broad band and dielectric substrate. That will influence on signal transition. [4] For this paper the second characteristic will be focused on.

One of the goals of the antenna optimization is to minimize the antenna dimension. Thus, the tapered slot structure of the Vivaldi antenna was chosen. In this paper, the first stage of Vivaldi antenna, conventional structure is taken for research to do the design and simulation process and further with analyzing the result obtained compare with different type of materials implement.

The channel sounding application imposes some challenging requirement for the antenna. The Conventional Vivaldi antenna have suitable features and very useful because of its simple construction, wide bandwidth, low cross polarization, high directivity and high gain.

In general, the Vivaldi antenna has an end-fire radiation pattern. [5] At different frequencies, different parts of Vivaldi antenna radiate, while the size of the radiating part is constant in wavelength.

Along with their efficiency and light weight characteristics, conventional Vivaldi antennas satisfy UWB requirements [6] and also attractive because they can work over wide bandwidth and produce a symmetrical end-fire beam appreciable gain and low side lobes. As such, the Vivaldi antenna has theoretically unlimited frequency range, with constant beam width over the range. This antenna consists of a tapered slot etched onto a thin metal film, either with or without a dielectric substrate on one side of the film. In consequence, the resultant of differentiate characteristic of the antenna dimension will also be analyzed.

2. Antenna Design

The design and simulation of the antenna is done by using CST Studio Suite 2009. The process of designing the by using CST Design Environment from consists of numerous steps:

[1] Create the physical dimension for an UWB frequency band tapered structure Vivaldi antenna.
[2] Choose the desired CST operating mode for simulating the Vivaldi antenna.
[3] Define the required substrate material from and its characteristics.
[4] Solve for the substrate parameters by precomputing the substrate used.
[5] Assign the antenna wave guide ports and define their properties.
[6] Set the specify boundary condition and mesh definition view of the physical antenna
[7] Set up the simulation and optimize the performance of the Vivaldi antenna.
[8] View the amplitude of S-parameter and contour plot.

The Vivaldi antenna that is being discussed can be presented in this section. A description of a designed conventional Vivaldi antenna with the waveguide port is presented in Fig. 1. Both antennas have exactly same configuration.

The difference between both designs is thickness of the substrate and copper respectively depending on the substrate used.

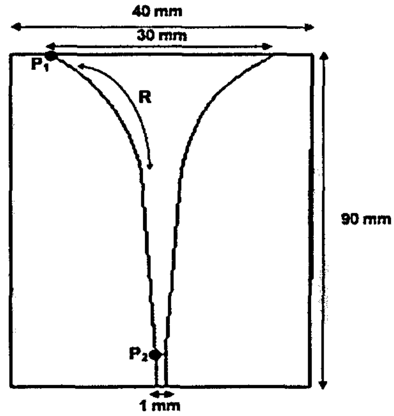

Fig. 1 Antenna configuration

The waveguide port is printed on the front of the substrate layer used for feeding the tapered slot antenna with one exponential taper element. The rear consists of the ground plane element. The top layer indicates the exponential taper profile [7] which is defined by the opening rate, R and the two points P_1 (x_1,y_1) and P_2 (x_2,y_2). The exponential taper profile is given by:

$$y = c_1 e^{Rx} + c_2 \text{ for } x_0 \leq x \leq x_1 \quad (1)$$

where R is the rate of opening and

$$C_1 = \frac{y_1 - y_0}{e^{Rx_1} - e^{Rx_0}} \quad (2)$$

$$C_2 = \frac{y_0 e^{Rx_1} - y_1 e^{Rx_0}}{e^{Rx_1} - e^{Rx_0}} \quad (3)$$

Given the highest frequency of operational (f_H), the width, W of the tapered slot antenna should satisfy equation (1) to circumvent the grating lobes of Vivaldi structure,

$$W > \frac{c}{f_H \sqrt{\varepsilon_e}} \quad (4)$$

where ε_e is the effective relative dielectric constant. After defining the parameter cited above, all other parameter are optimized with CST Design Environment to get both the compact size and good performance at the operating band.

An antenna configuration for channel sounding applications has access antenna ports separately to enable subsequent signal processing. The path of active antenna is chosen electronically by switching matrix while the unused elements are terminated. The active part of the antenna is signed as a waveguide port during the designing process. A travelling wave which is excited in the slot line will propagate along the widening slot and gradually radiate in the end fire direction with E-field in the plane of the substrate which is the second layer elements of the material. [8] The magnitude and phases of the signal at antenna port is then processed to resolve parameters to get the result as presented in third section in this paper.

Two different types of antenna elements (refers to substrate used) have been investigated. First antenna use RT/Duroid 5880 as the substrate while the second one uses FR4 as the substrate. The first antenna was designed on RT/Duroid 5880 material with a relative dielectric constant of 2.2, thickness of 0.508mm and loss tangent of 0.9. The second antenna was designed and simulated on FR4 material with a relative dielectric constant of 4.9, thickness of 0.117mm and loss tangent of 0.016.

Simulations of both antennas were done with CST Design Environment software. The three dimensional (3D) finite elements field – simulator is capable of modeling the single antenna structures. The application of 3D simulation software was necessary because the Vivaldi antenna is not planar structure in a strict sense. [9]

Fig. 2 show the 3D simulated model of the antenna included the mesh definition views and during specify boundary condition. Note that, both design of the antenna have similar configurations so that the views of the overall antenna are the same.

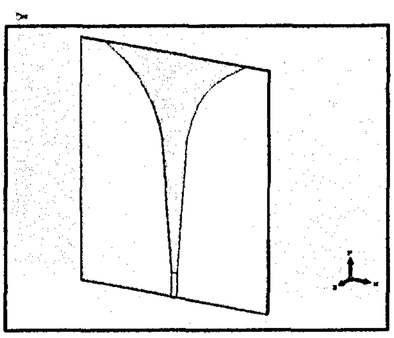

Fig 2(a) 3D view

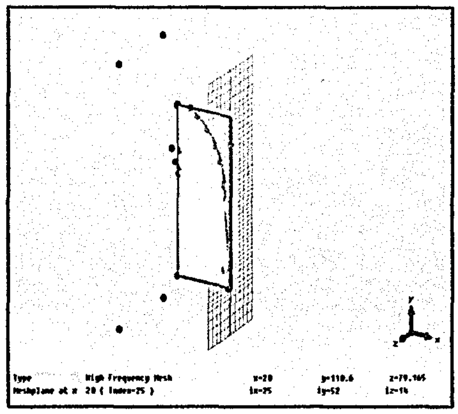

Fig 2(b) Mesh view

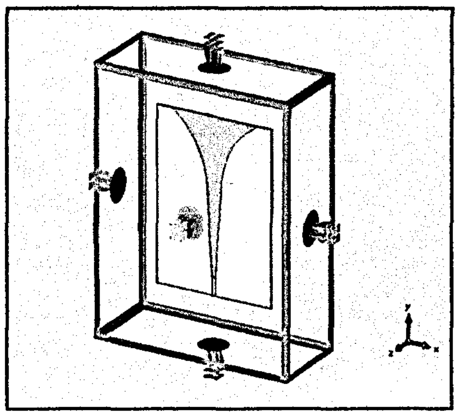

Fig 2(c) Specify boundary condition view

3. RESULTS

From the result obtain, it views that the result designed by using material RT/Duroid 5880 is better than using material FR4. This is because characteristics of Vivaldi antenna are influence by dielectric substrate that influence on signal transition. From the simulation done, by using RT/Duroid 5880 as a substrate, it gives better in term of magnitude of S-Parameter magnitude in (dB). This is because this substrate its self improves the antenna efficiency due to its uniform structure for microwave designs.

Fig. 3 illustrates the simulated amplitude (in dB) of S-Parameter for both antennas designed in the operating band from 9 to 11GHz. The amplitude of the S-Parameter for the antenna design at operating frequency of 10GHz is -34.7dB and -16.7dB respectively.

From the amplitude of the S-Parameter in dB, it is clearly shown that the amplitude for first design is better than the second one due to the frequency difference between the operating frequency and the frequency obtains that the curve show. For the second design the difference is about 0.74 GHz compare with 0.36 GHz for the first design. The small difference shows the small error, means that the first design is better than the second one. Therefore, it is proven RT/Duroid 5880 will give better performance than FR4 for Vivaldi.

Figure below shows the S-Parameter amplitude curve for both designs.

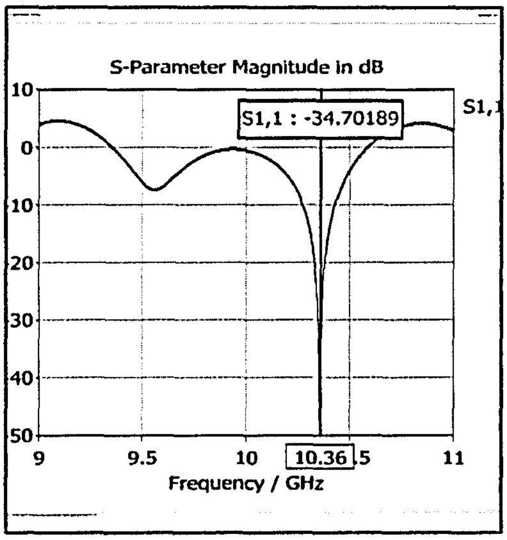

Fig. 3 (a) S-Parameter for first Vivaldi antenna

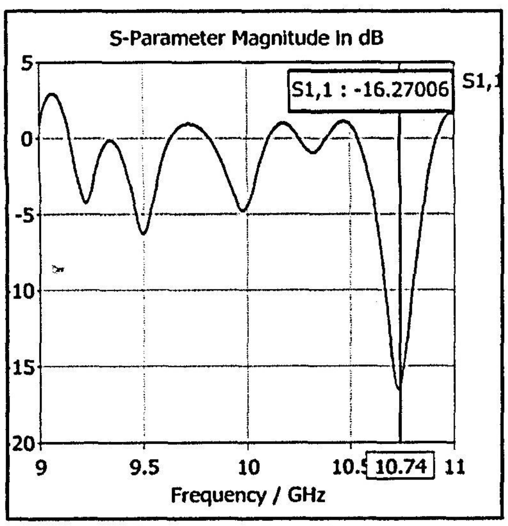

Fig. 3 (b) S-Parameter for second Vivaldi antenna

Other than amplitude of the S-Parameter, the performance of antenna generally can be view on the radiation pattern if the antenna. In the simulation process, we get the radiation pattern on the S-Parameter Polar Plot in 1D Results view. Figure below show the radiation pattern for both designs.

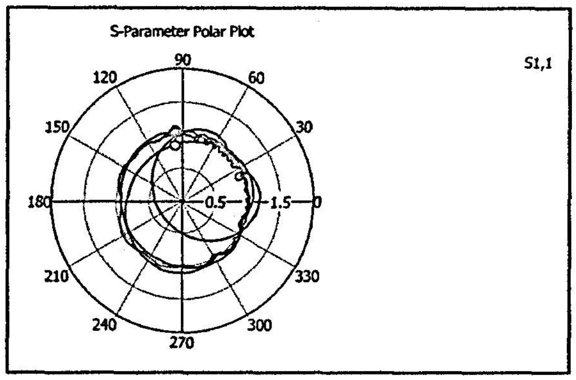

Fig. 4 (a) Radiation Pattern for first Vivaldi antenna

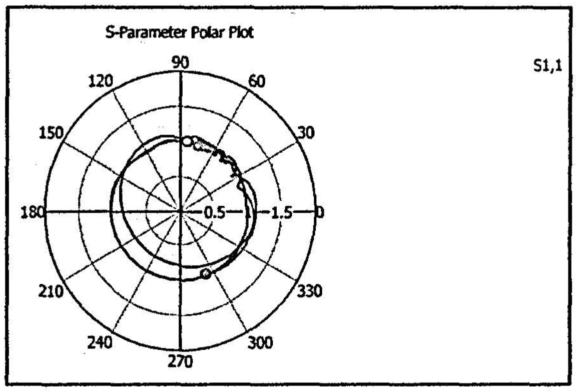

Fig. 4 (b) Radiation Pattern for second Vivaldi antenna

But, the radiation pattern for the tapered slot Vivaldi antenna should be in the Fig. 4 (c) as shown below.

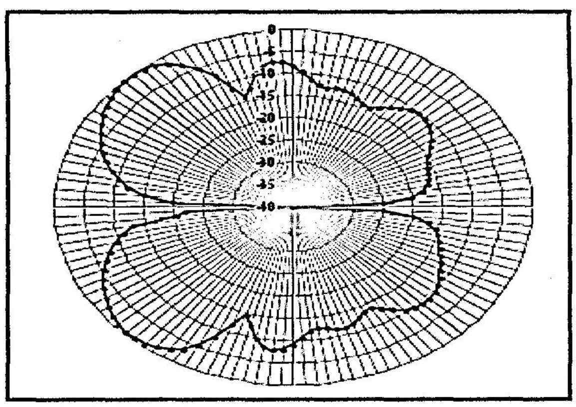

Fig. 4 (c) Radiation pattern for ideal tapered slot Vivaldi antenna

From the radiation pattern obtained during the simulation on single element for tapered slot Vivaldi antenna is obviously different compare with the ideal radiation pattern of the Vivaldi antenna. The simulation identified currents on the lateral antenna rim as the reason for the deformed radiation characteristic. This effect can be reduced efficiently by connecting each antenna with its neighbor elements in array. This is because the arrangement of the Vivaldi antennas within the array has strong influence on the electrical behavior of each individual radiator. [8]

The limitation, of half a wavelength for the lateral antenna dimension reduced the bandwidth of the Vivaldi antenna in the frequency domain drastically and, in addition the shadowing effects of the neighboring antennas limit the beam-width of the radiators.

Since the second characteristics of the Vivaldi antenna cannot give the clear performance of the Vivaldi antenna, the alternative is applied to view the behavior or the performance of the Vivaldi antenna which is view on Contour plot.

This plot shows the contour plot of the electric near field at 10GHz as presented in Fig. 5.

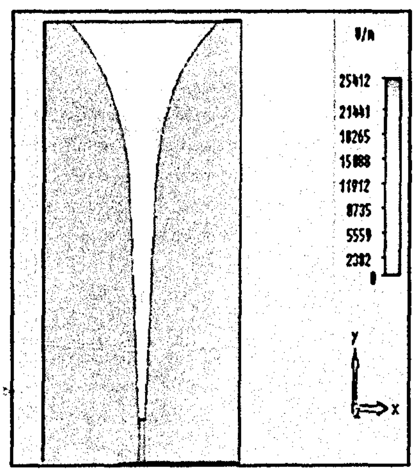

Fig. 5 (a) Contour plot for first Vivaldi antenna

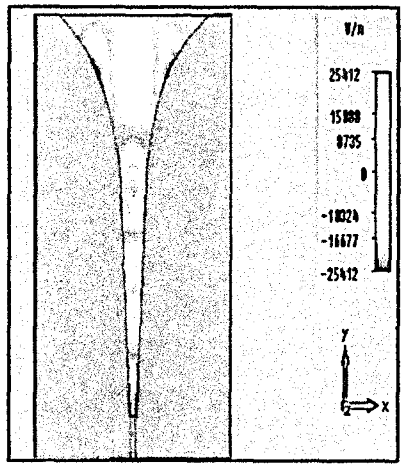

Fig. 5 (b) Contour plot for second Vivaldi antenna

The following figure shows a vector plot of current distribution on the antenna at 10GHz.

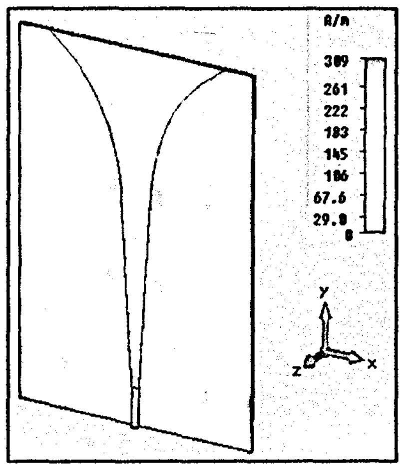

Fig. 6 (a) Current distribution for first Vivaldi antenna

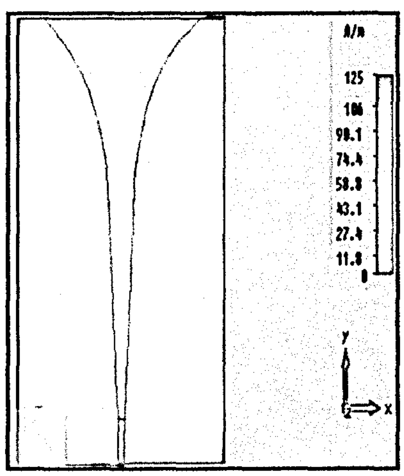

Fig. 6 (b) Current distribution for second Vivaldi antenna

From the contour plot views as presented in Fig. 5 and 6, the better performance showed when more red color interfere in the contour plot. The red color indicates how much the signal from the antenna can radiates. All the performance showed is in this for the single structure. Therefore, it is proven that RT/Duroid 5880 has better behavior or performance than the second substrate, FR4 for tapered slot Vivaldi antenna.

Form the amplitude of the S-Parameter and the Contour plot obtained, the results view that RT/Duroid 5880 will give better performance than FR4 for tapered slot Vivaldi antenna.

4. FUTURE WORK

For this paper, the tapered slot antenna is only simulated on the single structure of Vivaldi antenna. Thus, for future recommendations it can be done in array arrangement to get better performance. This is because the less the array element, the bigger the error will be. [10] The further analysis on array Vivaldi antenna with the real model should be done. In addition, the feed mechanism should be analyzed thoroughly. Particularly by fabricating and testing the transition on the model, it could be found out as to why the single transition behaves worse than the double transition.

5. CONCLUSIONS

The ultra-wideband technologies (UWB) ask for a complete new view on small communication antennas. Not only a good matching of the antenna over the frequency band is required but a stable phase centre to avoid ringing and a good efficiency are necessary to have only a small impact on the transmission function of the radio impulse. Because of the various applications of Vivaldi antenna in ultra-wideband systems, the dispersion performance of two different Vivaldi antennas is analyzed. This paper presents the design and detailed characterization of a conventional Vivaldi antenna. In this paper only single structure of antenna is simulated by applying open (add space) boundary condition. The simulated results of the S-Parameter, contour plot and current distribution demonstrated the good performance of the first Vivaldi antenna structure compared with the second design structure.

REFERENCES

[1] Humberto Lobata-Morales, Alonso Corona-Chavez, L. Gerardo-Ojeda, *Omnidirectional Planar Antennas for PCS – Band Applications using Fiberglass Substrates*, Tonantzintla, Puebla, Mexico, 1980

[2] Microwave Engineering Europe's, *Vivaldi antenna on Computer Simulation Technology*, CST Microwave Studio , 2001

[3] Dr. J.S. Mandeep, Mr. Nicholas, *Design an X – Band Vivaldi Antenna*, Issue of Microwaves & RF, 2008

[4] WIPL.D, *Vivaldi Antenna*, European Microwave Conferemce, Munich, Germany, 2000

[5] Petr Cerny, Josef Nevrly, Milos Mazanek, *Distortion Minimization of Radiated Impulses of Tapered Slot Vivaldi Antenna for UWB Application*, Department of Electromagnetic Field, Czech Technical University, Parague, 2008

[6] Rainee N. Simons, Richard Q. Lee, *Characterization of Miniatute Millimeter-Wave Vivaldi Antenna for Local Multipoint Distribution Services*, Ohio, 1997

[7] F.Jolani, G. Dadashzadeh, M. Naser-Moghadasi and A. Dadgarpour, *Design and Optimization of Compact Balanced Antipodal Vivaldi Antenna*, Electrical Engineering Department, Islamic Hazard University, Tehran, Iran, 2009

[8] Stefan Balling, Matthias Hein, Marko Hennhofer, Gerd Sommerkorn, Ralf Stephen, Reiner Thomä, *Broadband Dual Polarized Antenna Array for Mobile Communication Applications*, Ilmenau University of Technology, Germany, 2003

[9] Yazhou Wang, Aly E. Fathy, *Design of a Compact Tapered Slot Vivaldi Antenna Array for see Through Concrete Wall UWB Applications*, EECS Department, University of Tennessee, Knoxville, USA.

[10] Jian CUI, Min ZHANG, *Time-Domain versus Frequency-Domain Approach for an Accurate Simulation of Phased Arrays*, Tongji University, Shanghai, China, 1994