Design of Tapered Slot Vivaldi Antenna Array Using FR4 Substrate

Muhamad Ridzuan Bin Mohamad Ibrahim
Faculty of Electrical Engineering
Universiti Teknologi MARA Malaysia
40450 Shah Alam, Selangor, Malaysia
Email: ridzuan_ibrahim88@yahoo.com

Abstract- **This degree thesis discuss the performance and behavior of Vivaldi antenna array for the ultra-wideband (UWB) frequency ranges. The design construction and characterization of the Vivaldi antenna by using two (2) different design but same array which is 1 x 2 arrays. The difference is the design of tapered slot wide end where the wide end of the tapered slot of the first design (TSA1) was to meet one another and another design (TSA2) is by adding space between wide end of the array. Then these antennas were constructed using FR4 substrates by using CST microwave software. The Vivaldi antenna produced that can be operated at X-band and using substrate that available and cheap.**

Keyword: Tapered Slot Antenna (TSA); Computer Simulation Technology (CST).

I. INTRODUCTION

A. Objective

The aim and objective of the project is to analyze and compare the performance of the 1 x 2 types of array with different wide end of tapered slot design and using the FR4 material that being implement as a substrate of the tapered slot Vivaldi antenna. The analysis will cover up all the characteristics and behavior or performance of the Vivaldi antenna especially tapered slot Vivaldi antenna.

B. Scope of work

The main emphasis of the project is to design and develop the Vivaldi antenna for the different design of the wide end tapered slot using 1 x 2 type of array and using FR4 material as a substrate. By varying the type of array it is to investigate the performance of the propose antenna in term of return loss, VSWR and radiation pattern. In order to achieve that, the project is divided into software and hardware parts. The designed antennas are simulated using CST Microwave Studio. The parameters of the designed antennas are tuned accordingly to perfection in order to satisfy the best return loss and radiation patterns in frequency range. After that, a prototype of antenna will be fabricated using FR4 board which has a dielectric constant 5.0 and a comparative study will be made between the simulation and measurement results.

II. LITERATURE REVIEWS

A. Introduction of Vivaldi Antenna

Vivaldi antenna, sometimes also called Vivaldi notch antenna, is a planar travelling wave antenna with endfire radiation. It was first investigated by P.Gibson in 1979 [1]._In 1986, the simple case of a Tapered Slot Antenna (TSA) without a substrate was first analyzed with more advanced analysis methods to follow. Many improvements to the initial design came later, namely in the works of E. Gazit in 1988 [2] and Langley, Hall and Newham [3] in 1996. Antenna consists of a feed line, which is usually microstrip or stripline, transition from the feedline to the slotline or balanced stripline and the radiating structure. Radiating structure is usually exponentially tapered, however, examples of parabolic, hyperbolic or elliptical curves can be found in [4]. A Vivaldi antenna is a useful configuration because of its simplicity, wide bandwidth and high gain microwave frequencies. It also can provide excellent directional propagation at microwave frequencies. The terms tapered-notch, flared-slot, tapered slot antenna have been used interchangeably in the literature.

B. Tapered Slot Antenna

Tapered slot antenna it is basically a flared slotline, fabricated on a single metallization layer and supported by a substrate dielectric. The taper profile is exponentially curved, creating smooth transition from the slot line to the open space. This structure introduces limits for the operational bandwidth of the antenna, following the rule for slotline radiation. Slotline starts to radiate significantly under condition of $sw = \lambda o/2$ where sw is width of the slot. Therefore, the wide end of the exponential taper approximately defines the lowest possible frequency which radiated by the structure, while the width of slotline at the taper throat is introducing the high frequency cutoff [5]. Model of the radiating part had been designed accordingly to Figure 2.1 shows basic design variables, which can be changed in order to achieve desired antenna performance.

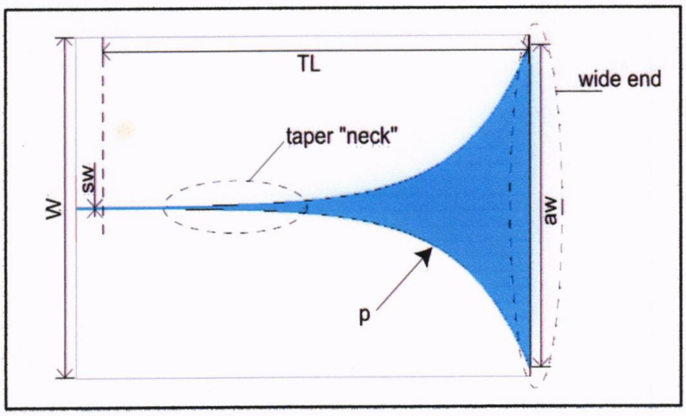


Figure 2.1: Schema of the tapered slot Vivaldi antenna design and variables

C. Curve Equation

Antenna tapers for both design types were defined as exponential curves in the x-y plane. To comply with the antenna board dimensions and slot line parameters, following curve definition was used:

$$f(x) = Ae^{px} - Ae^{p} + \frac{sw}{2} \quad (1)$$

where coefficient p is the curvature parameter, sw is the slotline width and A is defined as:

$$A = \frac{\frac{aw}{2} - \frac{sw}{2}}{e^{pTL} - e^{p}} \quad (2)$$

Parameter aw stands for aperture width at the end of the taper, TL is the taper length.

Similar study was also done for curvature parameter, p of the exponential flare. For larger curvature parameter, the flare angle becomes small at the origin and the lowest frequency of operation reduces as before. Further increase produces significant improvements in the SWR at the higher operating frequencies. In this design the value of aw = 30 mm, TL = 40 mm, sw = 1 mm and compromise value of p = 0.14 mm^{-1} was finally chosen. This is because reflection at the wide end of the taper is connected to the fin termination, and cannot be completely avoided. Changing parameter p does not influence the wide end reflection significantly. Following these observations, it can be inferred that increasing the parameter p can improve matching characteristics. The improvement is of course within the limits given by the antenna aperture and slot line width. Varying the value of p also influences the signal distortion, represented by the fidelity factor F. it can be seen, that the F is the best at lower values of p, as opposed to the return loss. Observations on different models suggest that for a range of p values, fidelity factor F reaches maximum at the point where the curvature is most "round".[5]

D. FR4 Substrate

The FR4 substrates are the material of choice for most PCB applications. The material is very low cost and has excellent mechanical properties, making it ideal for a wide range of electronic component applications. As more and more microwave systems aimed at consumer markets are developed, there is a considerable interest in minimizing the cost of these systems. Substantial cost savings could be realized by using FR4 in place of costly PTFE based substrates for microwave circuits and antennas [6].

Both the absolute values of material thickness, dielectric constant and loss tangent and the tolerances associated with these values are important when considering the use of materials such as FR4 for microwave applications. Typical RF/microwave materials have a dielectric constant with a tolerance of less than 3% at 10GHz, a dimensional stability of less than 5%, loss tangent values of less than 0.005 are required for most applications. FR4 has a rather greater variation in dielectric constant than for PTFE boards, particularly when comparing products from different manufacturers, though within a given batch, the variation is very small. The material has a typical loss tangent in the region of .02, which is too high for many circuit applications. Dimensional stability is, however, very good.

In general, the use of FR4 for microwave circuits is not likely to be viable for electrically large antenna / beamforming designs due to its high losses. However, for broadband antenna elements, where losses and absolute dielectric constant values are less critical, the material can be used in place of more conventional microwave substrates, offering significant cost savings. For hybrid active circuits, where the circuit area is minimal, the performance may also be acceptable. With the markets for consumer-based microwave systems set to grow rapidly in the next century, there will be increasing emphasis on new low cost solutions, and it is likely that FR4 substrates will find a number of applications in this area.[7]

III. METHODOLOGY

A. Flow Chart

In brief, the objective of this project can be achieved by implementing the work flow shown in Figure 3.1

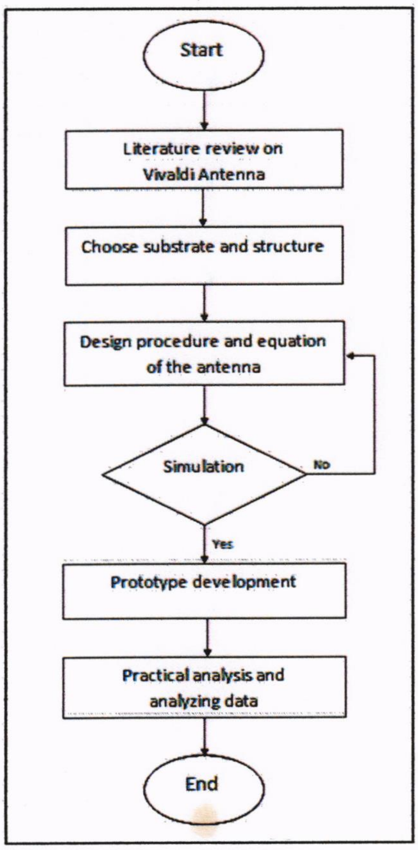


Figure 3.1: Development Flow Chart for the Antenna Design Process

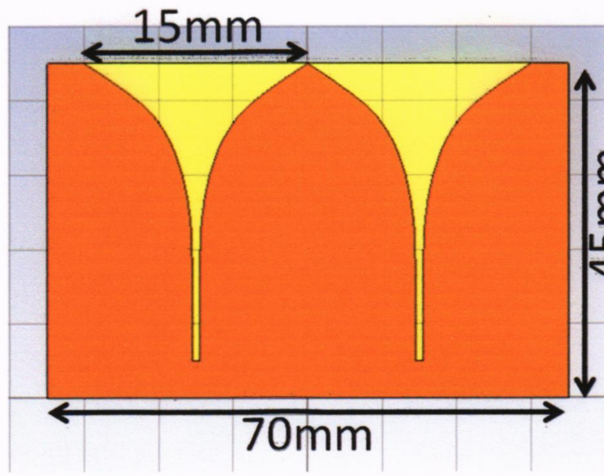
For this project, several steps have been identified to realize the objectives of this project and they are as mentioned in the following. Most of these steps can only be taken after the preceding step has been performed. Figure 3.1 showed the flow chart for the methodology was used in this project. First of all, the literature review of the Vivaldi Antenna has been conducted. Then, all the structure design and substrate information were implemented and simulated using CST Microwave Studio software. If the result does not meet the specification, the projects were redesign and repeat the simulation process. Results of the simulation was collected and analyzed before building the prototype. When the prototype has been produced, the measurements were analysis done and all of the data collected were compared and analyzed with the simulation results.

B. Software Design

In this project, the antenna is simulating by using CST Microwave Studio® (CST MWS) to determine the characteristic of antenna. CST MWS is a special tool for 3D electromagnetic wave simulation of high frequency components. It is based on the Finite Integration Technique (FIT). FIT in time domain has been efficiently implemented on various computer architectures. It is utilized in numerous disciplines of engineering and science such as the increasingly challenging problem in remote sensing, communications, optics, geophysical exploration, ground-penetrating radar, medical diagnosis and nondestructive evaluation. This software also can run more complex diagnosis, compute-intensive simulation, faster than ever before. High performance computing has never been more readily available and affordable. In addition, CST MWS is embedded in various industry standard workflows through the CST design environment.

C. Antenna Array Structure Design

Model of 1 X 2 array structure had been designed based on Figure 2.1. Then the array design were split into two design where the difference between these two design are where the wide end of tapered slot antenna meet one another (TSA1) and wide end tapered slot antenna not meet one another (TSA2). Figure 3.2 and 3.3 shows the differences between these two designs with the dimension for each design.



.Figure 3.2: Show the tapered slot antenna with wide end meet each other (TSA1).

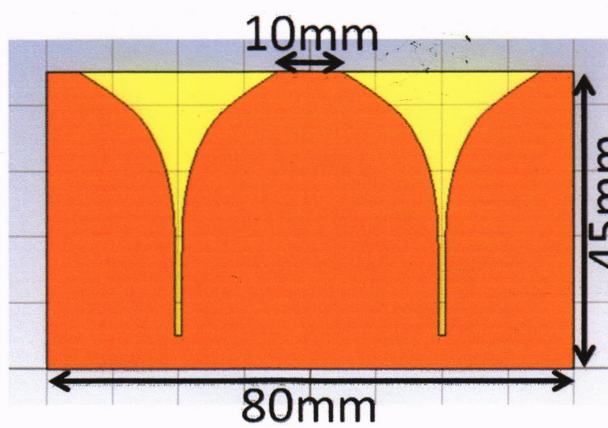


Figure 3.3: Show the tapered slot antenna array with the wide end is not meeting each other (TSA2).

D. Substrate Material

The substrate used for the antenna is FR4 due of its low cost and availability in Malaysia. The FR4 dielectric constant is 5.0 and thickness is 1.6mm. The top and ground surface is copper layer which has thickness a 0.035mm.

E. Design Specification

The Vivaldi Antenna array had been designed and simulated according to the specification as shown in Table 3.1.

Scope	Specification
Operating Frequency	8-10 GHz
Return Loss, S11	Less than -10 dB
Voltage Standing Wave Ratio	Less than 2.0
Line Impedance	50 Ω

Table 3.1: Show the specification of this project.

IV. RESULTS AND DISCUSSION

The performance of the Vivaldi antenna were analyzed in two different methods, by simulation and followed by the experimental measurement. In this result both simulation graph and measurement graph are combined together where the red line represents the simulation result and the blue line represent measurement result.

A. Tapered slot wide end meet each other

- Return Loss (S11)

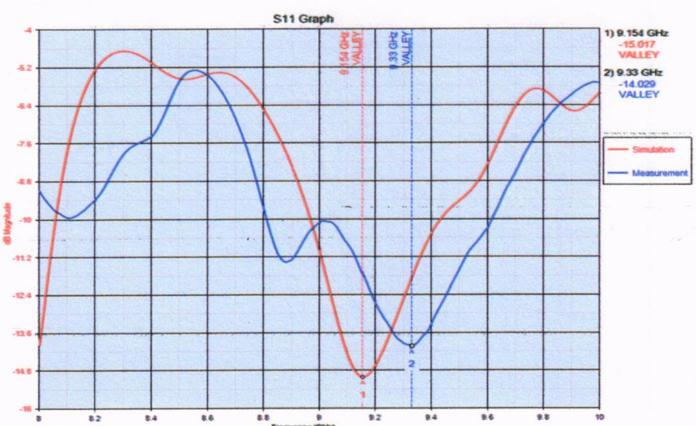


Figure 4.1: Simulation and measurement result of S11

- Voltage Standing Wave Ratio (VSWR)

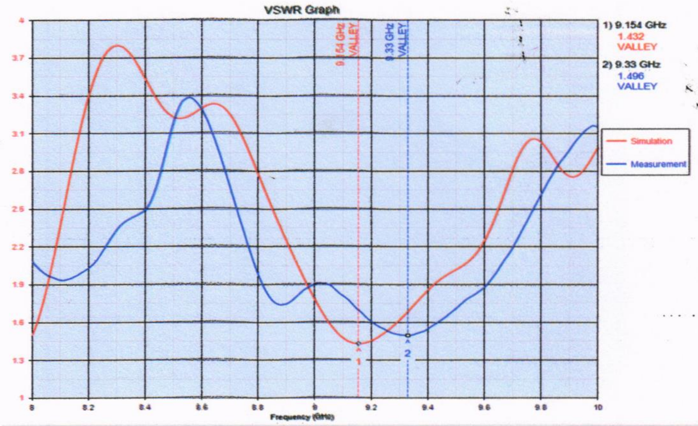


Figure 4.2: Simulation and measurement result of VSWR

B. Tapered slot wide end did not meet each other

- Return Loss (S11)

Figure 4.3: Simulation and measurement result of S11

- Voltage Standing Wave Ratio (VSWR)

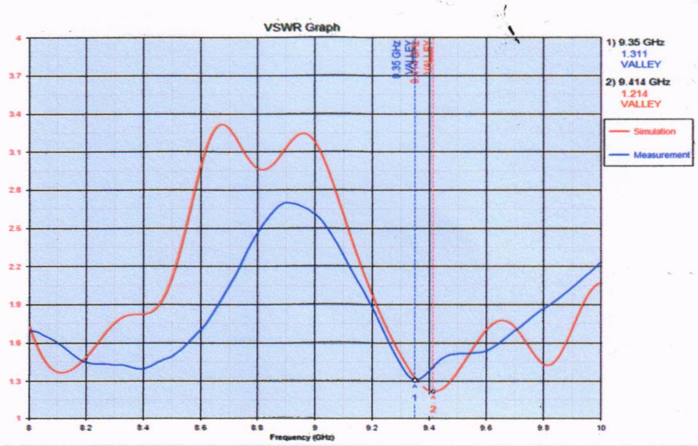


Figure 4.4: Simulation result of VSWR

From the observation between simulated and measurement results, it shows the frequency responses were slightly shifted. It is also found that TSA2 gives a much better output than TSA1.The simulation result shows the return loss and voltage standing wave ratio was slightly different in measurement result. This error maybe due to the fabrication structure where the prototype structure size is slightly different compared to the simulated design. Other possible contributing factors that lead to this experimental error are the condition of surrounding and human error such as soldering and during experiment process.

V. CONCLUSION

Two different design of tapered slot wide end using 1 X 2 arrays were designed and built. The performance of the antenna were analyzed and investigated by using simulation and measurement it can be concluded that performance of the design TSA2 is better than TSA1 when the result of S11 and VSWR were compared. The use of FR4 as substrate, offers the advantages in terms of its low cost and availability in Malaysia. The application of this antenna can support application in the range of frequency such as for radar, military equipment and satellite communication.

VI. FUTURE DEVELOPMENT

The future recommendation is to design more arrays based on this study of the same substrate or other substrate such as RT/Duroid.

VII. ACKNOWLEDGEMENT

All praise is to Allah S.W.T, The Most Gracious and Most Merciful who has given me the strength, ability and patient to complete this project. I would like to convey my deepest gratitude and appreciation to my project supervisor, Puan Norhayati Binti Hamzah for his invaluable suggestion, guidance, advice and discussions for the completion and success of this project.

VII. REFERENCES

[1] P.J. Gibson. The Vivaldi aerial. *Proceedings of the 9th European Microwave Conference,* pages 101-105,1979.

[2] E. Gazit. Improved design of the vivaldi antenna. *IEE Proceedings,* 135:89–92, 1988.

[3] J.D.S. Langley, P.S. Hall, and P. Newham. Balanced antipodal Vivaldi antenna for wide bandwidth phased arrays. IEE Proc. Microw. Antennas Propag., 143:97–102,1996.

[4] H. Schantz. *The art and science of ultrawideband antennas.* Artech House, Inc.,2005.

[5] Josef Nevrl´y, *Design of Vivaldi Antenna,* 2007.

[6] J R Aguilar, M Beadle, P T Thompson and M W Shelley, *"The Microwave and RF Characteristics of FR4 Substrates"* Low Cost Antenna Technology,1998.

[7] Sharp, Alexander N.; Kyprianou, Ross; , "Vivaldi Antennas: Wideband radar antennas simulation and reality," vol., no., pp.1-5, 15-18 Oct. 2007

[8] Li Tianming; Rao Yuping; Niu Zhongxia; , "*Analysis and Design of UWB Vivaldi Antenna,*" Aug. 2007

[9] Dr.J.S, Mandeep, Mr.Nicholas, Design an X-Band Vivaldi Antenna,http://www.mwrf.com/Articles/Index.cfm?Ad=1&ArticleID=19382, July 2008 .

[10] R. Rajaraman, "Design of a Wideband Vivaldi Antenna Array for the Snow Radar," Master's thesis, The University of Kansas, India, 2004.