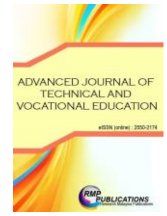
Advanced Journal of Technical and Vocational Education, 3 (1): 14-21, 2019
e-ISSN: 2550-2174

DOI: 10.26666/rmp.ajtve.2019.1.3



COMPARATIVE STUDY BETWEEN X-BAND VIVALDI ANTENNA AND X-BAND VIVALDI ANTENNA WITH LOW RADAR CROSS SECTION (RCS)

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Abstract- A low radar cross-section (RCS) design method is proposed and its application on Vivaldi antenna that covers the range of X-band is examined. According to the difference of the current distribution on the radiator when the antenna radiates or scatters, the shape of the metal radiator is modified so that maximally value RCS reduction is achieved which satisfied radiation performance. Simulated and measured results about gain, S11, RCS are presented. As a result, the effectiveness of the presented low RCS design method is validated. The nose cone of an aircraft is the most treating area for radar detection, but the electromagnetic scattering of antenna array belongs to the firing control system in this area is usually very strong, which result in the importance of stealth design of antenna. Vivaldi antennas are widely used in fire control system due to broad bandwidth and small physical dimension. Therefore, the stealth design of Vivaldi antenna is highly desirable in many prospective airborne applications. Many methods have been proposed to reduce the (RCS) of microstrip antennas. Usually, RCS reduction will increase the complexity of the antenna system or degrade the radiation performance of the antenna. The design will be based on the analysis of the antenna current distribution in the radiating and scattering status respectively for radar aviation application.

Key words: *Vivaldi Antenna, X-Band, 10GHz, Low radar cross section*

INTRODUCTION

The Vivaldi antenna to use at X-band frequencies, which is from 8 to 12 GHz. A Vivaldi antenna is a useful characteristic because of its wide bandwidth, simplicity, and high gain at microwave frequencies.
The nose cone of an aircraft is the most treating areas for radar detection, but the electromagnetic scattering of antenna array belongs to the fire control system in this area is usually very strong, which result in the importance of stealth design of antenna. Vivaldi antennas are widely used in the fire control system due to broad bandwidth and small physical dimension. Therefore, the stealth design of Vivaldi antenna is highly desirable in many prospective airborne applications [1].

Vivaldi antenna, sometimes also called Vivaldi notch antenna, is a planar travelling wave antenna with end fire radiation. It was first investigated by P.Gibson in 1979 [2] and many improvements to the initial design came later, namely in the works of E. Gazit in 1988 [3] and Langley, Hall and Newham [4] in 1996.

The basic shape of the antenna can be seen in Figure 1. Antenna consists of a feedline, which is usually micro strip or Strip line, transition from the feedline to the slot line or balanced Strip line and the radiating structure. Radiating structure is usually expo- mentally tapered, however, examples of parabolic, hyperbolic or elliptical curves can be found in [5].

The continuous scaling and gradual curvature of the radiating structure ensures theoretically unlimited bandwidth, which is, in practice, constrained by the taper dimensions, the slot line width and the transition from the feed line. The limitation introduced by transition was later partially overcame in the antipodal design investigated in [3].

Vivaldi antennas provide medium gain depending on the length of the taper and the shape of the curvature. The gain also changes with frequency, with values ranging typically from 4 dBi to 8 dBi [5]. Because of the exponential shape of the tapered radiating structure, antenna maintains approximately constant bandwidth over the range of operating frequencies [4] [3].

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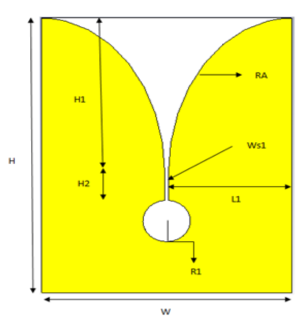
From the time-domain point of view, the principle of radiation through the tapered slot is lacking any resonant parts, which results in very low distortion of radiated pulses. This aspect, together with large bandwidth of the antenna, makes Vivaldi very good UWB radiator in cases when a directional antenna is desired.

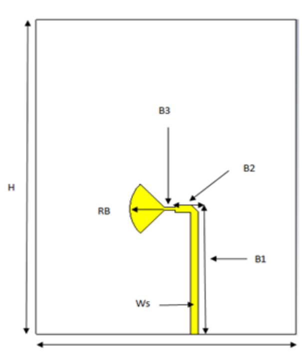
DESIGN

Vivaldi antenna is designed to radiate at 2 to 18 GHz. Figure 2 depicts the layout of the Vivaldi antenna structure by using CST Microwave Studio. The antenna consists of a layer where top layer is a copper layer having a thickness of 0.035 mm. While other side is the micro strip ground plane. In this design, micro strip line is used as a transmission line located in the notch closed. A typical Vivaldi antenna without any low RCS design is shown in Figure 3. The antenna prints on the two sides of a TF-2 (εr=10. 2) Substrate with a thickness of 0.635mm. On one side of the substrate is the metal patch consisting of a tapered slot line and a transmission line as illustrated by the solid lines of in Figure 3. On the other side, there is a feeding structure as illustrated by the solid lines of in Figure 3.2. For better illustration, dotted lines are employed in both views to indicate the position of the structures on the opposite side. The parameters marked in the figure are optimized with CST to match the feeding ports to 50Ω.



Notation	Parameter
H	Overall length
H2	Length section slot line
R1	Length and width of cylinder cavity
Ws1	Width of uniform section of slot line
W	Width of antenna
Ra	Exponential taper
H1	Length of exponential taper
L1	Length slot line to boarder

Figure 1: The front view and parameter Vivaldi Antenna



Notation	Parameter
H	Overall length
B1	Height of ground
B2	Length and ground to B3
Ws1	Length from B2 to cylinder
RB	Radius of radial strip line
Ra	Width of antenna

Figure 2: The rear view and parameter

Calculation

The calculation involves in determine the maximum and minimum opening width of the Vivaldi antenna.
In theory, the maximum opening width is:

$$\lambda g = \frac{c}{f_{\min}\sqrt{\varepsilon r}}$$

where,

c = speed of light (3×10^8)
$f_{\min}$ = frequency minimum (2G)
ε_r = dielectric constant (2.33)

Thus,

$$\lambda_g = \frac{3\times10^8}{2G \times \sqrt{2.33}}$$

$$= 98.27 \text{ mm}$$

So,

$$W_{\max} = \lambda_g/2$$
$$= 98.27 \text{ mm} / 2$$
$$= 49.13 \text{ mm}$$

Then, the minimum of opening width is:

$$W_{\min} = \frac{c}{f\sqrt{\varepsilon r}}$$

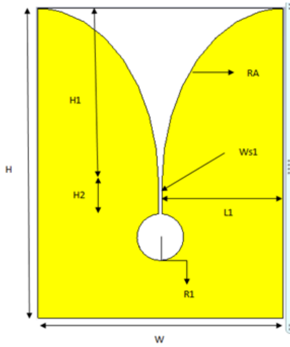
where,

f = center frequency (10G)

$$W_{\min} = \frac{3\times10^8}{10G \times \sqrt{2.33}}$$

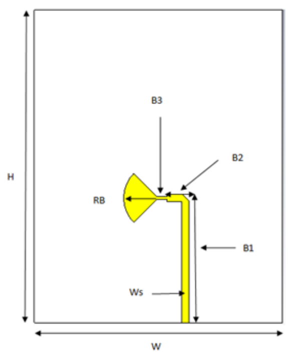
$$= 19.65 \text{ mm}$$

From the calculation, the dimension of all parameters of the antenna being obtains. All parameter is being transferred to the design below in CST software. This is needed to obtain simulation result of return loss of the antenna (S11) as shown in Figure 3 and Figure 4.



Notation	Parameter	(mm)
H	Overall length	25.2
H2	Length section slot line	4.4
R1	Length and width of cylinder cavity	1.9
Ws1	Width of uniform section of slot line	0.28
W	Width of antenna	20
Ra	Exponential taper	14.2
H1	Length of exponential taper	14.2
L1	Length slot line to boarder	9.86

Figure 3: The front view and parameter value.



Notation	Parameter	(mm)
H	Overall length	25.2
B1	Height of ground	10.35
B2	Length and ground to B3	1.2
Ws1	Length from B2 to cylinder	0.84
RB	Radius of radial strip line	2.8
Ra	Width of antenna	20
Ws	Width of ground	0.6

Figure 4: The front view and parameter value.

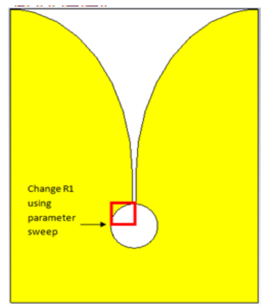
Parametric Studies On Design of Vivaldi Antenna.

Parametric studies on Vivaldi antenna has been made in terms of size of Length and width of cylinder cavity and width of ground . Vivaldi behavior is able to shift the resonant frequency of an antenna.

The target is to get the minimum resonant frequency produced by the Vivaldi antenna in order to reduce the size of the patch for miniaturization purpose. The design process began with a width of cylinder cavity a where the length and the width is calculated from a microstrip antenna formula. From previous design , shown that the desired frequency is out of range from frequency needed. So change must be made to the design 1. Method that being use to find the desire antenna frequency. The method being wise is parametric studies. To change the suitable parameter, parameter sweep from CST 2010 is being used.

Changes in terms of size of Length and width of cylinder cavity.

In order to achieve resonant frequency 10GHz, minor adjustment being changed in order to achieve resonant frequency and bandwidth needed. First parameter that changed was the size of Length and width of cylinder cavity.



Notation	Parameter	OLD (mm)	NEW (mm)
R1	Length and width of cylinder cavity	2.8	2.5

Figure 5: R1 is change using parameter sweep to achieve new value.

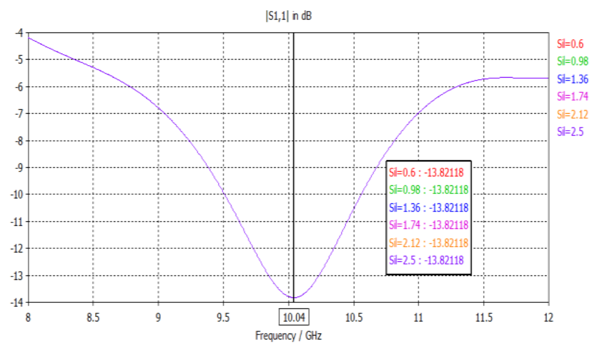


Figure 6: Graph return loss (S11) and resonant frequency from varying parameter.

From the graph above return lost (S11) , R1 that have 2.5 mm shown its frequency is 10.04GHz. It is an almost 10 GHz that being obtained.

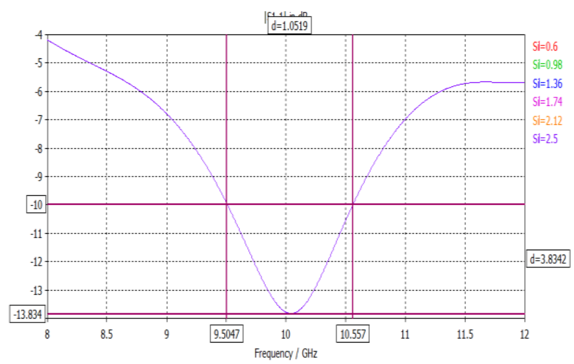
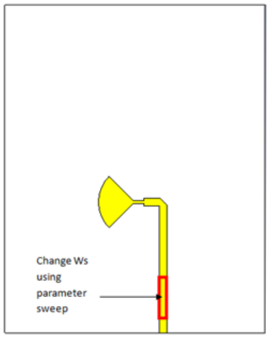


Figure 7: Graph return loss (S11) and bandwidth from varying parameter

From the graph above return lost (S11) , R1 that have 2.5mm shown its bandwidth is 1.0519Ghz.

Changes in terms of width of ground.

In order to achieve resonant frequency 10 GHz, minor adjustment being changed in order to achieve resonant frequency and bandwidth needed. First parameter that has been changed was in terms of width of ground.



Notation	Parameter	OLD (mm)	NEW (mm)
Ws	Width of ground	0.6	1.15

Figure 8: Ws is change using parameter sweep to achieve new value.

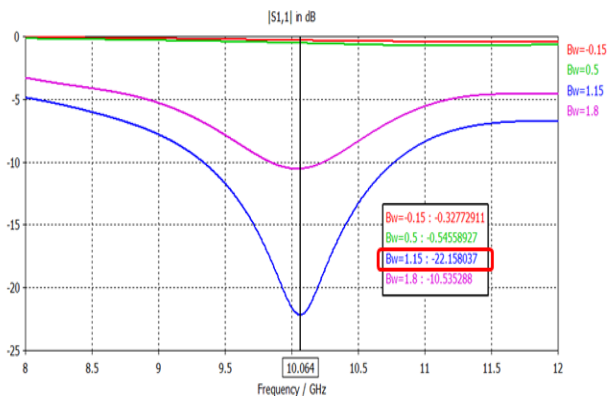


Figure 9: Ws is change using parameter sweep to achieve new value.

From the graph above return lost (S11), BW that have 1.15mm shown its frequency is 10.064Ghz. It is almost 10Ghz that being obtained.

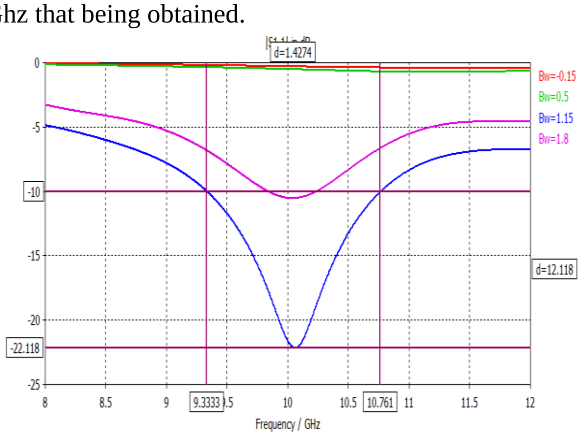


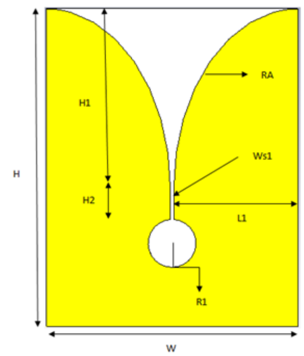
Figure 10: Ws is change using parameter sweep to achieve new value.

From the graph above return lost (S11) , BW that have 1.15mm shown it bandwidth is 1.4274Ghz.

Final Design for Vivaldi Antenna

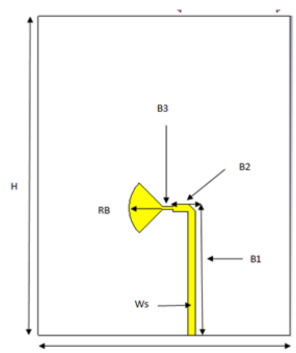
From the result of the parameter sweep simulated, a new parameter has been found.

- The new parameter obtains will the use of the ideal design antenna.
- It will make the antenna operate at the frequency desire (8-12 GHz).
- A parameter that suitable to change is parameter 1 (R1) and parameter 2 (Ws).



Notation	Parameter	(mm)
H	Overall length	25.2
H2	Length section slot line	4.4
R1	Length and width of cylinder cavity	2.5
Ws1	Width of uniform section of slot line	0.28
W	Width of antenna	20
Ra	Exponential taper	14.2
H1	Length of exponential taper	14.2
L1	Length slot line to boarder	9.86

Figure 11: Front view of antenna with new value from parametric sweep.

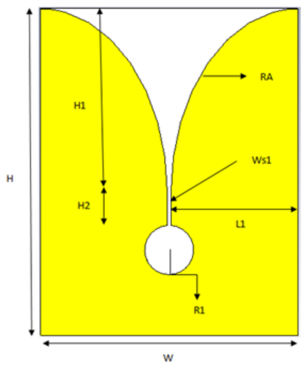


Notation	Parameter	(mm)
H	Overall length	25.2
B1	Height of ground	10.35
B2	Length and ground to B3	1.2
Ws1	Length from B2 to cylinder	0.84
RB	Radius of radial strip line	2.8
Ra	Width of antenna	20
Ws	Width of ground	1.15

Figure 12: Back view of antenna with new value from parametric sweep.

RESULT AND DISCUSSION

The new design of the Vivaldi Antenna is simulated to receive a result indeed. When simulated using CST software at the resonant frequency is at 10 GHz, the return loss is a main parameter in almost all antenna analysis. It is also known as the S11 parameter on the one port network. It measures the antenna's absorption of the fed power over the total power fed. A good antenna should indicate a return loss of less than -10 dB, which indicates that the antenna absorbs more than 90%of the fed power.



Notation	Parameter	(mm)
H	Overall length	25.2
H2	Length section slot line	4.4
R1	Length and width of cylinder cavity	2.5
Ws1	Width of uniform section of slot line	0.28
W	Width of antenna	20
Ra	Exponential taper	14.2
H1	Length of exponential taper	14.2
L1	Length slot line to boarder	9.86

Figure 13: Front dimensions and parameter

The simulated return loss characteristic of the antenna is illustrated in Figure 14.

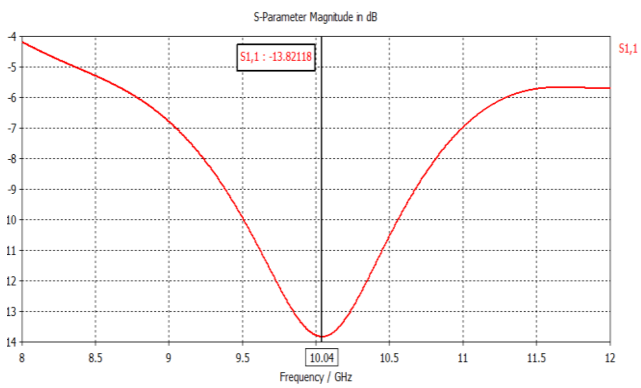


Figure 14: Return loss (S11) and resonant frequency

From the return loss (S11) graph shown in figure 14 above, the frequency of this antenna is 10.04GHz. It is an almost 10 GHz that being obtained. Return loss (S11) for this antenna is -13.82118 dB. A better return loss might be achieved if the position of the probe feed is located at the right position on the antenna.

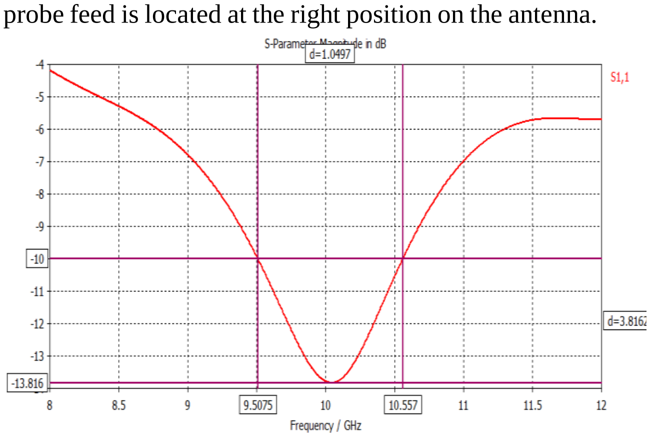
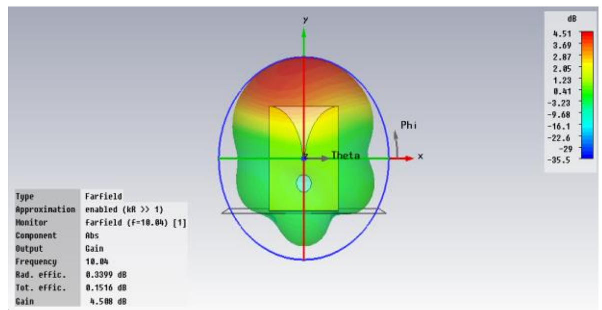


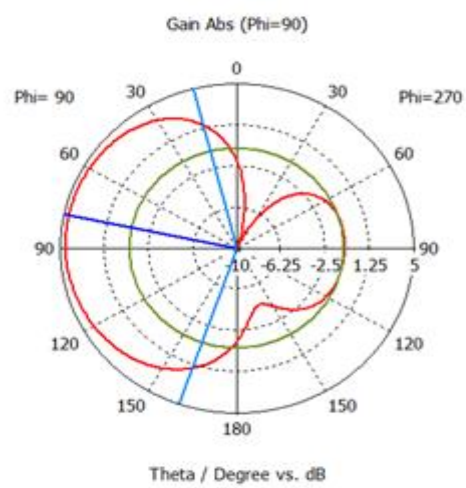
Figure 15: Return loss (S11) and bandwidth

It is evident from the plot that the simulation result predicts the wide bandwidth of the antenna with a reasonable accuracy covering from 9.5075GHz to 10.557 GHz. From the graph above return lost (S11) , the bandwidth of this antenna is 1.0497Ghz . It within 10Ghz that being obtained.

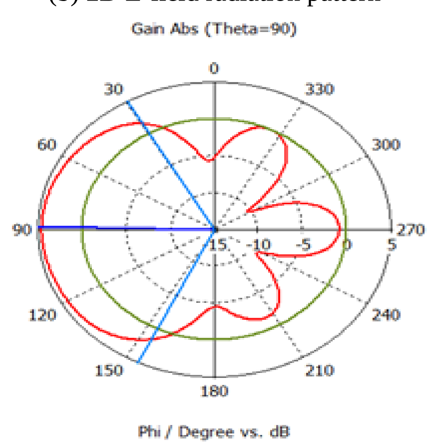
The simulated 3D and 2D radiation patterns at 3.5 GHz extracted from the simulation results, using CST Microwave Studio are shown in Figure 16. It can be seen from the plot that the opening element is almost a good radiator with directional radiation coverage. The HPBW (half power beamwidth) of the simulated antenna is equivalent to 146.6º.



(a) 3D radiation pattern



(b) 2D E-field radiation pattern



(c) 2D H-field radiation pattern

Figure 16: Simulated radiation pattern of the antenna (a) 3D radiation pattern (b) 2D E-field radiation pattern (c) 2D H-field radiation pattern

The simulated 3D and 2D radiation patterns for all the resonant bands are illustrated in Figure 16. It is seen that the radiation patterns are almost omnidirectional while the radiation patterns in the higher frequency are likely to be directional. It is also important to note that the integration of the short circuit slot into the antenna provides both omnidirectional and directional radiation patterns without disturbing the radiation behavior of the first resonant band.

Design of Vivaldi Antenna with Low Radar Cross Section

Generally speaking, the scattering of an antenna can be divided into two parts .One part is the so called structural mode scattering that excludes the effect of the antenna's receiving channel. This part of the scattering is almost the same as the scattering of a common caterer. The other part is the mode scattering that is caused by the radiation of the reflected power from the receiving channel due to the impedance mismatching. Nevertheless, the mode scattering of a well-matched antenna is usually much smaller than the structural mode scattering.

The new design of the Vivaldi Antenna with low radar cross section (RCS) is simulated to receive a result needed. When simulated using CST software at the resonant frequency is at 10 GHz, the return loss is a main parameter in almost all antenna analysis. It is also known as the S11 parameter on the one port network. It measures the antenna's absorption of the fed power over the total power fed. A good antenna should indicate a return loss of less than -10 dB, which indicates that the antenna absorbs more than 90%of the fed power.

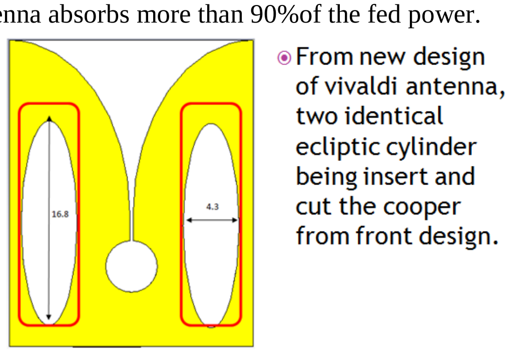


Figure 17: Front dimensions of Vivaldi Antenna with RCS.

Based on the aforementioned idea, two ellipses are symmetrically cut out from the metal patch to ensure the maximum metal reduction to reduce RCS. However the large area cut down on the metal patch will unavoidable results in a slight current distribution changing in the radiation model, which will lead to high side lobe and dispersive gain in a wide frequency range. To prevent the lateral radiate ion, a rectangular strip is placed within the area of the two cut ellipses and connected to the remaining part of the metal patch.

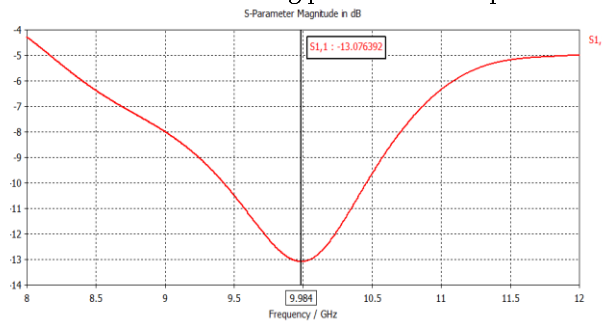


Figure 18: Graph return lost (S11) and resonant frequency.

From graph figure 18 above return lost (S11), the frequency of this antenna is 9.32GHz. It is an almost 10 GHz that being obtained. Return loss (S11) for this antenna is -13.076392dB. A better return loss might be achieved if the position of the probe feed is located at the right position on the antenna.

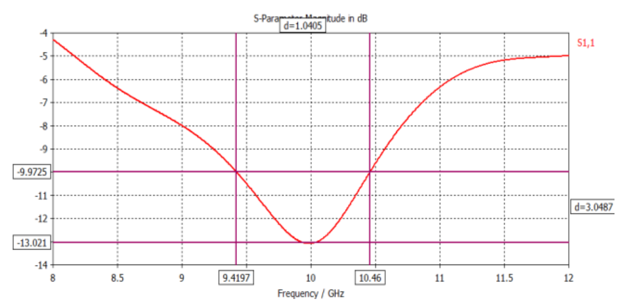
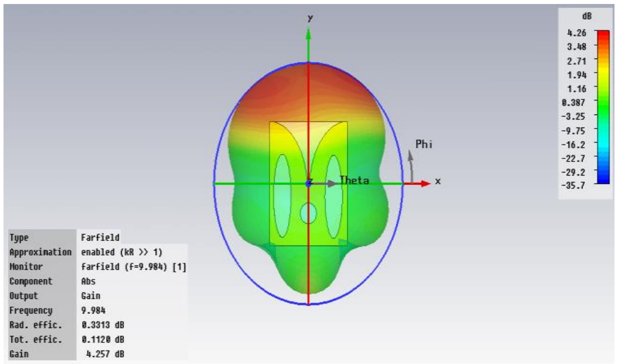
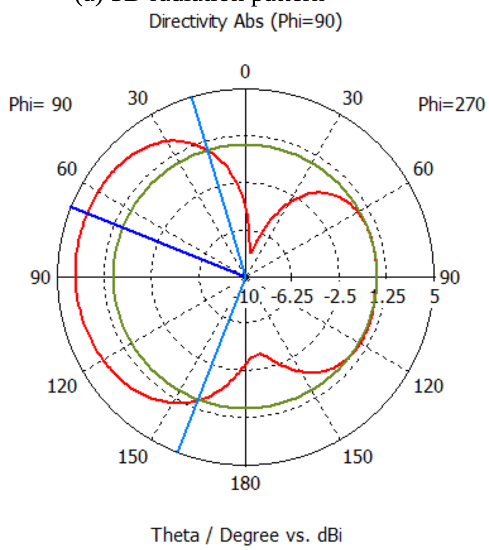


Figure 19: Graph return lost (S11) and bandwidth.

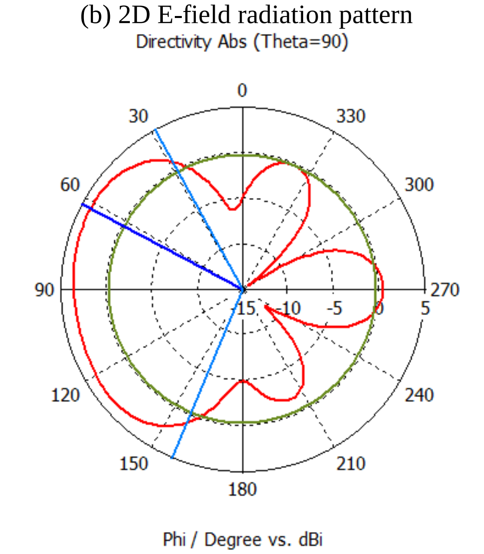
It is evident from the plot that the simulation result predicts the wide bandwidth of the antenna with a reasonable accuracy covering from 9.4197GHz to 10.46GHz. From the graph above return lost (S11), the bandwidth of this antenna is 1.0405 GHz. It within the 10 GHz that being obtains. The HPBW (half power beam width) of the simulated antenna is equivalent to 128.3º.



(a) 3D radiation pattern



(b) 2D E-field radiation pattern



(c) 2D H-field radiation pattern

Figure: 20 Simulated radiation pattern of the antenna (a) 3D radiation pattern (b) 2D E-field radiation pattern (c) 2D H-field radiation pattern

The purpose of a stealth design is to decrease RCS of an antenna while maintaining the antenna's radiation performance, which is usually conflict and should be balanced between scattering model and radiation model. In this stealth design method, the balance is well achieved by utilizing the difference between the current distributions of the antenna in the two modes. At 10GHz, the induced current distribution due to scattering and radiation are shown in Figure 20.

The simulated 3D and 2D radiation patterns for all the resonant bands are illustrated in Figure 20. It is seen that the radiation patterns are almost omnidirectional while the radiation patterns in the higher frequency are likely to be directional. It is also important to note that the integration of the short circuit slot into the antenna provides both omnidirectional and directional radiation patterns without disturbing the radiation behavior of the first resonant band.

Comparison between Simulation Vivaldi Antenna and Vivaldi Antenna with Low Radar Cross Section.

From the graph below shown return lost (S11) of this graph 1 is -13.819dB and for graph 2 is -13.076dB. From the graph shown above that the antenna RCS is archived. It is because the dB from graph 2 is lower than graph 1. Even ore the return loss has reduced but in term of reducing the Radar Cross Section is achieved. Resonant frequencies for graph 1 is 10.051GHz and graph 2 is 9.9898GHz. Both of resonant frequency located in X-band that ranging 8GHz to 12GHz.

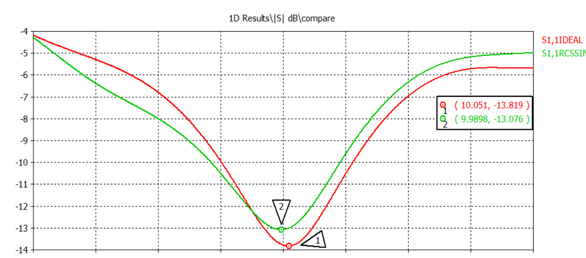


Figure 21 Graph return lost (S11) and resonant frequency of simulation Vivaldi Antenna and Vivaldi Antenna with low RCS

Achieving Low Radar Cross Section.

To determine the Radar Cross Section is achieved or not, the gain value of both designs of antenna for simulation and measurement.

Table 1 Comparison between gains of both Vivaldi Antenna

Result	Simulation	Measurement
Vivaldi Antenna	4.489dB	4.823 dB
Vivaldi Antenna With RCS	4.257dB	4.453 dB

From Table 1 shown that reducing the gain between Vivaldi Antenna and Vivaldi Antenna with Radar Cross Section. From this result shown that radar cross section reducing on both antennas.

CONCLUSION

The goal of this thesis was to design, simulate and fabricate a compact Vivaldi antenna with low radar cross section (RCS) in X-band for radar aviation application. Which resulted in the importance of stealth design of antenna. Vivaldi antennas are widely used in the fire control system due to broad bandwidth and small physical dimension. Therefore, the stealth design of Vivaldi antenna is highly desirable in many prospective airborne applications. Many methods have been proposed to reduce the radar cross section (RCS) of micro strip antennas. Usually, RCS reduction will increase the complexity of the antenna system or degrade the radiation performance of the antenna. The design will be based on the analysis of the antenna current distribution in the radiating and scattering status respectively of radar aviation application.

Simulations indicated the best signal fidelity results can be achieved with antipodal structure, at the cost of the antenna size. Creating smooth antipodal crossing, with wide, rounded fins can minimize the pulse distortion. If the small Vivaldi antenna is desired, tapered slot structure can be used. Lowest signal distortion was observed with round taper profiles. Unfortunately, round curvature is not well matched, therefore a compromise solution must be always found with parameter sweeps.

It also tests the method of novel low RCS design method and applied it to Vivaldi antennas. An excellent stealth performance in the entire X-band and the wide angle range is achieved. With the proposed design method, the RCS is reduced up to 0.232dBsm for simulation and 0.37dBsm with satisfactory radiation characteristic maintained, which shows that the proposed design is effective and potential for other micro strip antenna stealth design.

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