Studies on the Design of Two-Port Vivaldi Antenna with Polarization Diversity for Microwave Applications

A project report submitted

in partial fulfilment of the requirement for the degree of

Bachelor of Technology

In

Electrical Engineering

by

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INDIAN INSTITUTE OF TECHNOLOGY JAMMU

(JUNE 2021)

CERTIFICATE

This is to certify that the work contained in this report entitled **"Studies on the Design of Two-Port Vivaldi Antenna with Polarization Diversity for Microwave Applications"** is a bonafide work of **Devid Yadav (2017UEE0068)**and **Gurpreet Sarngal (2017UEE0070)**, carried out in the **Department of Electrical Engineering, Indian Institute of Technology Jammu** under my supervision and that it has not been submitted elsewhere for the award of any degree

June, 2020
Jammu

Supervisor: Dr. Kushmanda Saurav
Assistant Professor
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DECLARATION

I declare that this report presents my ideas in my very own words and where others' ideas or words are included, I've got adequately cited and referenced the initial sources. I also declare that I've got adhered to all or any principles of educational honesty and integrity and haven't misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above are cause for disciplinary action by the Institute and may also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when required.

Devid Yadav (2017UEE0068)

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ACKNOWLEDGEMENT

We want to express my sincere gratitude to several individuals and organizations for supporting us throughout our graduate study. First, we wish to express our sincere gratitude to our supervisor, Dr. Kushmanda Saurav, for his enthusiasm, patience, insightful comments, helpful information, practical advice, and unceasing ideas that have helped us tremendously at all times in our research and completion of this project. His immense knowledge, profound experience, and professional expertise in Antennas and Wireless Communication have successfully enabled us to complete this project. Without his support and guidance, this project would not have been possible.

We also wish to express our sincere thanks to the BTP coordinator of the Electrical Dept. Dr. Ankur Bansal for his support and guidance in the B.Tech Projects. In addition, we are deeply indebted to the Electrical Dept. of IIT Jammu for accepting us into the undergraduate program.

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ABSTRACT

Since the Federal Communications Commission (FCC) release for ultra-wideband wireless communications, UWB is rapidly advancing. As within the conventional wireless communication systems, an antenna plays a vital role in UWB systems, bringing more challenges in designing a UWB antenna than a narrow band one. an acceptable UWB antenna can operate over an ultra-wide bandwidth and has satisfactory radiation properties over the complete frequency range. The Vivaldi antenna is taken into account the foremost advanced antenna for various applications like wireless communications, military, and biomedical engineering.

In this work, a two-port Vivaldi antenna operating at 15.15 GHz with an impedance bandwidth of 13.17% is proposed. Two microstrip line fed co-planar Vivaldi antenna elements are placed orthogonal with respect to each other to arrive at the design of polarization diversity antenna. The antenna exhibits an end-fire radiation with a gain greater than 5.4 dBi and radiation efficiency of 98% corresponding to the excitations of the two ports. The isolation better than -28 dB is achieved between the two ports of the antenna.

Chapter 1

Introduction

Vivaldi antenna is a planar antenna with a wide bandwidth, High Gain, Directional Radiation pattern. The Radiation Pattern and Bandwidth of Vivaldi Antenna usually depends upon the shape of Antenna such as length of antenna, width of antenna, shape of slot, slope of tapered slot and many other things. The performance of Vivaldi antenna also depends upon the feeding strip; it can be balun strip or a simple rectangular micro strip. The Vivaldi Antenna provides end-fire radiation with a beam width approximately the same of E-and H- planes. Vivaldi Antennas has infinite bandwidth [1]

Vivaldi Antennas are divided into 3 categories i.e. Coplanar Vivaldi Antenna, Antipodal Vivaldi Antenna (AVA) and Balanced Antipodal Vivaldi Antenna (BAVA), each has its own pros and cons. In this project, we will work with Coplanar Vivaldi Antenna

SISO (single input, single output) antennas are mainly used for transmission and reception. SISO is the simplest antenna technology [2]. Typical example of this category is Single Port Vivaldi Antenna.

The MIMO (Multiple Input, Multiple Output) antenna is the combination of two or more antenna elements that are used simultaneously for transmission as well as for reception over a radio channel.

Chapter 2

Literature Review

The Vivaldi antenna is considered most advanced antenna for different applications such as wireless communications, military and biomedical engineering. To begin with, the high-gain Vivaldi antenna mounted by dielectric substrate is proposed in [3]. Also the basic design of this antenna is proposed by[4]. Also the feed line of this antenna is verified by [4]. Moreover, the ultra-wideband Vivaldi antenna using tapered slot edge with resonant cavity structure is explored in [5].

Chapter 3

Problem/Work 1

1. Introduction

The motive of our project is to design a MIMO Coplanar Vivaldi Antenna in CST of Center Frequency of 17 GHz and high Gain. We have designed the Antenna in CST Electromagnetic Solver.

In Vivaldi antennas, we feed antenna using a feedline and the characteristic impendence of transmission line 50 ohms, So for maximum power transfer, impendence of both transmission line and micro strip should be same So in this antenna we are using a rectangular micro strip to transfer the power. If the Impedance mismatched then, antenna will not get max full and its bandwidth Impedance will decrease.

2. Designing of Antenna

To Design this antenna in CST, we have started from the Coplanar Vivaldi Antenna which is our Base Antenna. To convert this SISO antenna into a MIMO, we have attached a similar Coplanar Vivaldi Antenna Orthogonally to it. After that to decrease the Center frequency, and to do this we have to increase the values of Antenna parameter such as its Width, length and exponential Factor.

3.2.1 Designing of Base Antenna

The Basic Design of our project is shown in Fig 3.2.1 which contains Label. The Dimensions of those labels is given in table No 3.2.1. In order to design the curve as shown in Fig 3.2.1, we have to the follow the equation 1 which gives us the exponential curve. After designing in CST Software the front and back side of Antenna should look like Fig 3.2.2. We have used Taconic RF 60A with dielectric constant of 6.15 and dielectric loss tangent of 0.0028 for Substrate Material. Material Used for Antenna and Feed line is PEC (Perfect electrical conductor).

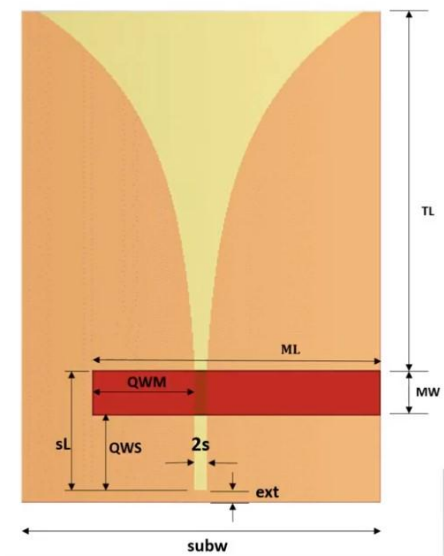
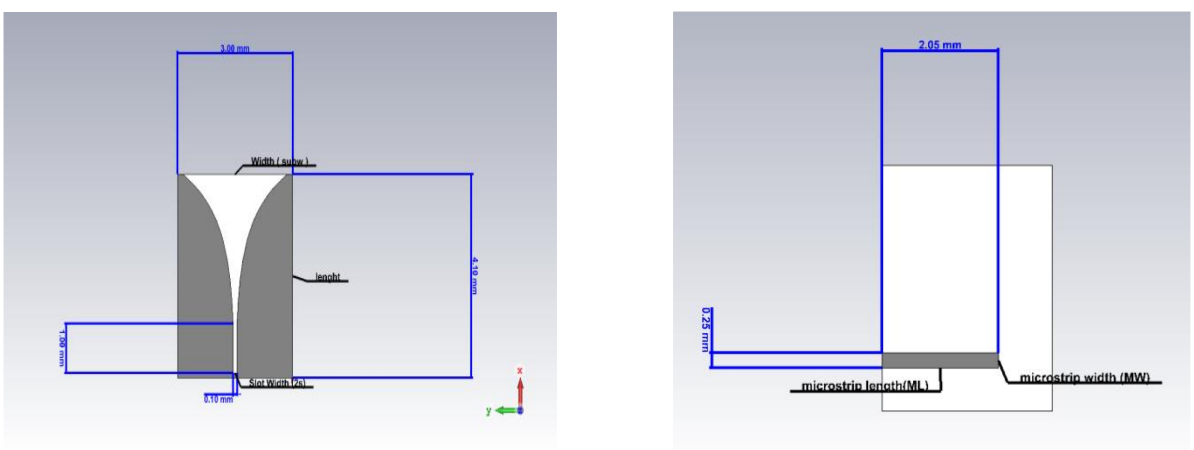


Fig 3.2.1 Design and Labels of Coplanar Vivaldi antenna



(a) (b)

Fig 3.2.2 (a) Front Side and (b) Back Side of Coplanar Vivaldi Antenna

LABEL	Description of Label	Value (in mm)
TL	Distance between microstrip and top edge	3
subx	Width of antenna	3
sL	Slot Length	3
QWS	Width of Microstrip	0.75
QWM	distance between microstrip edge and center of antenna	0.5
r	exponential factor	1.1
MW	Microstrip Width	0.25
h	height of substrate	0.254
ext	distance between edge of Slot and width	0.213
s	slot Width	0.05

Table No. 3.2.1. Parameters of Coplanar Vivaldi Antenna

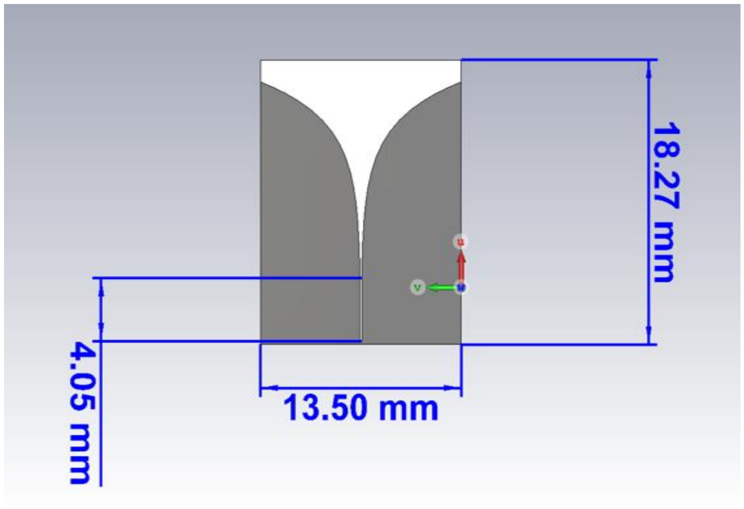
3.3.2 Reducing the Frequency of antenna

Now the main motive is to reduce the working frequency of 34 GHZ to 16-18GHz. In order to reduce Frequency, we have to increase the Dimension of Antenna until we get the desired Frequency with a good Radiation pattern and Bandwidth Impedance.

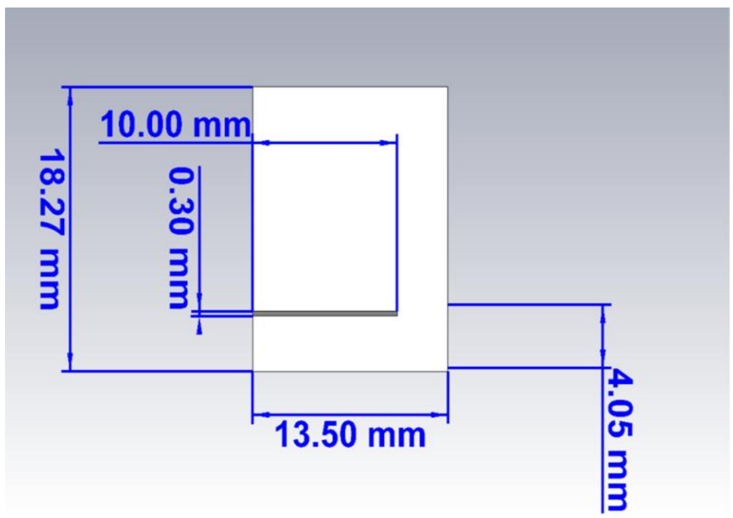
The modified antenna and it new parameters are shown in Fig. 3.2.3 and Table No. 3.2.2

LABEL	Description of Label	Value (in mm)
TL	Distance between microstrip and top edge	14
subx	Width of antenna	13.5
sL	Slot Length	4.045
QWS	Width of Microstrip	3.5
QWM	distance between microstrip and	3.2
r	exponential factor	0.39
y	distance between 2 antennas	0.345
MW	Microstrip Width	0.3
h	height of substrate	0.254
ext	distance between edge of Slot and width	0.213
s	slot Width	0.05

Table No 3.2.2 New Parameters of Antenna



(a)



(b)

Fig 3.2.3 (a) Front and (b) Back Side of Modified Coplanar Vivaldi Antenna

3.3.3 Final Design

The gain of the base Antenna is not good enough for the requirement, so we have attached a identical Coplanar Vivaldi antenna orthogonally to the First Antenna as shown in Fig. -. The motive of doing this is to increase the Resultant Gain/Directivity of Antenna in End fire Direction.

In this design, we have extended the substrate of first antenna and connected it to the Second Antenna . Also there is a small gap between both antennas, so they won't get shorted.

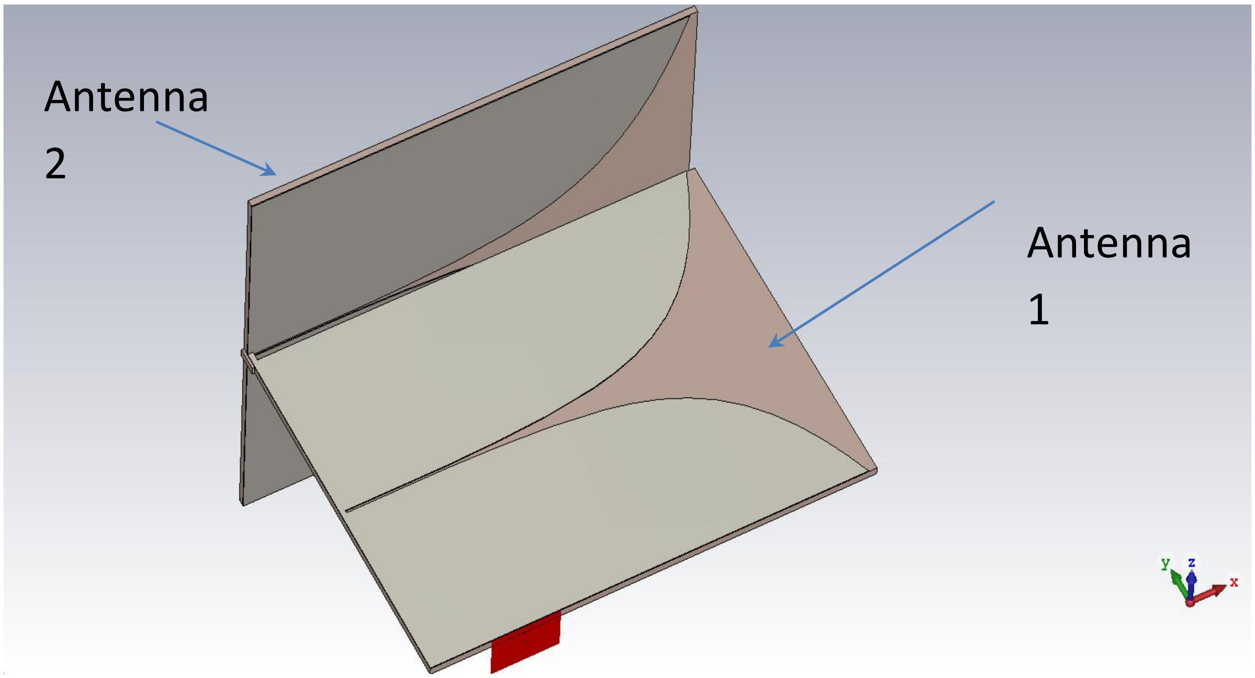


Fig. 3.2.4 Final Design of MIMO Antenna

3. Methods.

Equation 1 is used to designed the exponential curve.

$$Y = 2s^* \exp(r^*x) \qquad \text{------ (1)}$$

Where Y represents the points in y direction (in the direction of width) and X means the length parameter in x direction. ‘2s’ gives us the width if slot length. The shape of curve depends upon the value of ‘r’, larger the value of ‘r’, smaller the width of Antenna.

The Bandwidth Impedance is given by the equation 2.

$$BI = F_h - F_l \qquad \text{------(2)}$$

And Fractional Bandwidth is given by:

$$\text{BI \%} = \frac{\text{Fh} - \text{Fl}}{\text{Fc}} \qquad \text{------ (3)}$$

Where F_h is the maximum frequency in the band, F_l is the minimum frequency and fc is center frequency in the band.

For the ECC calculation using S-parameters as shown in equation 3, but this method is only effective only when the efficiency of Antenna is above 95%[], for smaller antennas we use another equation

$$\rho_e = \frac{|S_{11}^{\star} S_{12} + S_{21}^{\star} S_{22}|^2}{(1 - |S_{11}|^2 - |S_{21}|^2)(1 - |S_{22}|^2 - |S_{12}|^2)} \qquad \text{-------- (4)}$$

The other method of Finding ECC is using Far-Field. So far field of single antenna can be expressed as

$$\overline{F_1(\theta, \phi)} = F_{1\theta}(\theta, \phi) \cdot \overline{a_\theta} + F_{1\phi}(\theta, \phi) \cdot \overline{a_\phi} \qquad \text{------- (5)}$$

Where (Θ, Φ) represents the spherical angles which are elevation and azimuth, and a_Θ represents a unit vector in the theta direction, and a_Φ represents a unit vector in the phi direction.

The ECC using Far filed is written below

$$\rho_e = \frac{|\int\int \overline{F_1} \cdot \overline{F_2^{\star}} \, d\Omega|^2}{\int\int |\overline{F_1}|^2 d\Omega \cdot \int\int |\overline{F_2}|^2 d\Omega} \qquad \text{------ (6)}$$

Where Ω = sin *θ dθdφ* is the beam solid angle, and *F1 and F2* are far field of antennas

4. **Results**

All the Antennas are simulated in the CST Software. And the result and improvements are shown Below. The Center Frequency of Base Antenna is 48.77 GHZ and its Bandwidth Impedance is 7.638 GHz as shown in Fig. 3.4.1. We can see the Radiation pattern of this antenna in Fig 3.4.2, its in end-fire direction and the Gain of this antenna is 5dBi.

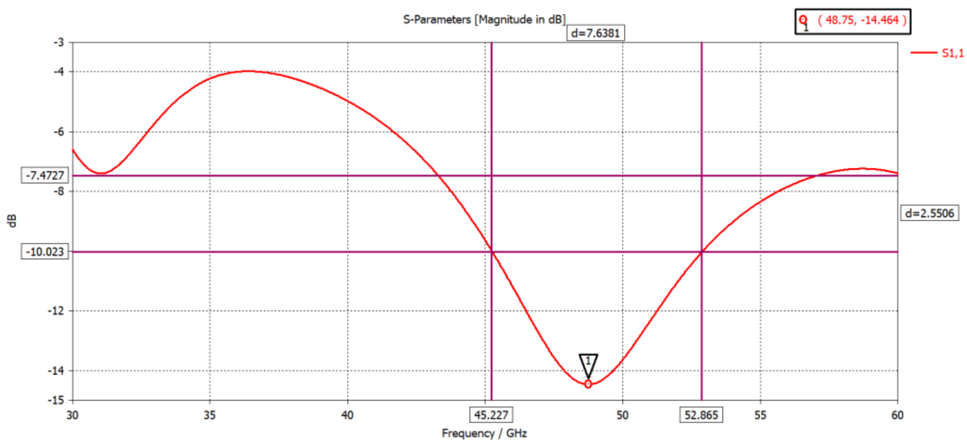
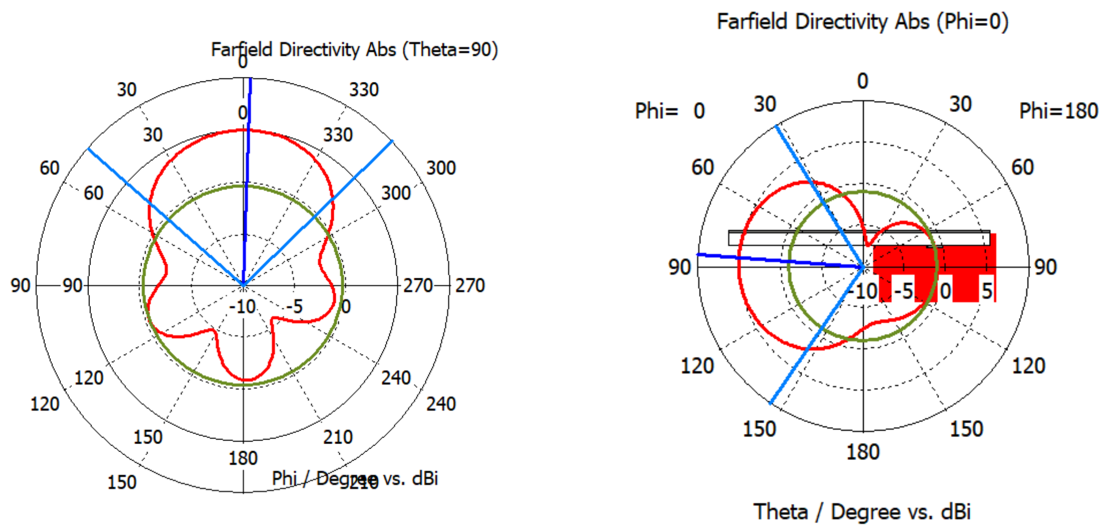


Fig 3.4.1. S-Parameter of Base Antenna and its center frequency is 48.75 GHz



(a) (b)

Fig 3.4.2 Radiation Pattern of Base Antenna in(a) xy plane (b) xz plane at frequency of 48.5 GHz

In Fig. the S-parameter of new antenna and the new center frequency of Antenna is 15.22 GHz and the Bandwidth Impedance of Antenna is 2.2706 GHz refer to Fig. 3.4.3. The Gain of this Antenna is 5.6 dBi and Radiation pattern is shown in Fig 3.4.4 which in end-fire direction.

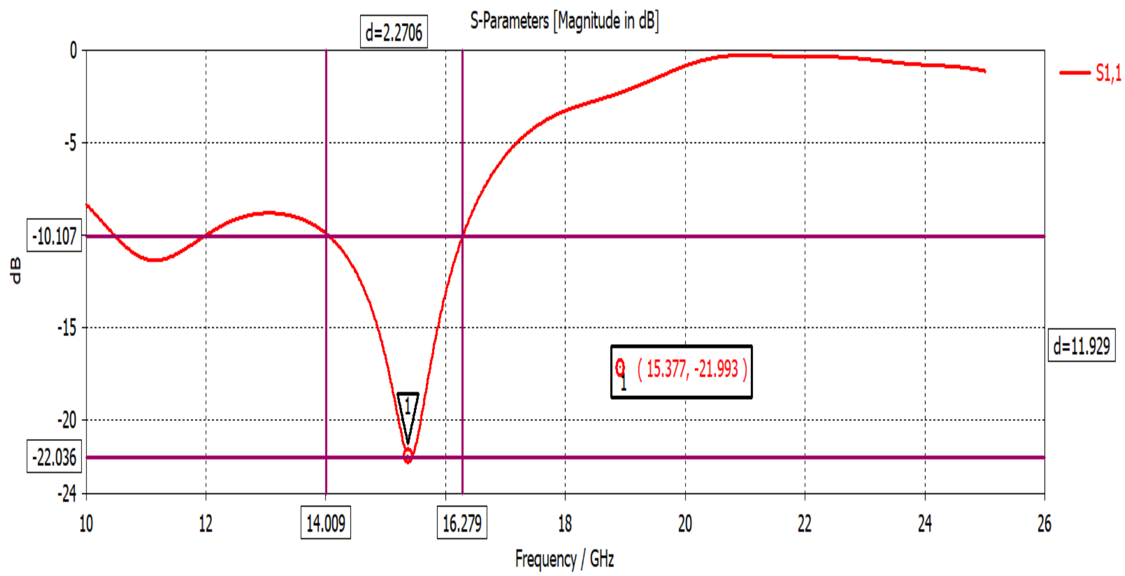
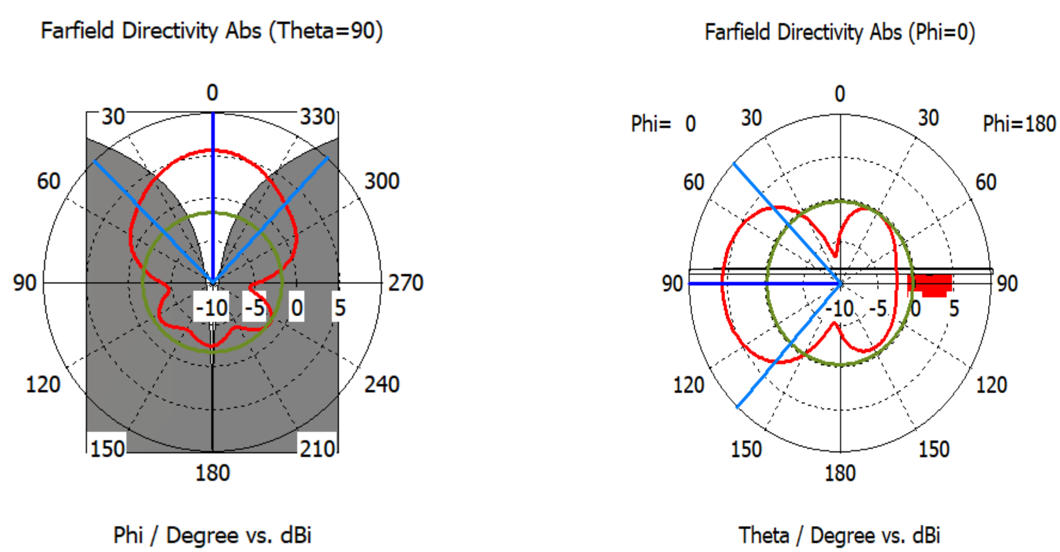


Fig 3.4.3. S-Parameter of Modified Antenna and its center frequency is 15.337 GHz



(a) (b)

Fig 3.4.4 Radiation Pattern of Modified Antenna in (a) xy plane (b) xz plane at frequency of 15.337 GHz

In final Design, the S_{11} and S_{22} are not overlapping on each other although they are similar antennas this due to the Effect of Radiation. So we take the common region for our result, the High Frequency is 16.163 GHz and low Frequency is 14.16GHz. The bandwidth Impedance of this Antenna is 2.0024 GHz and its center frequency is 15.15 GHz as seen in Fig 3.4.5. The Mutual Coupling of Antenna (S_{12} and $S_{21)}$ is below -28 dB as shown in Fig. 3.4.6.

Performance table of all antennas is shown in Table 3.4.1 which contains Gain, Radiation Efficiency and Bandwidth Impedance. Envelope Correlation Coefficient (ECC) is used in MIMO Antenna to determine the effect of Radiation of second Antenna onto first Antenna. The ECC of Antenna 1 to Antenna 2 at Center frequency using far field data is 0.0547 or -25.24 dB, which is in desired range as shown in Fig 3.4.10. The ECC using S-Parameters shown in Fig.3.4.7

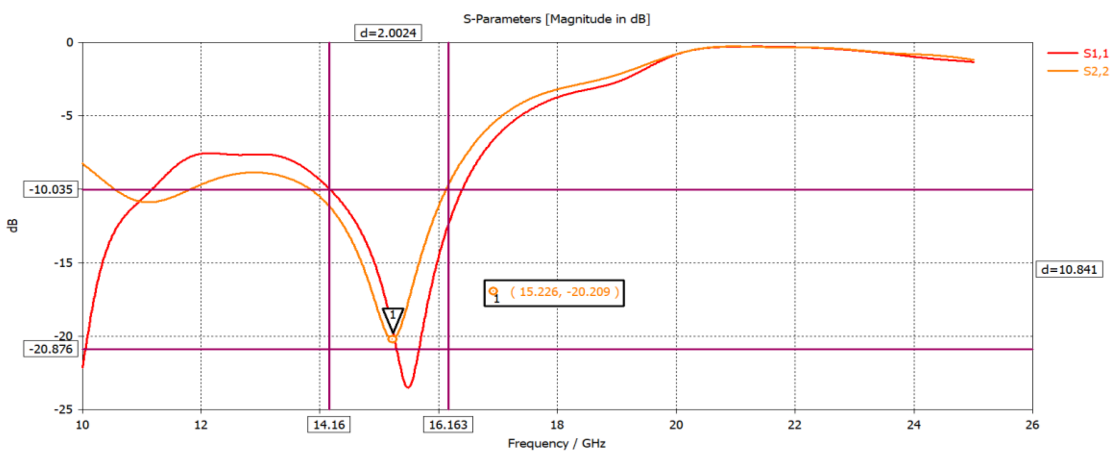


Fig 3.4.5 S-Parameter of 2-port MIMO Antenna at frequency of 15.22 GHz

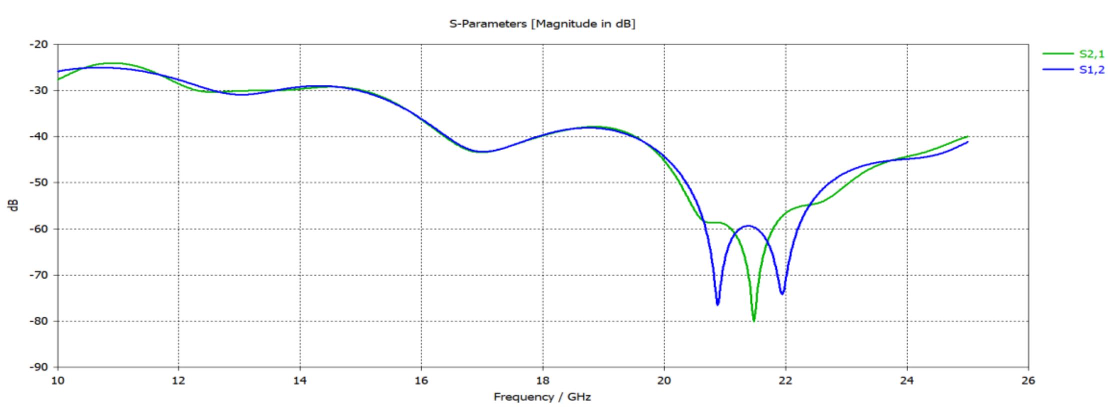


Fig 3.4.6 Mutual Coupling of two-port Vivaldi Antenna

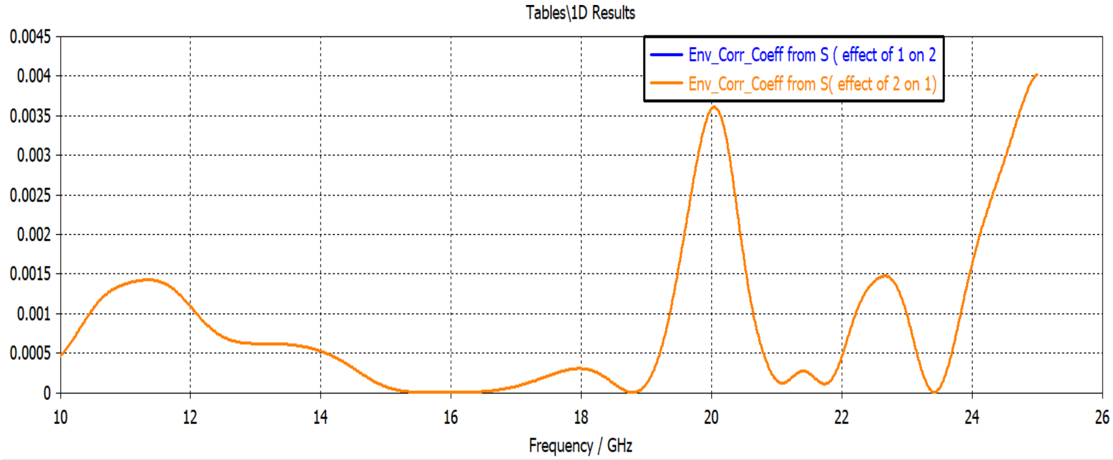
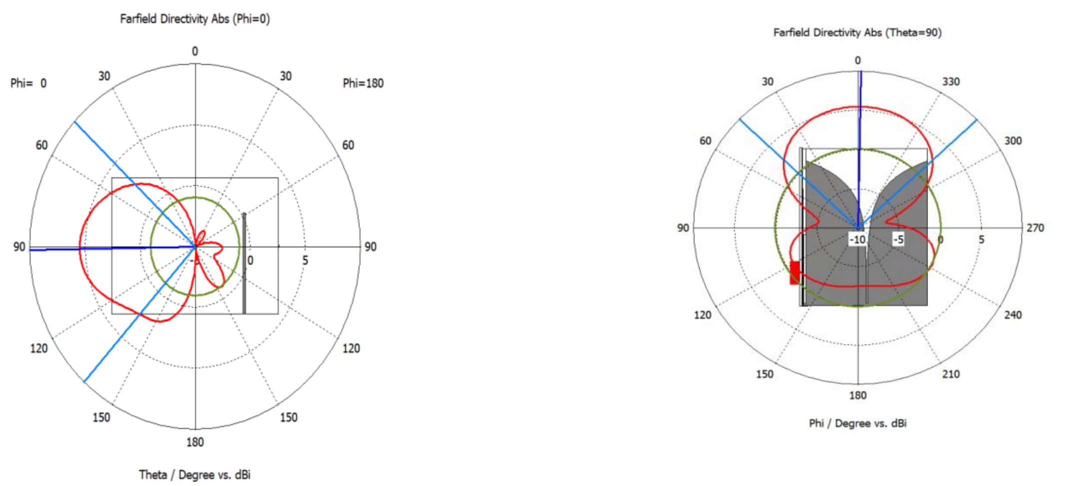


Fig 3.4.7 ECC of 2 port Antenna using S-parameters.



(a) (b)

Fig 3.4.8 Radiation Pattern of Modified Antenna in (a) xy plane (b) xz plane at frequency of 15.337 GHz

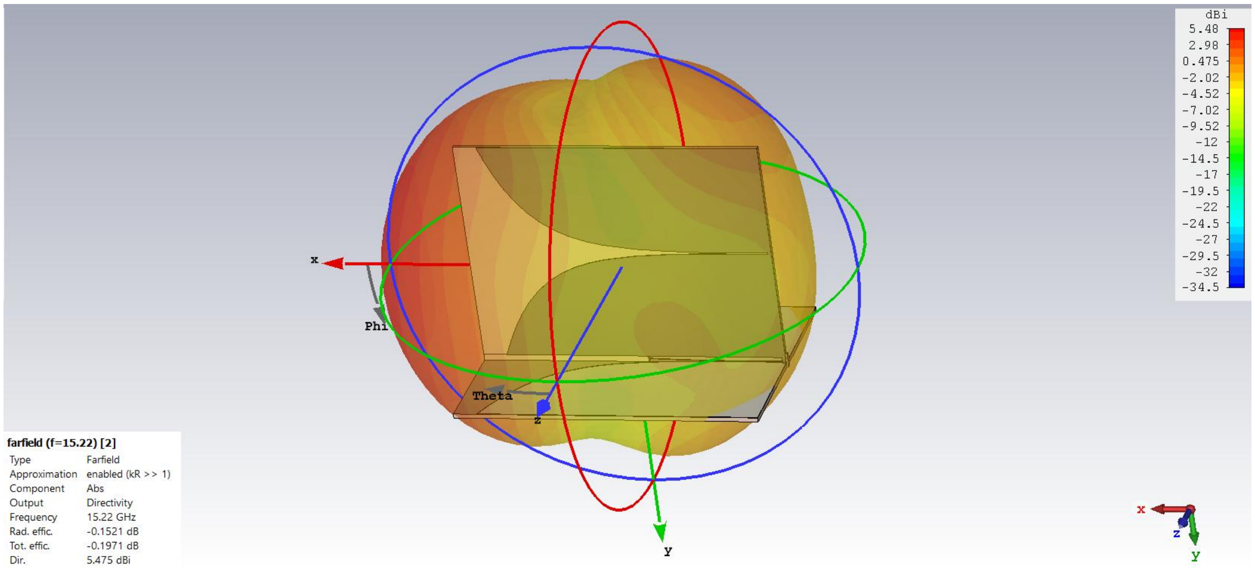


Fig 3.4.9 Radiation Pattern of 2 port Antenna in end-fire direction

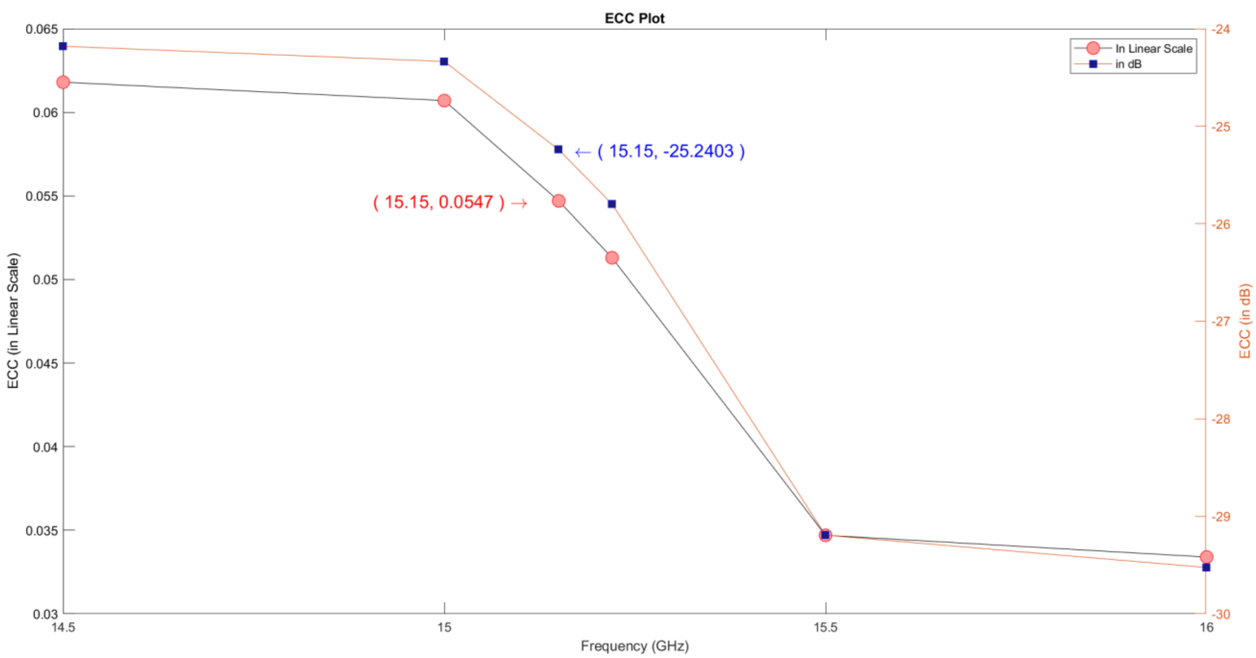


Fig 3.4.10 ECC Plot of two- port Vivaldi Antenna using Farfield data.

Antenna	Impedance Bandwidth	Fractional Impedance Bandwidth	Gain in End-fire Direction	Radiation Efficiency	Center Frequency
Base Antenna	45.2 – 52.8 GHz	15.51 %	5.0 dBi	-0.2697 dB	48.75 GHz
Modified Antenna	14.009–16.1279 GHz	14.06 %	5.6 dBi	-0.1344 dB	15.33 GHz
2-Port Antenna (Port 1 excited)	14.155–16.16 GHz	13.22 %	6.23 dBi	-0.1564 dB	15.22 GHz
2-Port Antenna (Port 2 excited)	14.125 – 16.408 GHz	14.95 %	5.43 dBi	-0.1521 dB	15.22GHz
2-Port Antenna	14.155 – 16.16 GHz	13.17 %	-	-	-

Table No 3.4.1 Performance Parameters of All Antenna

5. **Summary**

We have seen that the direction of radiation pattern of all antennas is in end-fire direction. By adding another antenna, the overall gain of our antenna is increased. We have to manage to reduce the center frequency of Antenna by increasing the geometrics parameters of Antenna.

Chapter 4

Conclusion and Future Work

In this project, a two port Vivaldi antenna with polarization diversity characteristics is studied. The two port antenna design is achieved by placing two identical microstrip line fed coplanar Vivaldi antenna elements orthogonally with respect to each other. The proposed two port antenna operates at 15.15 GHz with an impedance bandwidth 13.17%. The isolation between the ports is better than -28 dB in the operating band of the antenna. The two-port antenna exhibits an end-fire radiation with gain better than 5.4 dBi at both the ports. The ECC of two port Vivaldi Antenna at center frequency is 0.0547 or -25.24 dB.

For future work, a prototype of the proposed antenna will be fabricated. Furthermore, measurements will be carried out on the fabricated antenna to validate the results obtained in the simulation. The two-port antenna design concepts may be extended for the design of multi-port antenna for MIMO applications.

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