DESIGN OF A HIGH BANDWIDTH CIRCULARLY POLARISED ANTIPODAL VIVALDI ARRAY FOR 5G COMMUNICATION SYSTEMS

A DISSERTATION

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Submitted by:

Anirudh Nakra — DTU/2K17/EC/022

Abhijeet Vats — DTU/2K17/EC/003

Under the supervision of:

Prof. Asok De

ELECTRONICS AND COMMUNICATION ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

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B. Tech (Electronics and Communication Engineering) Anirudh Nakra Abhijeet Vats 2021

ELECTRONICS AND COMMUNICATION ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

CANDIDATE'S DECLARATION

We, Anirudh Nakra and Abhijeet Vats, Roll Nos. 2K17/EC/022, 2K17/EC/003, students of B. Tech. Electronics and Communication Engineering, hereby declare that the project Dissertation titled "Design Of A High Bandwidth Circularly Polarized Antipodal Vivaldi Array For 5G Communication Systems" which is submitted by us to the Department of Electronics and Communication Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Bachelor of Technology, is original and not copied from any source without proper citation. This work has not been previously formed the basis of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

Place: Delhi

Date: 24 May 2021

Anirudh

Anirudh Nakra DTU/2K17/EC/22

Abhijeet

Abhijeet Vats DTU/2K17/EC/03

ELECTRONICS AND COMMUNICATION ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

CERTIFICATE

I hereby certify that the Project Dissertation titled "Design Of A High Bandwidth Circularly Polarized Antipodal Vivaldi Array For 5g Communication Systems " which is submitted by Anirudh Nakra and Abhijeet Vats, Roll Nos. 2K17/EC/022, and 2K17/EC/003, Electronics and Communication Engineering Department, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Bachelor of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi

Date: 24 May 2021

Prof. Asok De

Thesis Supervisor
Professor
Electronics and Communication
Engineering Department
Delhi Technological University
Bawana Road, Delhi-110042

ABSTRACT

5G systems are the pathway to endless possibilities. There are numerous technologies that will benefit from the added bitrate and lower latency that is envisioned by current scientists. Despite the obvious upgrades in multimedia streaming and real time services, 5G seeks to foster new high potential ideas that were previously limited due to bandwidth and other capacities. Our work has focused on modifying the existing 5G infrastructure especially the antenna hardware to be better prepared for future changes. We design an antenna array that is circularly polarized to combat multipath and interference effects and help ensure the viability of future last mile and satellite communication-based setups. By developing a new system based on the integration of two high bandwidth, highly directive slotted antipodal antennas, a six-stage high isolation Wilkinson power divider and a broadside aperture coupling based phase shifter, we have achieved axial ratios of around 0.098 dB which is an improvement over similar researches that focused on the lower X band. Our work at 8.56 GHz has strong potential to be extrapolated to sub 6GHz bands of 5G technology as well as mm Wave frequencies where interference effects due to polarization are more widespread. The system, developed using CST Design Studio, has near ideal return losses (~ -35 dB) at the design frequency and would be instrumental in future hardware proof of concepts for next gen communication systems. Future fabrication of the designed system is needed to experimentally verify our findings and help test it with the whole infrastructure.

ACKNOWLEDGEMENT

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CONTENT

LIST OF FIGURES AND TABLES

Fig. No. **Title** **Page No.**

LIST OF SYMBOLS, ABBREVIATIONS AND NOMENCLATURE

S.No.	Symbol	Definition
1	Ws	Width of the substrate
2	h	Height of substrate
3	H_e	Function of dielectric constant
4	$\in_{\boldsymbol{r}}$	Relative dielectric constant
5	Zo	Characteristic impedance
6	C	Coupling Factor
7	β_{ef}	Effective phase constant
8	$\emptyset$	Phase angle
9	Zoe	Even mode impedance
10	Zoo	Odd mode impedance
11	K	First kind Elliptical integral
12	K’	K ($\sqrt{1-k^2}$)
13	k1	Parameters used to find Ds and Dm
14	k2	Parameters used to find Ds and Dm
15	D_s	Diameter of slot
16	D_m	Diameter of patch

CHAPTER 1 INTRODUCTION

In this chapter, we discuss the background of antenna literature and concepts that have been used extensively to bring forth the main point of the research. In concise, we have researched on microstrip technology based planar antennas such as patch antennas of different geometries like circular and rectangular as well as more complicated recently developed antennas such as printed lotus type Quasi-Yagi and an antipodal Vivaldi antenna. The antennas discussed are as follows:

1. Patch antennas: Rectangular microstrip patch antenna, Circular patch antenna, Semicircular patch UWB antenna.
    - These antennas are cheap and easily fabricated. They work great at lower frequencies but have high losses at high frequencies, especially the lower X band which is the focus of our work.

2. Printed antennas: The lotus shaped printed Quasi Yagi antenna, antipodal Vivaldi antenna, Vivaldi antenna
    - These antennas enjoy easy fabrication procedures and also have an excellent response in the higher frequency bands. They are easy to make, relatively inexpensive and can be arranged into antenna arrays pretty easily.

This chapter also deals with the theoretical background of important concepts like polarization, antenna arrays and 5G specific implementations. It focuses on giving a brief background on the considerations taken and the concise reasoning for the implementation. Future chapters will elaborate more on the design procedures and efficiency comparisons.

1.1 BACKGROUND

Antennas are an important part of today's technological advancements. Every little handheld device that millions of people are holding around the world has tiny sensors and antennas embedded in them. These little creations are nothing but transducers that allow the interconversion between AC and electromagnetic power. Antennas have a relative recent history when compared with other revolutionary technologies. They were initially designed as an experimental verification for proving the validity of Maxwell's EM wave theory and have now been employed for any and every tool. RFID, GPS, 5G and other paradigms have been made possible only, with the evolution of antennas.

5G is the new hyped next generation technology, and rightly so. The obvious advantages are that it brings such as an increase in peak speed of up to 100 times as compared to 4G systems. However, it also has a drastic influence on network latency. Fields such as Internet of Things (IOT) have been conventionally limited by network bandwidth and high delays. 5G aims to ensure that human delay is the only limiting factor in machine-to-machine communication. Fun emerging technologies like virtual reality, augmented reality and cloud gaming will benefit from these numerous advantages. Services like Google Stadia and PlayStation Remote Play may finally reach the levels they were advertised to have. It is important to note that the antenna is therefore a very important part of the 5G system and antenna fabrication needs to be geared towards the above-mentioned applications. There needs to be a huge increase in bandwidth with 5G systems aiming to reach north of 1000x more capacity than existing 4G infrastructure. In the world of ubiquitous sensing, there needs to be some work done on antenna design that have high bandwidths and enable fast links.

High bandwidth applications such as VR, AR and 3D video conferencing need to be taken into consideration while real time working conditions need to be prioritized by reducing latency using the architecture created. There are a wide variety of issues that need to be solved so that 5G can reach its potential. There is a need for creating a system that negates absorption due to city infrastructure and environmental hindrances such as shrubbery and rainfall. 5G systems have broadly operated in the range of 3 to up to 300 GHz however recently these were categorized into sub 6 band and mm Wave bands. Our work will however focus on the techniques implemented in the lower X band and their feasibility in 5G systems. The system will also be tunable for sub 6Ghz bands and would enable high bandwidth transmission.

Due to the nature of high frequency signals being used, there is an advantage of 5G antennas being able to be highly directive while at the same time being much smaller than previous generation antennas. The 5G infrastructure has the capability of stacking many directional antennas and thus providing coverage to a very large number of users. There is still the issue of LOS communication that will be very difficult to achieve especially in the case of huge metropolitan cities with lengthy skyscrapers and obstructions at every corner.

The antenna works as a transducer and for that purpose, we need to understand how the antenna is polarized, which tells us about the plane in which the EM wave is vibrating. There are 2 types of Polarization.

- Linearly polarized:

In Linear Polarization, the vibrations of the electric field component are only in one plane, depending on the relation between the cross product of the magnetic field vector and the electric field vector gives the direction of the EM wave. We can understand this by a simple example. If the EM wave is propagating in the x direction, the electric field component will be restrained only in either YX plane or ZX plane. Depending on whether the electric field is parallel or normal to the earth's surface, Linear Polarization can be termed as vertical and horizontal linear polarization respectively.

- Circularly polarized:

In this Polarization, the Electric Field Component circulates around the EM wave in one unit wavelength time. If the electric field circulates clockwise, then the EM wave is Right Hand Circularly Polarized and if it Circulates in anticlockwise direction, then the EM wave is left hand circularly polarized.

When it comes to designing an antenna, polarization must be considered as it is used to attain maximum gain and suffer low losses. When we consider communication in mobile devices, an omnidirectional antenna is needed for increasing gain and thus cause no polarization issues.

The concept of circular polarization is an important study here. For antennas with high directivity, the concept of a CP integrated antenna array can help achieve very low latencies. Especially in indoor environments, the received power in 5G is highly correlated to the polarization of the signal wave. Creating a CP thus helps enable a high enough power at frequencies of concern. Circular polarization is an effective way to combat noise and other issues. First and foremost, power losses in circular polarization are much lower than linear polarization-based antennas due to their ability to recapture energy in planes that are different from the incident wave plane. Circular polarization negates these effects of reflectivity Furthermore CP creates a better linkage between the transmitter and receiver due to its property of transmitting in all planes at once. It also counters interferences added due to weather and multipath effects making it an obvious choice for next-gen applications.

1.2 DESIGN BACKGROUND

Our design works most efficiently in the lower X band between 8-9 GHz where the fifth generation of mobile communication is increasingly relevant. These microwave frequencies have been crucial in RF design and research with benefits in LOS and point to point communication. During our design process, we chose the range carefully after noticing some drawbacks in the higher bands namely high attenuation losses and high weather dependencies. Our research has focused on choosing the best antennas to create an array that is circularly polarized and is broadband enough to justify 5G applications.

CP can be pretty easily created by creating a phase shift of 90 degrees between the two feed lines going to the various antennas. Our work justifies the use of a Wilkinson power splitter and broadside aperture coupled phase shifter that can essentially create a perfect orthogonal phase difference in our target design range and can allow wideband characteristics that have been difficult to achieve in the past. We have also in our work justified the consideration of an antipodal Vivaldi antenna that has been chosen as our choice after an in-depth comparison based on parameters such as bandwidth, return loss, VSWR, Gain, Directivity and radiation efficiency. By calculating the axial ratio of the system and studying the radiation patterns we also justify why our system is unique and performs better than other studies done in the past.

5G systems have much to gain from CP antennas. When the systems penetrate further and satellite communications become a necessity to integrate, CP antennas will be an essential part of the infrastructure. Their good loss handling will make 5G systems better and future mobile phones will have wide beam width and portable CP antennas that are used ubiquitously.

1.3 LITERATURE REVIEW

Polarization has long been one of the most important factors in modern antenna theory. It can be easily determined by checking the orientation of the E field as described in above. Polarization of transmission and reception antennas can be a huge deciding factor in the SNR of the signal transmitted. Cross polarization is one such phenomena that incurs huge losses and it happens when the polarization of the receiving and transmitting antennas are opposite. In case of circular polarization, the signal is present in all planes and thus the resulting orientation of the transmitting and the receiving antenna doesn't matter. Signals can thus be captured in any direction. Certain microstrip patch antennas such as those we studied in earlier chapters can easily be used for CP antennas by minor modifications. For example, cutting the diagonal opposite edges of a rectangle patch in the antenna can create an effect of CP. However, for higher frequencies such simplistic models do not work very effectively. There is thus a need for antenna arrays that transmit in opposite polarization to create a CP model.

Recently, much work has been focused on UWB applications for CP arrays. Papers by Narbudowicz and other researchers have discovered good axial ratios in broadband applications only over the last decade or so. Widespread rule changes have also sped up the activity in UWB research and much work has been done recently on coupling the benefits of UWB systems with CP antenna arrays. Delay reference microstrip lines have been used in the past for CP applications and generating an orthogonal phase shift but they have been rendered ineffective in UWB applications. Research by Dr AM Abbosh on UWB phase shifters based on broadside coupling techniques has been the state of art over the last few years. Edge coupled and Schiffman phase shifters are also quite popular but they suffer from issues such as high fabrication costs and difficulties.

There have also been major studies on the optimal choice of the antennas for the CP array. We ourselves have conducted studies in the past on the efficacy of six popular antennas that signify the evolution of the industry over time. We studied the rectangular patch antenna, the circular patch antenna, the UWB patch antenna, the antipodal Vivaldi antenna (AVA), the printed lotus Quasi Yagi antenna and the modified slotted AVA. Through comparisons based on different parameters such as directivity and radiation efficiency, we arrived at our conclusion that the antipodal Vivaldi antenna gives the best tradeoffs between gain, bandwidth and other parameters. Past research by other researchers have also suggested that a Circularly Polarized end firing Vivaldi antenna is an excellent solution for the problem once spatially optimized due to its low-cost fabrication and excellent broadband response.

CHAPTER 2. ANTENNA STUDY

2.1 MICROSTRIP PATCH ANTENNA

Microstrip is a transmission line technology that is heavily used in higher frequencies, especially focusing on microwave frequencies. The technology is easily fabricated and is an encompassing term for a dielectric sandwiched between a conductor and a usually metallic ground plate. This so-called "substrate" or the dielectric that has been sandwiched can enable frequency signal transmission. Microstrip usually have higher losses and weak power handling. However, they excel at being easy to fabricate with their ability of being realized on multiple technologies such as PCB's, coated alumina, etc.

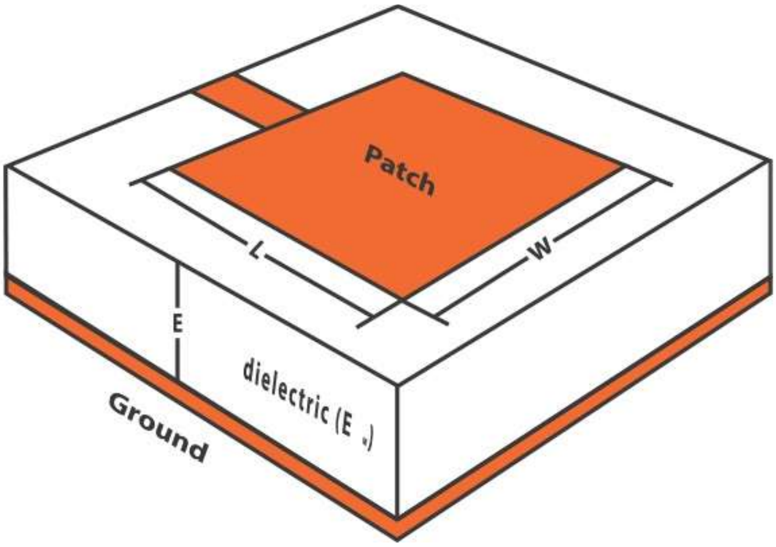

Fig.2.1 Rectangular Microstrip Patch antenna

Microstrip patch antennas are thus an effective way to construct easily realizable antennas. They can be printed onto circuit boards and are usually very inexpensive which adds to their strength. Due to their low cost and easy realization, they are increasingly ubiquitous in the cell phone market. In our work, we focused especially on primitive types of microstrip patch antennas such as a rectangular and circular patch to compare the state of the art against the relatively simpler offerings. Using a semicircular patch, we were also able to combine the patches to form a cup-based structure that enabled UWB applications at lower frequencies of around 3-4 GHz.

2.2 ANTIPODAL VIVALDI ANTENNA

With the recent shift in demand to more UWB applications such as virtual reality, augmented reality, and even wideband imaging, there is a need for antennas that operate at higher frequency ranges and provide the benefits of high gain, a good VSWR, huge bandwidth among others. Another advantage of the antipodal Vivaldi antenna is its ability to transmit and receive ultra-short pulses. Other alternatives to the antenna such as the spiral and horn antenna suffer from non-compensation of dispersion-based effects and thus do not provide reasonable performance in applications like UWB radios. In the case of ground penetrating radars or GDR, the antipodal Vivaldi antenna’s energy transmitted doesn't drop very fast when it is lifted from the soil where the detection items are buried. Thus, the antipodal Vivaldi antenna is a very important part of future UWB system design.

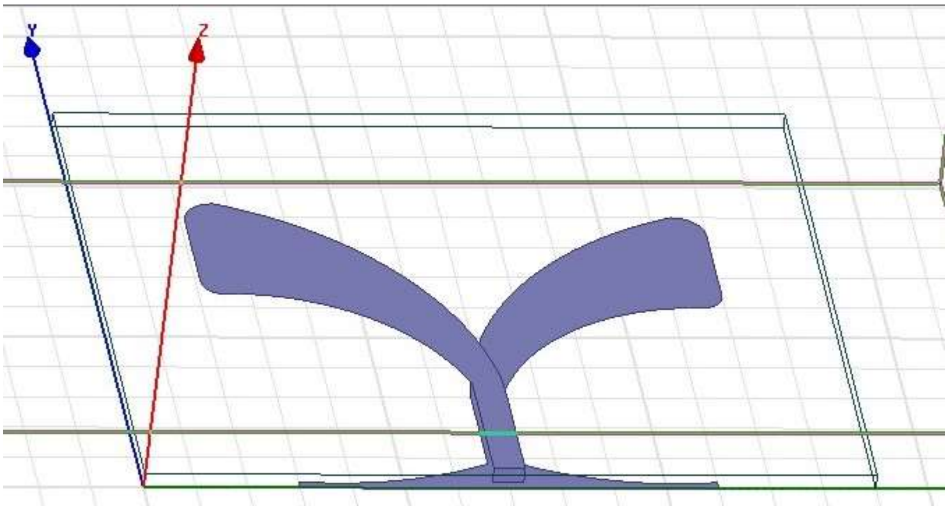

Fig.2.2 Antipodal Vivaldi antenna without slots

2.2.1 DESIGN

The Vivaldi antenna is designed using constraint equations for its exponential taper. Since the antenna is developed from a conventional tapered slot antenna with the only difference being the taper equations themselves, it is quite easy to mathematically solve under the constraints required. Although the Vivaldi antenna has an infinite B/W and constant beam width theoretically, it is practically limited by issues such as the feeding network and the actual formulated geometry.

The antenna dimensions are most easily calculable using a FDTD computational program. This tool enables us to create field visualizations which can then be further examined to analyses some difficult planar antenna designs. Given the constraints such as center or resonant frequency, we can fully control the design of the length and width according to our geometries and taper equations. This flexibility in design is very rare and is an appreciable feature of the Vivaldi antenna.

$$\frac{Ws}{h} = \frac{8\ e^{He}}{e^{2He} - 2} \qquad 2.1$$

$$He = \frac{Zo\sqrt{2(\epsilon_r + 1)}}{120} + \frac{1}{2}\frac{(\epsilon_r + 1)}{(\epsilon_r - 1)}(ln\frac{\pi}{2} + \frac{1}{\epsilon_r}ln\frac{\pi}{4} \qquad 2.2$$

Using QFDT90 software, we define parameters: dx=1.5, dy=1.3, dz=1.2 in mm. For our specific case, we designed an antipodal Vivaldi antenna using RT Duroid (K=2.3) as our substrate of choice due to its low loss tangent at our chosen resonant frequency. RT Duroid is essentially a replacement for FR4 at higher frequencies as FR4 tends to get very lossy at high microwave frequencies. Specifically, we implemented the QFDTD90 software to get our parameters of dx, dy as well as dz. using a standard Gaussian pulse response as a primary excitation, we were able to solve for fields and compare it with our CAD model designed on HFSS 15. Although we will compare the antenna and its parameters in greater detail in later chapters, the high directivity along with wideband response was a perfect match for much work ongoing in the UWB systems area. It offers a great performance while also being more compact. It does have a high gain although not one of the best when compared to other antennas like the Quasi-Yagi antenna. There is also an introduction of cross polarization effects when an impedance matching circuit is introduced in the system but it is a simple process to create a matching network. The antenna is not without its drawbacks but is an excellent prospect for our specific investigation.

2.3 SLOTTED ANTIPODAL VIVALDI ANTENNA

The antipodal Vivaldi antenna designed above has been an all-round great antenna. It has a high directivity, can be easily fabricated on a PCB and can be employed in numerous high bandwidth applications. However, there has been a lot of research that has advanced the generic antipodal Vivaldi antenna to a stage where its gain and other response become even better. Methods such as creating ridges in the exponential taper of the two symmetrical lobes and modifying the

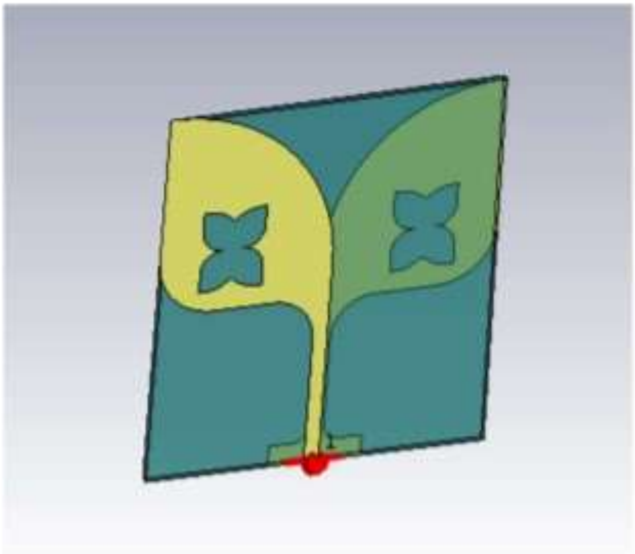

Fig.2.3 Antipodal Vivaldi antenna with slots

Geometry of the supporting substrate have been highly relevant in enhancing the end fire radiation characteristics of the antenna. Other works have investigated cutting different shaped patches on the antenna to increase its gain response. People have also juggled with ideas of triangularly shaping the taper successfully.

Our work has expanded our previous design and accommodated work by other researchers on the topic. We have heuristically designed slots on the two symmetrical metal patches. The design is done on the dielectric substrate ASTRA®MT77, which is a metamaterial. This is a novel attempt because of the fact that earlier antennas were made from substrates like FR4 and RT Duroid. It improves the performance because of its good electrical and non-electrical properties like resistivity, conductivity, temperature coefficient and dielectric strength. This model is constructed with a square microstrip patch with a microstrip transmission line mounted on a dielectric substrate.

A balun is created as the radiating element is a balanced structure, which provides a match between the 50-ohm feed line and the antenna. The final antenna is achieved by introducing and placing slots on the front and back side of the AVA. The exponentially tapered edge is defined by two things. First the opening rate and second the two points representing the center of the chamfer edge of radius r1 and r2 respectively. Such a curve can be constructed on a planar surface by using the mathematical equations of the curve on CST studio.

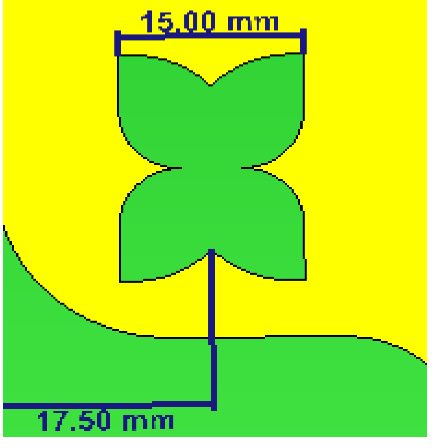

Fig.2.4 Design of Slot

For the antipodal Vivaldi antenna, if the inner edge is sharply tapered, the length of the inner notch decreases and the travelling wave property and the radiation properties decreases. Therefore, the tapering must be gradual in nature. Further the properties can also be affected by thickness and dielectric constant of the substrate. Applications can include transmissions which requires a very high bandwidth. It can prove to be an important facet in radar and wireless communication applications. This can also be widely used in dual polarization applications. Almost infinite bandwidth of this antipodal Vivaldi antenna can further be utilized in ultra-wide band applications, for e.g., where high data rate is required such as in sensing applications.

2.4 QUASI-YAGI ANTENNA

The Quasi-Yagi antenna was devised as a way to cumber the demand of wide bandwidth and good far field characteristics. One of the greatest advantages of the printed Quasi-Yagi antenna is its great beam pattern and very low coupling effects.

The antenna is used in telecommunication applications such as Worldwide Interoperability for Microwave Access also known as WiMAX and Wi-Fi. The conventional Yagi antennas had a very high gain and were quite simplistic in nature as well. The high gain coupled with an increased directivity as well as cheap and easy fabrication made the Yagi antenna a no-brainer in the RF field. However due to its narrow bandwidth and relatively bigger size, it had some important drawbacks that needed to be considered.

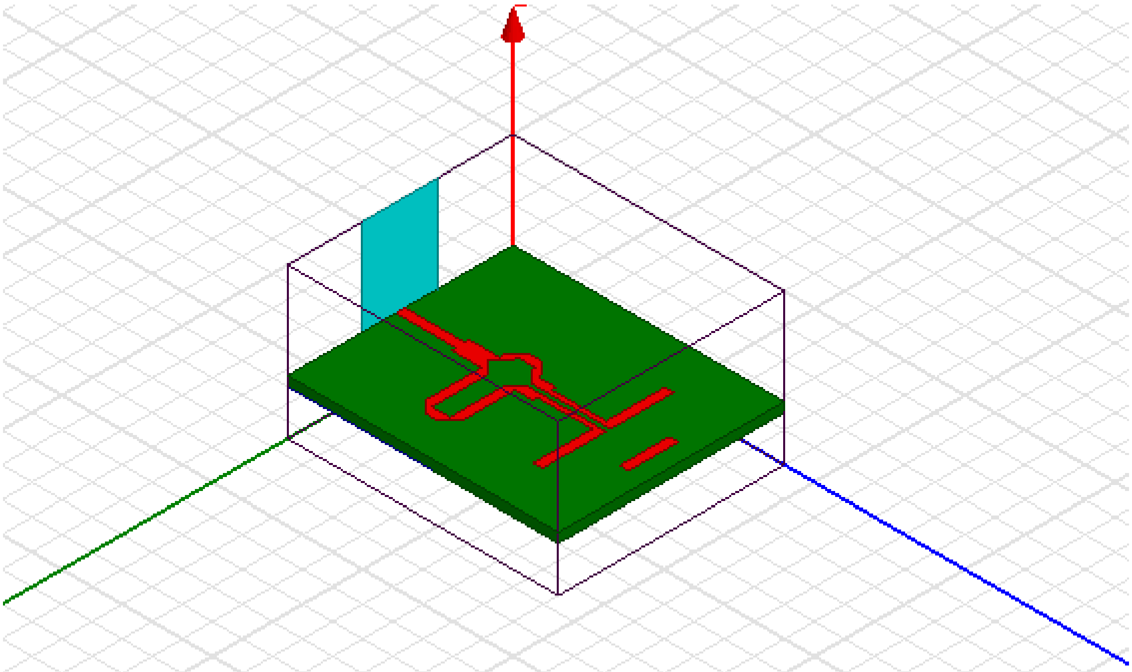

Fig.2.5 Quasi Yagi Antenna

The substrate chosen for our application is RT Duroid of relative permittivity 10.2 with metal deposits on both planes. The antenna has been designed with a microstrip feed line along with a balun and multiple dipole elements. The ground is microstrip based and works similar to a reflector. One of the dipole elements work as a parasitic director and it directs EM energy into a specific direction while also performing impedance matching. The Quasi-Yagi antenna is quite flexible with it being able to provide a tradeoff between gain and bandwidth when subjected to different parameter constraints. On substrates having relatively very high permittivity and metallization is done on both the sides. Multiple parasitic parts can be combined or introduced in the structure to enable higher gain and B/W. However, this causes the antenna structure to become more elaborate and is usually not required.

FDTD code is used to find the dimensions of the antenna. 0.635 mm thick Duroid is used, having a dielectric constant of 10.2. The broadband characteristics come by decreasing the size of the director element of the antenna than the conventional yagi-uda antenna. This antenna shows the best results when it comes to planar antennas showing a wide bandwidth with a compact design. The drawback is that the quasi-Yagi antenna requires a complex feeding network.

CHAPTER 3. POWER SPLITTER NETWORK

As the name suggests, a power splitter splits an input signal into two signals and it also acts as a combiner by combining two inputs to give an output. When we consider an ideal case, we assume that the power splitter is lossless but the case is not that simple. Infact, the power splitter does suffer from some loss and for that purpose, different types of power splitter were researched upon to have high isolation, blocking signal cross-talk between output ports, low insertion and return loss. For our purpose, we tested different power splitters, for e.g., a T junction splitter and a 3 stage Wilkinson power splitter and a 6 stage Wilkinson power splitter. We compared the results for all these splitters and the Wilkinson power splitter showed better return loss for our specified purpose. Then, we concentrated on 3 Stage and 6 stage Wilkinson power splitter and the 6 stage Wilkinson power splitter gave better results for our purpose.
Ideal splitters must divide power equally with zero phase difference between the output ports. To achieve this, S parameters analysis is done and the phase difference is checked in the required frequency range.

3.1 WILKINSON POWER SPLITTER

Wilkinson Power Divider is used for power splitting between outputs ports in different ratios using different values of resistances connected between the output terminals.

It is considered superior to other power dividers like T junction power divider, T junction power divider with slot line etc. because of the qualities of it being lossless, reciprocal and matched at the same time. The Wilkinson power divider also has good isolation between the output ports when compared to above mentioned power dividers. This Wilkinson power divider circuit can also be used for the purpose of power combiner as the output ports are isolated and all the three ports are matched.

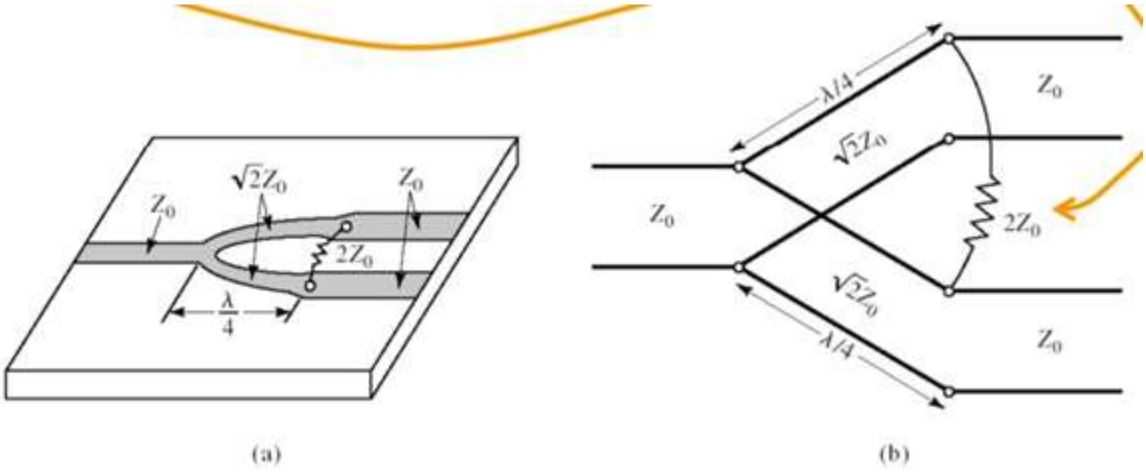

Fig.3.1 Basic Wilkinson Circuit Diagram

It also shows great reciprocity between the ports, i.e., when we send the signal from one port to the other without giving significance to direction, the outcome is the same for both.

There is one special property regarding the three port networks i.e., they cannot be matched and reciprocal at the same time without lossy nature of the circuit. The solution to this problem is to add a resistor between the two ports. So, what this resistor does is, it absorbs the energy if in case, there is mismatch between the output terminals. Moreover, when this circuit acts as a power combiner, this resistor also helps in isolation between the two terminals when the power is added to get an increased power output.

Most of the Microstrip designs are made for an impedance of 50 ohms to minimize reflection and return loss and it has also been chosen for most of the industrial applications. So, when we assume the system impedance at 50 ohms, 50 ohms should also appear at the input for matching and this should further be connected to resistance of 100 ohms each in parallel in order to be 50 ohms. In the Wilkinson power divider, this is achieved by using the concept of quarter wave transformers.

S parameters of the Wilkinson power divider are shown in the figure.

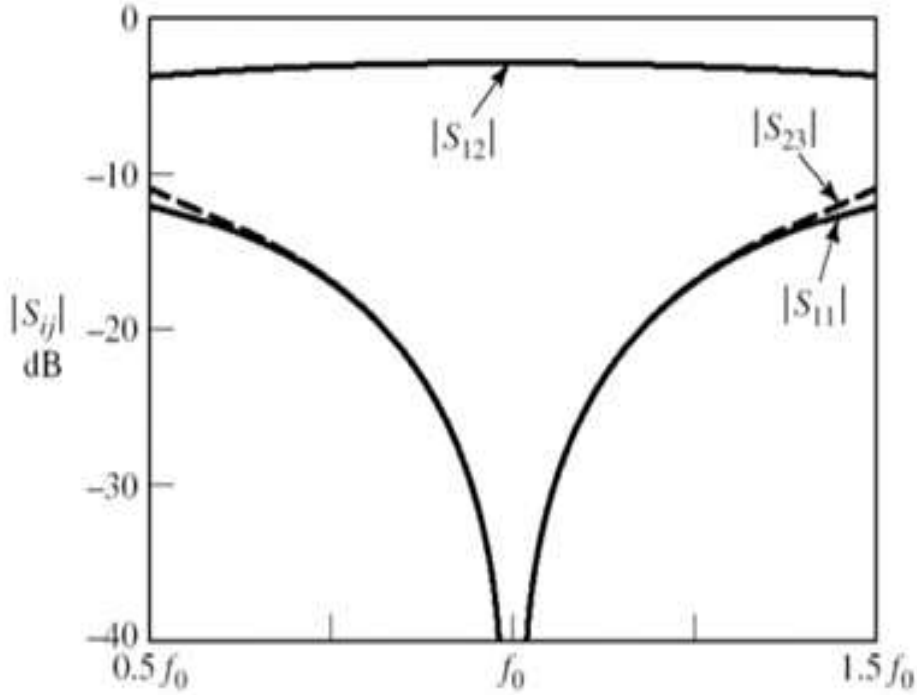

Fig.3.2 Ideal Wilkinson S parameters curve

By this, we can conclude that all the ports are matched. (s11=s22=s33=0), port 2,3 are isolated(s23=s32=0) and there is reciprocity(sij=sji).

Regarding the number of stages to be employed for the design of the Wilkinson power divider, as the no. of stages increases the isolation between the two ports increases but the loss also increases somewhat. Therefore, an optimization is needed depending on the applications. For this circuit to be implemented on microstrip, the impedances were transformed into different widths and lengths using the microstrip formula.

For the purpose of understanding, let's assume the power ratio between the ports to be 1, so, the power is equally divided between the output ports. Both the ends of the isolation resistor are found to be at the same electric potential considering the symmetry of the circuit, therefore current through that resistor becomes zero and decoupling of the resistor takes place and there is practically no loss.

3.1.1 Three Stage Wilkinson Power Divider

As the name suggests, this has 3 resistors in between the output ports and the impedances are drawn on microstrip using equivalent length and width formulas. The relation between the number of stages and application is significant as the performance suffers when it is not to the point. When we increase the number of stages in a Wilkinson power splitter, the isolation between the ports becomes better but the loss also increases. Therefore, we need to create a balance on how much our system can suffer losses in relation to the power constraints of the integrated system.

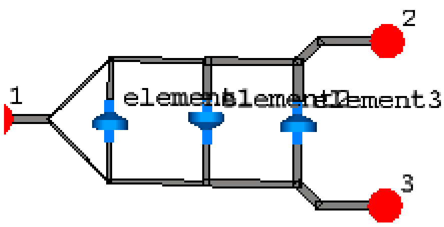

Fig.3.3 Three stage Wilkinson Power Splitter

We designed a 3 stage Wilkinson power splitter on Rogers substrate with Er= 2 and thickness of the substrate as 0.508mm. The isolation was 5 dB worse than the prediction because of the resistor not being ideal. Therefore, we shifted to 6 stage power splitter

3.1.2 Six Stage Wilkinson Power Divider

This has 6 resistors between the output ports. As the power constraints of our integrated system allowed some losses, therefore we went ahead with a better isolation between the output ports. The material of the substrate is Rogers 5880 with a dielectric constant of 2 and the thickness was the same as 0.508mm. This splitter gave zero phase difference in the frequency range of 3-9 GHz.

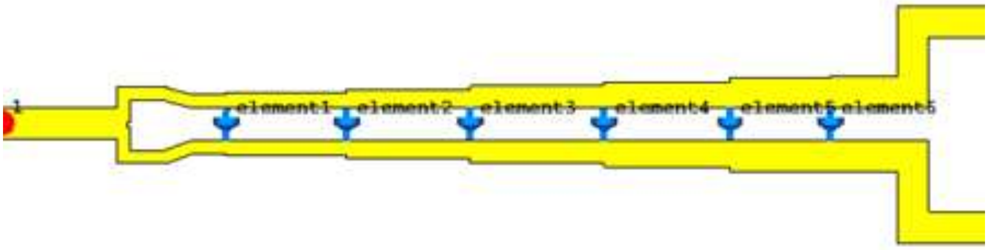

Fig.3.4 Six Stage Wilkinson Power Splitter

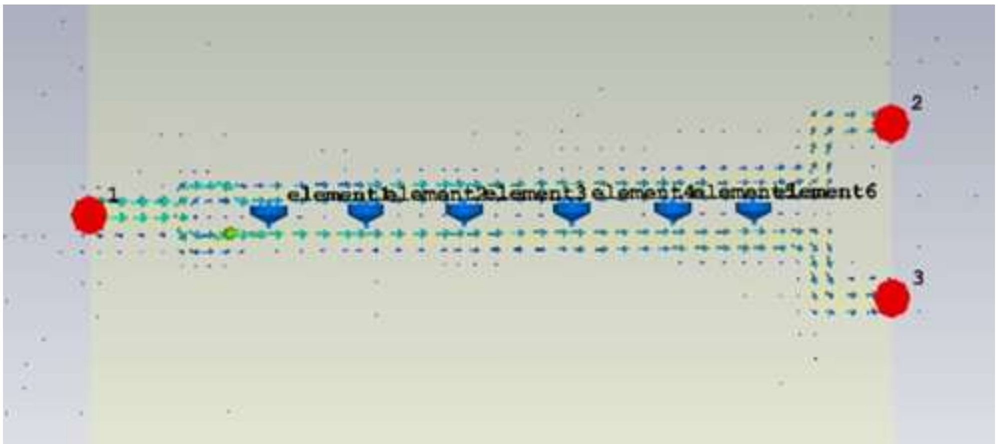

Fig.3.5 Power flow in 6 stage Wilkinson Power Splitter

3.2 DESIGN OF 6 STAGE WILKINSON POWER SPLITTER

Two power splitters were tested in the feed network: a 3 stage Wilkinson power splitter and a 6 stage Wilkinson power splitter. The 6 stage Wilkinson power divider designed on a substrate of thickness 0.508 mm and dielectric constant 2.2 and it showed better isolation between the output ports compared to the 3-stage divider.

A Multi Sectional structure with different impedances were used to achieve the operation of the power divider in the required frequency range. The values of the resistances were calculated by the formulas given in theory of the Wilkinson presented above.

Using the LineCalc tool provided in the schematic interface of Keysight ADS, we were able to define our control parameters to calculate the optimal length and width of the different stages. After calculating the characteristic impedances of the various stages mathematically and using TX line, we calculated, and fine-tuned the dimensions to those that gave us the best results. These widths and lengths were then translated into a 3d model in CST design studio using a delta separation of 1.3mm between the two isolated arms. By analyzing the S parameter curves, we saw that we were able to achieve an isolation greater than 28 dB which was better than the isolation from the splitters in both researches that we studied for references.

Resistors	**Dimensional Parameters of Wilkinson power divider**		
	Resistor values(ohms)	***Width(mm)***	***Length(mm)***
R1	153	W1=0.42	L1=5.20
R2	166	W2=0.53	L2=5.14
R3	258	W3=0.66	L3=4.99
R4	351	W4=0.75	L4=5.32
R5	299	W5=1.09	L5=4.78
R6	481	W6=1.14	L6=4.27

Table3.1. Wilkinson Power splitter Parameters

CHAPTER 4. ULTRA WIDEBAND PHASE SHIFTER

The Phase Shifter circuit in Microwave applications is used to create a phase difference between the output port and the reference line.

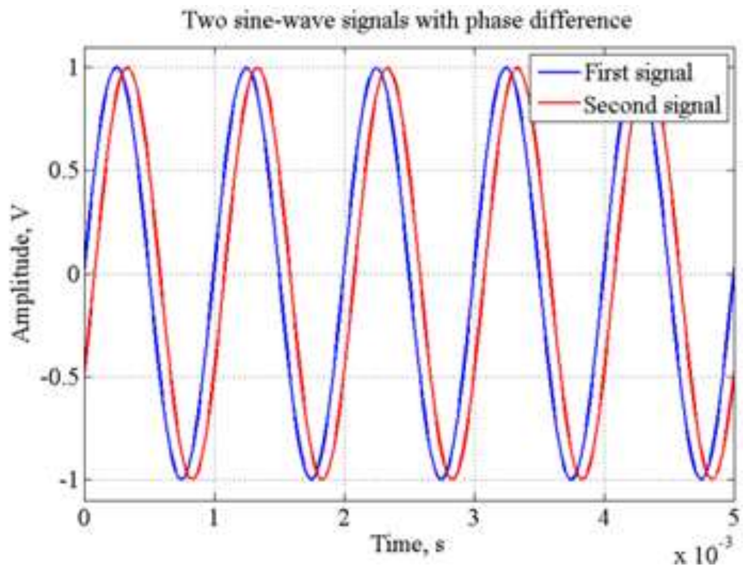

Fig.4.1 Phase Difference between 2 Signals

Different Phase shifters are used for different purposes for e.g., the radial phase shifter, Tandem Coupled Phase shifter, Broadside coupled phase shifter. For Phase shifters occurring at high frequencies, Broadside coupled phase shifters are used as they can perform the required phase difference in a lesser number of stages.

For the analysis of the broadside coupled Phase Shifter, conventional method of considering it as a four-port device is used.

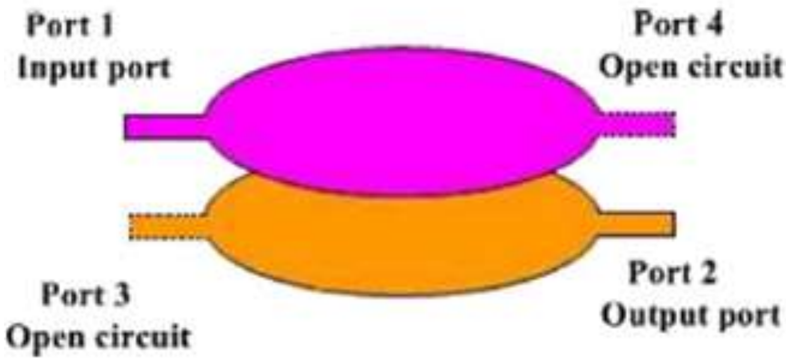

Fig.4.2 Phase Shifter as a 4-port network

Fig.4.3 Structure of Patch and slot

Two elliptical patches are made on each substrate with an elliptical slot in the ground which is sandwiched between the substrates. Different researches show that for the coupling value of C, the output signal at port 1 and port 2 can be written as—

$$b_1 = \frac{jC\sin(\beta_{ef}l)\,a_3 + \sqrt{1 - C^2 a_4}}{\sqrt{1 - C^2}\cos(\beta_{ef}\,l) + j\sin(\beta_{ef}l)} \qquad 4.1$$

$$b_2 = \frac{jC\sin(\beta_{ef}l)\,a_4 + \sqrt{1 - C^2 a_3}}{\sqrt{1 - C^2}\cos(\beta_{ef}\,l) + j\sin(\beta_{ef}l)} \qquad 4.2$$

Assuming that the 3rd and 4th ports are matched. Further from the concepts of 4 port network, since the port3 and port4 are open circuited, a3=b3 and a4=b4, because of no reflection.

S11 and s21 can be given by-

$$S_{11} = \frac{1 - C^2(1 + \sin{\beta_{ef}}^2\,l)}{[\sqrt{1 - C^2}\cos(\beta_{ef}\,l) + j\sin(\beta_{ef}l)]^2} \qquad 4.3$$

$$S_{21} = \frac{j2C[\sqrt{1 - C^2}\sin(\beta_{ef}l)}{[\sqrt{1 - C^2}\cos(\beta_{ef}\,l) + j\sin(\beta_{ef}l)]^2} \qquad 4.4$$

The differential phase shift can be calculated by measuring the phase difference with the input signal and then subtracting the phase given by the reference line of length l. The phase difference between the output port and the reference line can be given by--

$$\Delta\emptyset = 90^{\circ} - 2\tan^{-1}\left(\frac{\sin(\beta_{ef} l)}{\sqrt{1-C^2}\cos(\beta_{ef}\, l)}\right) + \beta_m l_m \qquad 4.5$$

Where the term Bm.lm represents the phase given by the reference line and the rest of the term can be calculated by the S parameters s21 and s11. It can be seen that the phase difference is dependent on length and coupling factor. Moreover, for the purpose of designing, we also have to take care of the insertion loss along with the bandwidth and for that purpose Bef * l should be 90 degrees at the center frequency. Phase shifters in general are important when it comes to applications in antennas. They are used extensively with array antennas as it can focus the radiation direction, so we don't need to change the orientation of the antenna every time. It also becomes important when there is a need for circular Polarization as in our case.

4.1 DESIGN

The phase shifter used in the model is based on broadside aperture coupling technique. The analysis of the Phase shifter is done using the conventional approach done for coupled microstrip line- treating it as a four-port device with two of its ports open circuited. Previous research has been done on creating microwave phase shifters. However, these works have often been non usable on high bandwidth equipment. Edge coupled and Schiffman phase shifters are popular but they suffer from issues such as high fabrication costs and difficulties.

The design proposed in broadside aperture coupling technique has been optimal because of its relative ease to design for its own purpose and high bandwidth. Three major steps have been utilized in creating this broadband phase shifter. The first step

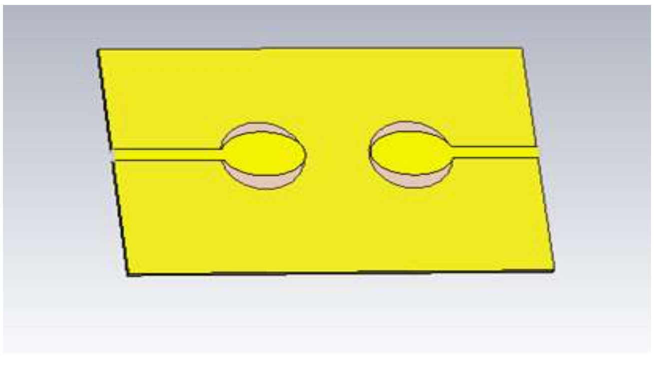

Fig.4.4 Phase Shifter Design

is to mathematically solve for the even and odd mode characteristic impedances for the proposed ellipses. After solving for them, an elliptical integral of the first kind was calculated for finding out the dimensions of the elliptical slots.

The even and odd mode impedances were calculated using the following equations—

$$Z_{oe} = Z_o\sqrt{\frac{1+C}{1-C}} \quad 4.6$$

$$Z_{oo} = Z_o\sqrt{\frac{1-C}{1+C}} \quad 4.7$$

From our earlier discussions, for the 45 degrees phase difference, coupling factor comes out to be 0.73. By using characteristic impedance of 50 ohms and C=0.73, even and odd mode impedances for 45 degrees can be easily calculated. To attain the dimensions of the coupled area, following equations were used-

$$Z_{oe} = \frac{60\pi K(k1)}{\sqrt{\epsilon_r}\ K'(k1)} \quad 4.8$$

$$Z_{oo} = \frac{60\pi K'(k2)}{\sqrt{\epsilon_r}\ K(k2)} \quad 4.9$$

By solving elliptical integral of first king and using the substrate value to be 2.2, the major and minor axis length can be calculated using the following equations--

$$k_1 = \sqrt{\frac{[\sinh(\pi^2 D_s/16h)]^2}{[\sinh(\pi^2 D_s/16h)]^2 +\ [\cosh(\pi^2 D_s/16h)]^2}} \quad 4.10$$

$$k_2 =\ \tanh(\pi^2 D_m/(16h)) \quad 4.11$$

The length calculation however is a relatively straightforward process with quarter wave formula being used at the resonant frequency of design. The modelling of these patches is the next major step. Using the calculated dimensions, we cut two nearly circular slots with the size of length 7.9mm and minor axis of 3.2mm in the ground plane. The ground was then sandwiched between two substrates of thickness 0.508mm and dielectric constant 2.2. Above and below the slots, we designed elliptical patches of the same length (7.9 mm) and minor axis 2.41mm.

The two elliptical patches placed below the lower substrate were joined using a microstrip line of characteristic impedance 50 ohms. The topmost patches were joined to the output port and the Wilkinson divider output respectively. The last step we undertook was to optimize the dimensions of both the slots and the elliptical patches to give us a 90-degree phase shift in the lower X band between 8 to 9 GHz. Fine tuning the dimensions was a largely cumbersome process and was solved using trial and error.

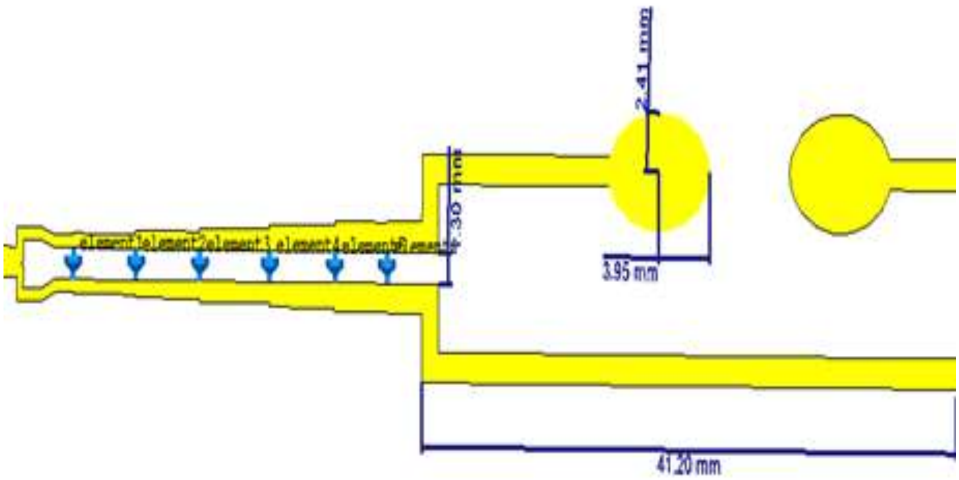

Fig.4.5 Wilkinson Power Splitter 6 stage and Phase shifter Combined

CHAPTER 5. SYSTEM INTEGRATION

The creation of antenna array is a complex task. Antenna arrays are created with the idea of combining multiple antennas to work together as a unified antenna and transmit information via EM waves. They work on the principle of constructive interference from the separate antennas to create a superposed radio wave that can enable high power for transmission. The same concept is also true for a receiver side antenna with arrays increasing the antenna receiving capacities. Usually, an increase in the number of antenna array elements increases the gain and decreases the usable bandwidth.

Our antenna and in general CP antennas are in high demand in RADAR applications as it can circumvent rain depolarization, Faraday rotation and other effects. A singular circularly polarized antenna is difficult to achieve due to its inability to match radiation patterns. This balance is however much simpler to achieve in a phased array.

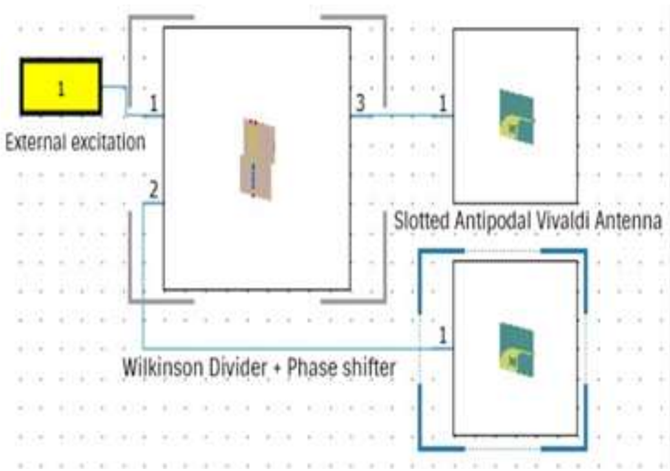

Fig.5.1 Schematic design of the whole system

In our design we have created the three major components that are required for creating a CP array. We have a power splitter/divider than can effectively cut the input signal into two equal halves while not compromising on the isolation between the two split parts. We have a phase shifter that is both suitable for high frequency applications as well as broadband applications. Our antenna, which we chose after an in-depth comparison, gives us a high gain, a high directivity as well as near ideal radiation efficiency.

After designing the individual components like Wilkinson power divider, phase shifter and antipodal Vivaldi antenna with slots, we integrated the system. The six stage Wilkinson power splitter gives around -30 dB isolation at our design frequency of 8.57 GHz when excited with a Gaussian impulse signal. Using the UWB phase shifter, we induce a phase shift of 90 degrees in order to make the polarizations of both antennas the exact opposite and induce circular polarization effects. The other arm is joined to a reference line in order to have no phase shift thereby getting an orthogonal shift between the two arms. The output of the phase shifter and the reference line were fed to individual end firing slotted antipodal Vivaldi antennas which were spatially optimized and kept at right angles to each other.

For the purpose of achieving circular polarization, both the antennas must be kept in such a way that their phase centers are close to each other, but factors like size and the space required to prevent coupling counters it. So, for optimization, the antennas are kept at right angles to each other.

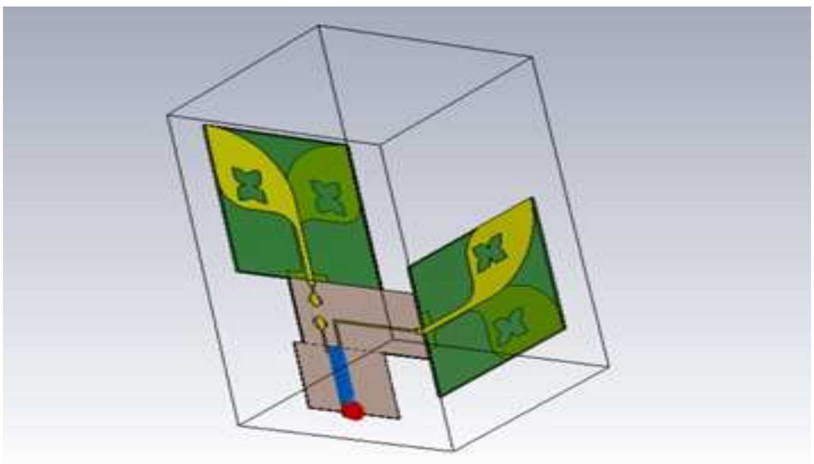

Fig.5.2 3D model of the Whole System

CHAPTER 6. RESULTS AND OBSERVATIONS

6.1 COMPARISON

	Rectangular patch	**Circular patch**	**Ultra-wide band**	**Antipodal Vivaldi**	**Quasi Yagi**	**Slotted Antipodal Vivaldi**
Bandwidth	104 MHz	81 MHz	10 GHz	1.2 GHz	4.1 GHz	8.2 GHz
Gain(dB)	4.7	1.9	3.56	7.64	3.4	9.16
Directivity(dB)	6.7	4.5	3.75	7.72	3.45	9.55
Radiation efficiency	70.14%	44%	94.9%	98.9%	99%	95.82%
VSWR	1.05	1.4	1.15	1.2	1.06	1.054
Return Loss(dB)	-32	-15.66	-23.48	-20.05	-29.62	-35.645

Table.6.1. Comparison of different antennae

6.2 ANTENNA

6.2.1 Antipodal Vivaldi Antenna

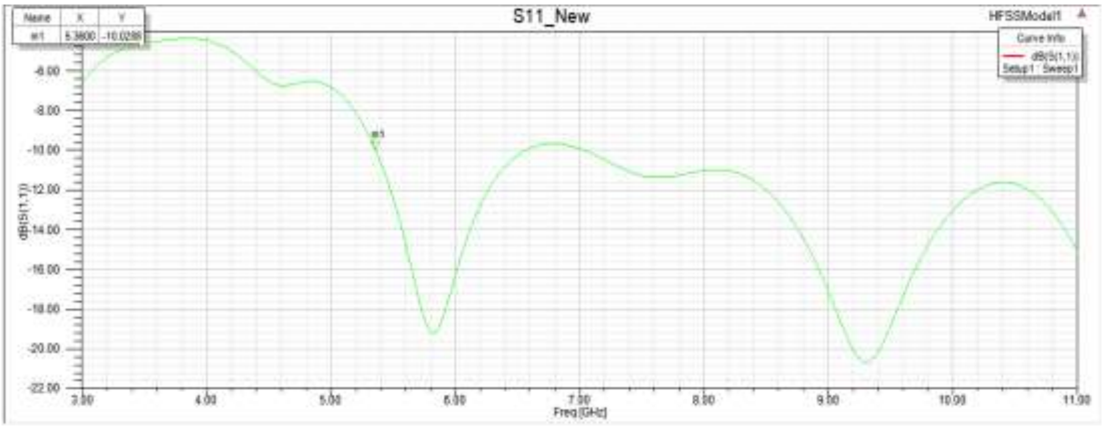

Fig.6.1 Return Loss of Antipodal Vivaldi Antenna

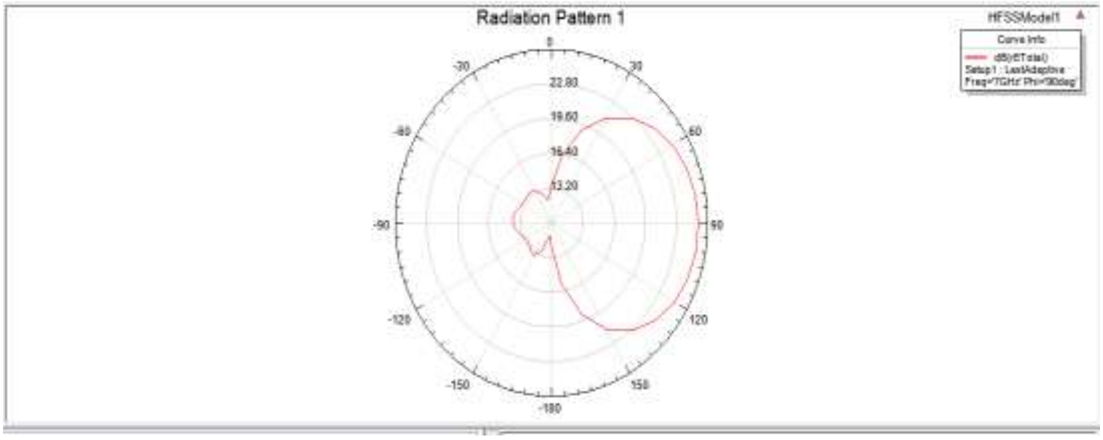

Fig.6.2 Radiation Pattern of Antipodal Vivaldi antenna

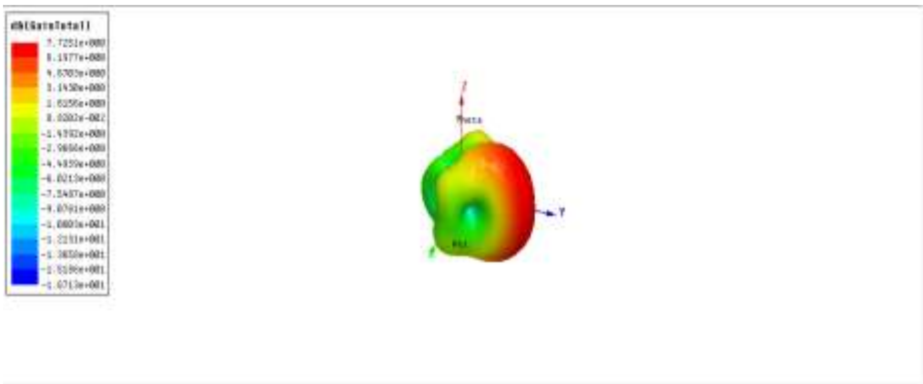

Fig.6.3 Polar plot of Antipodal Vivaldi antenna

6.2.2 Slotted Antipodal Vivaldi Antenna

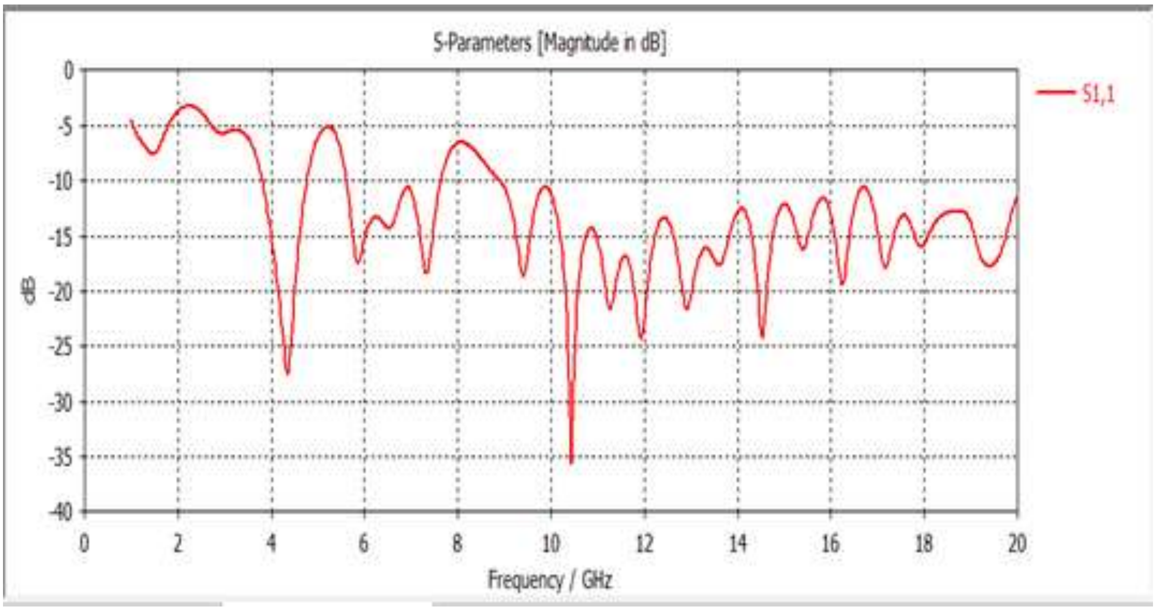

Fig.6.4 Return Loss of the Antenna

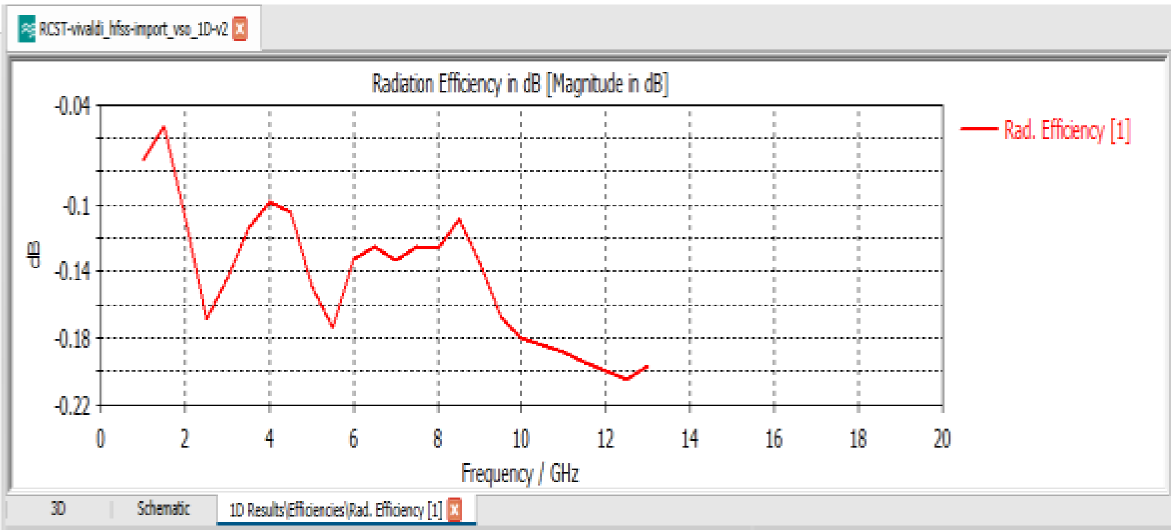

Fig.6.5 Radiation Efficiency

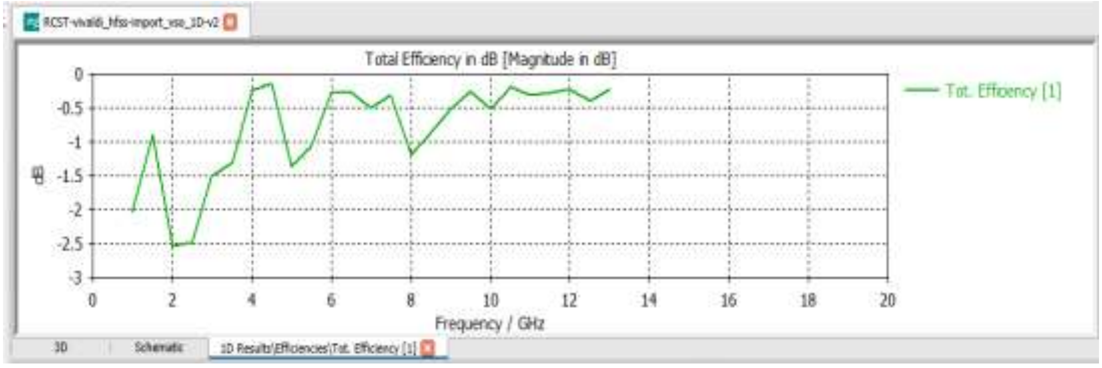

Fig.6.6 Total Efficiency

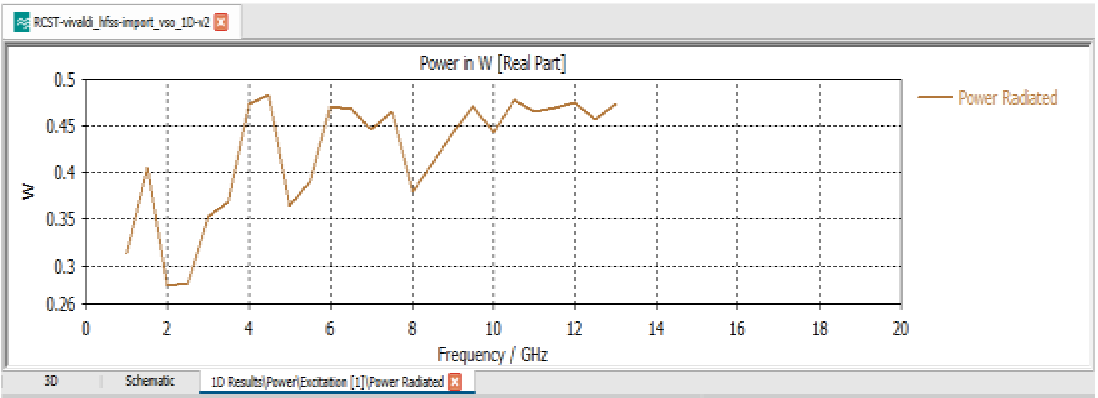

Fig.6.7 Power Radiated

6.3 POWER SPLITTER

6.3.1 Three Stage Wilkinson Divider

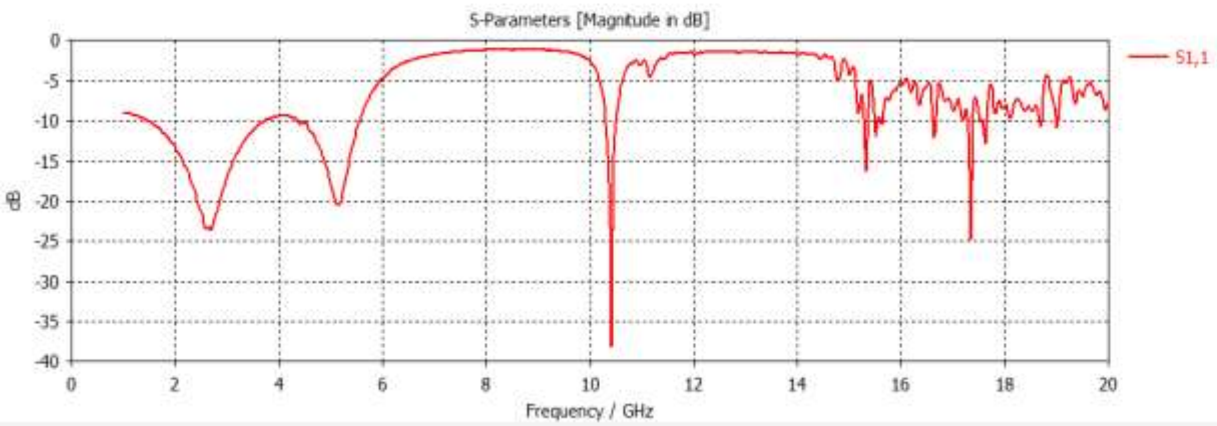

Fig.6.8 Return Loss of 3 stage Wilkinson

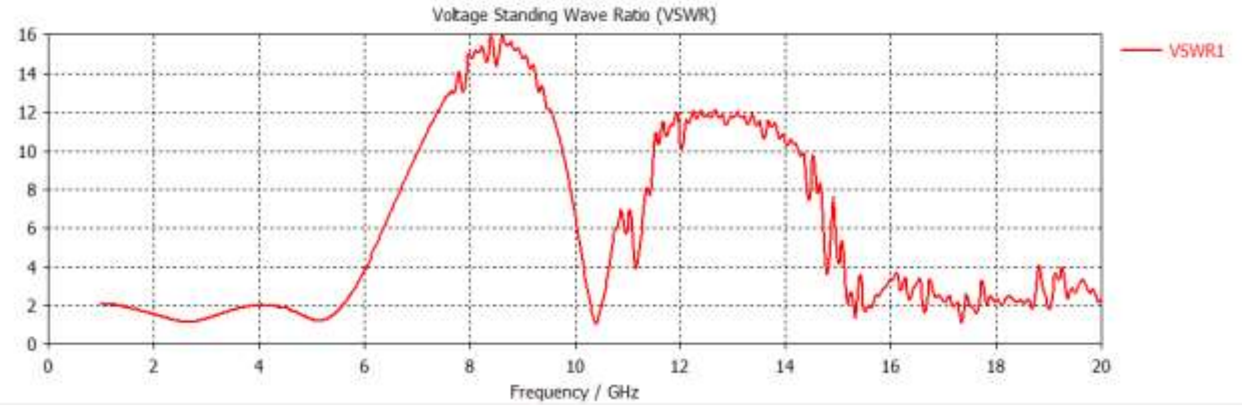

Fig.6.9 VSWR of 3 stage Wilkinson

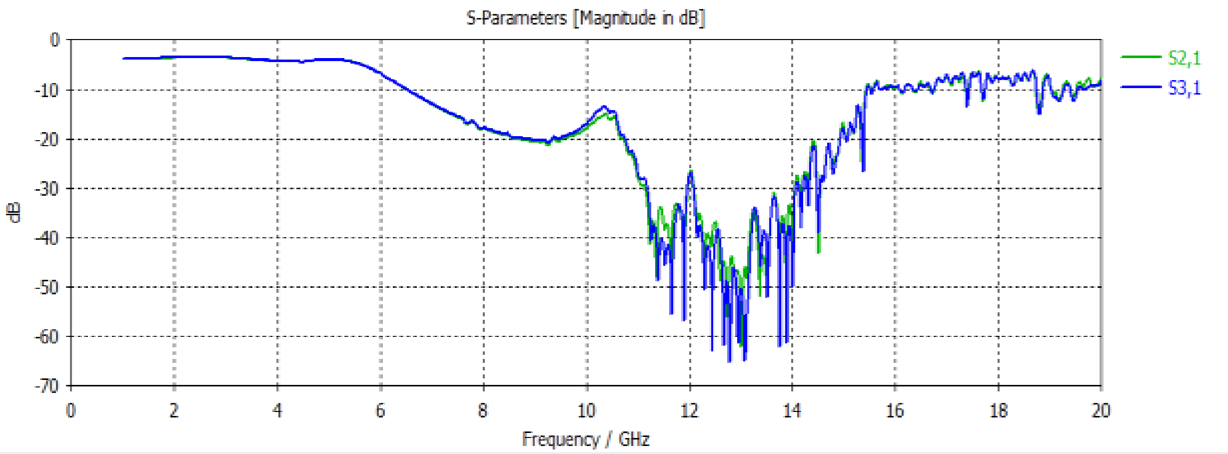

Fig.6.10 Power division between port 2 and port 3

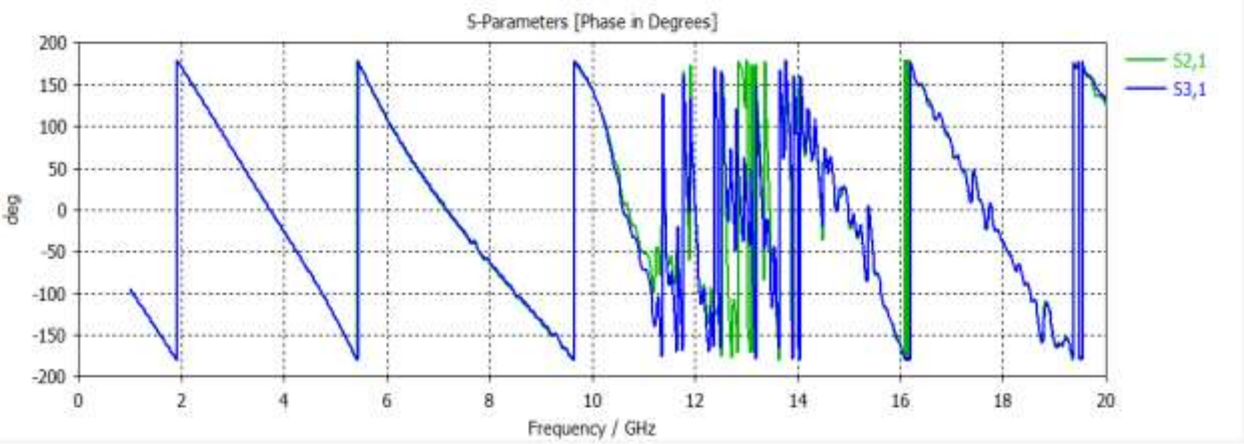

Fig.6.11 Phase difference between Port 2 and Port 3

6.3.2 Six Stage Wilkinson Divider

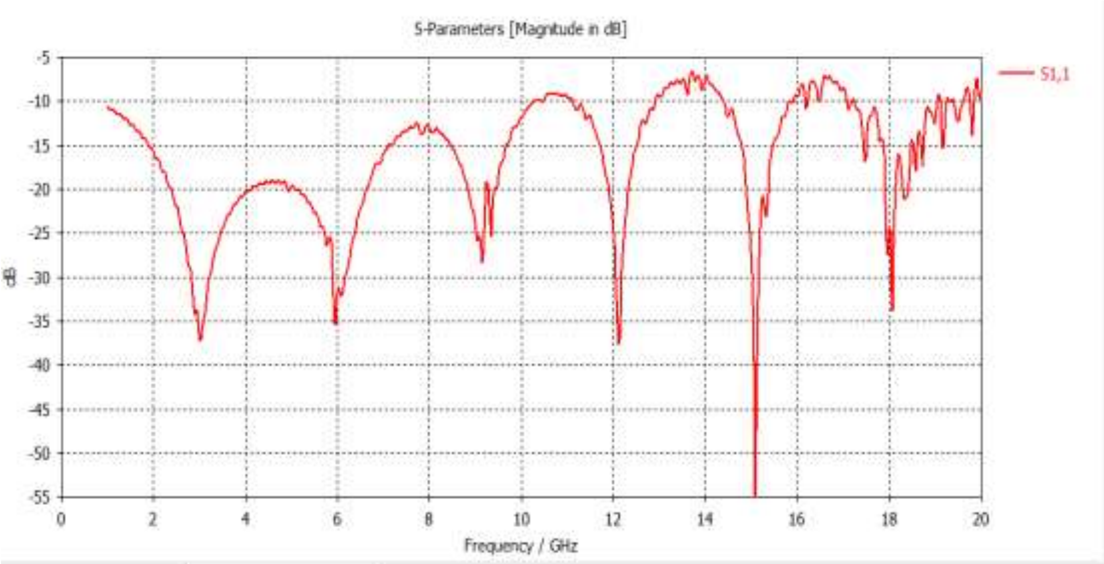

Fig.6.12 Return Loss of the 6 Stage Wilkinson power divider

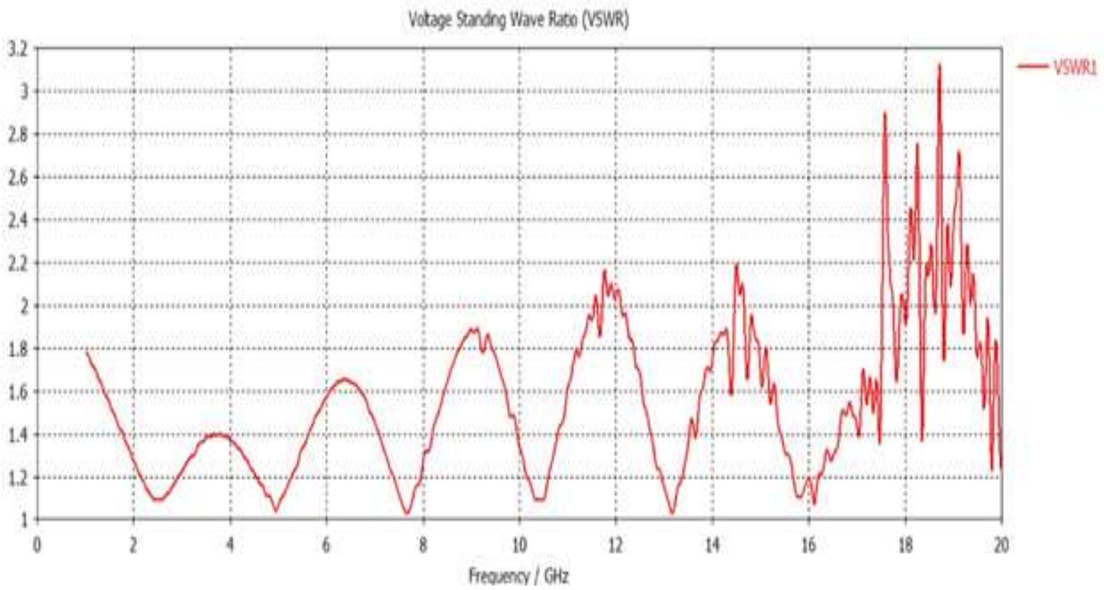

Fig.6.13 VSWR of 6 stage Wilkinson

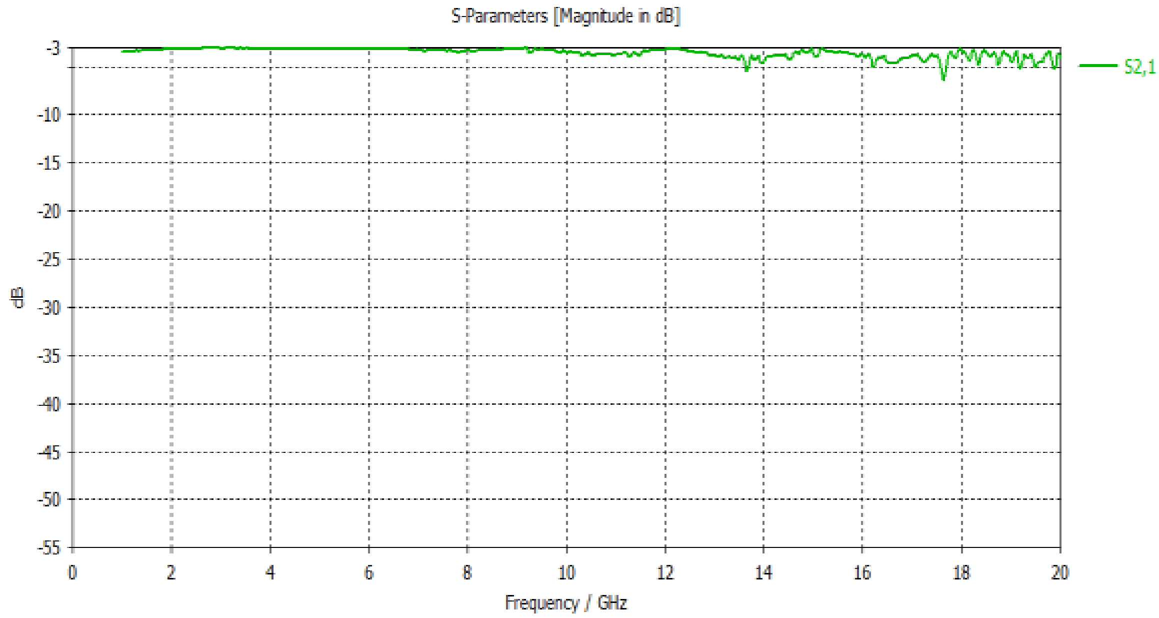

Fig.6.14 Equal Power division between the 2 Ports

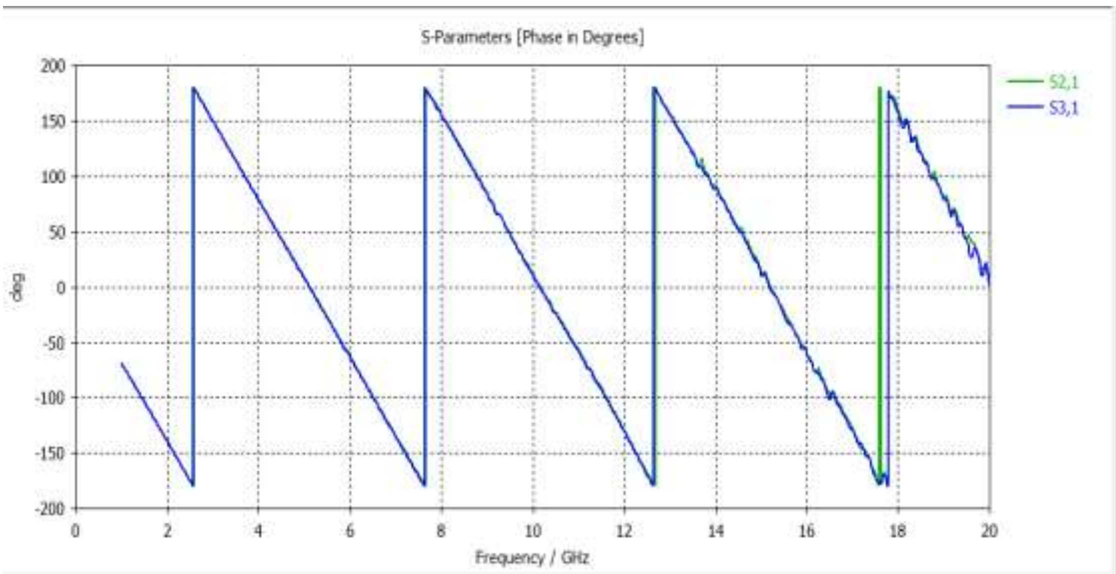

Fig.6.15 Phase difference between the 2 output ports

6.4 PHASE SHIFTER

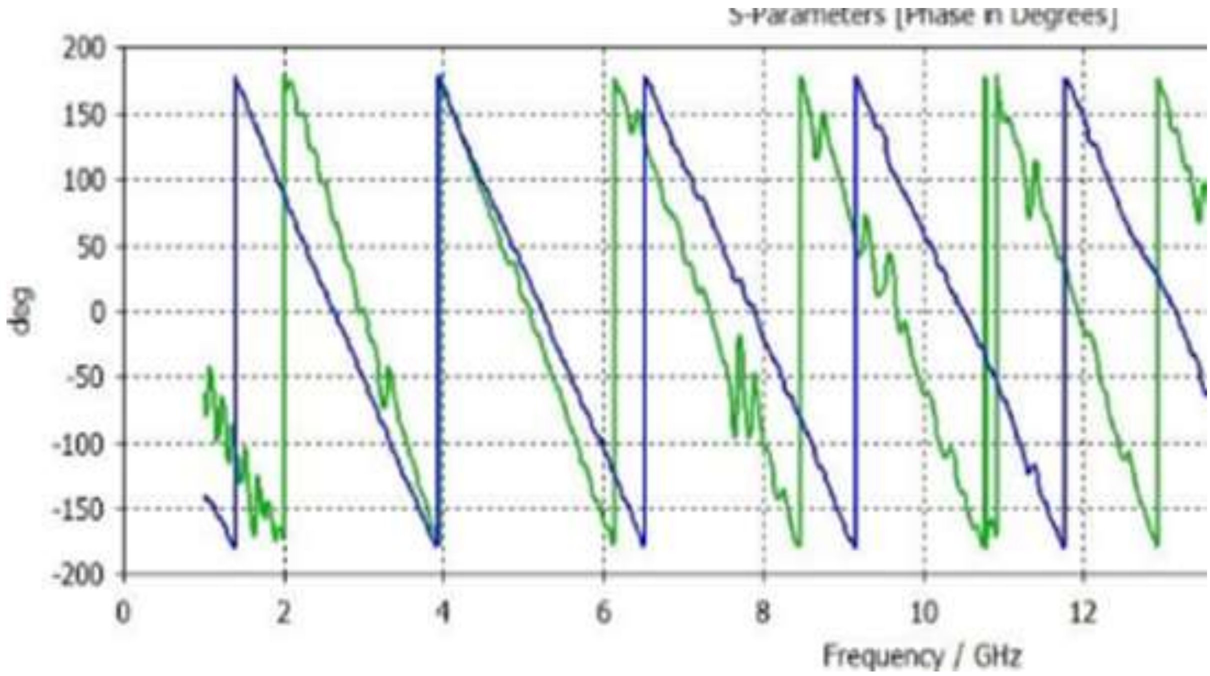

Fig.6.16 Phase difference between reference line and the output of phase shifter

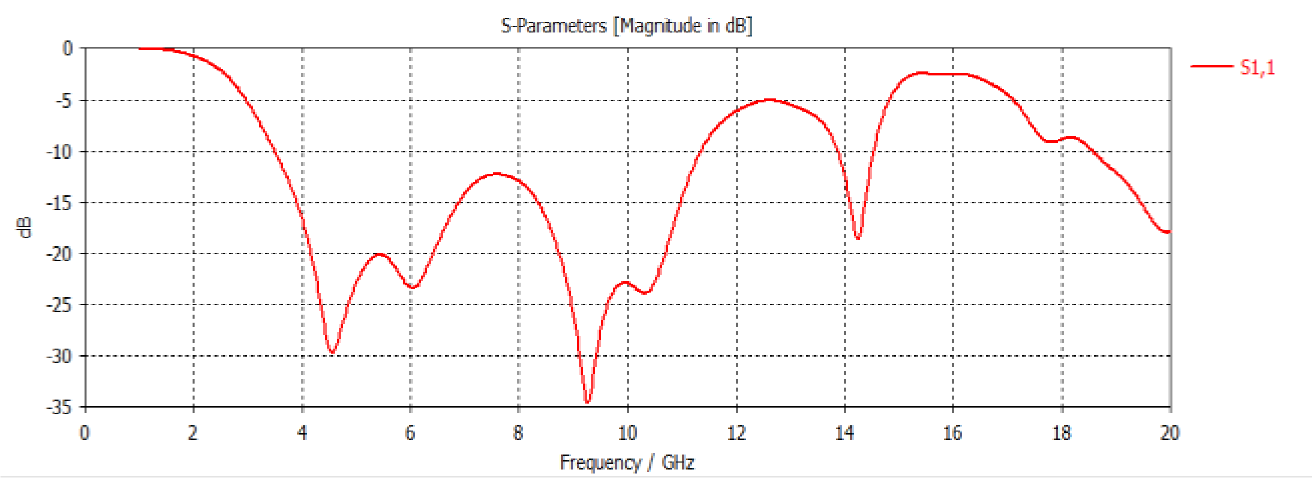

Fig.6.17 Return Loss of Phase Shifter

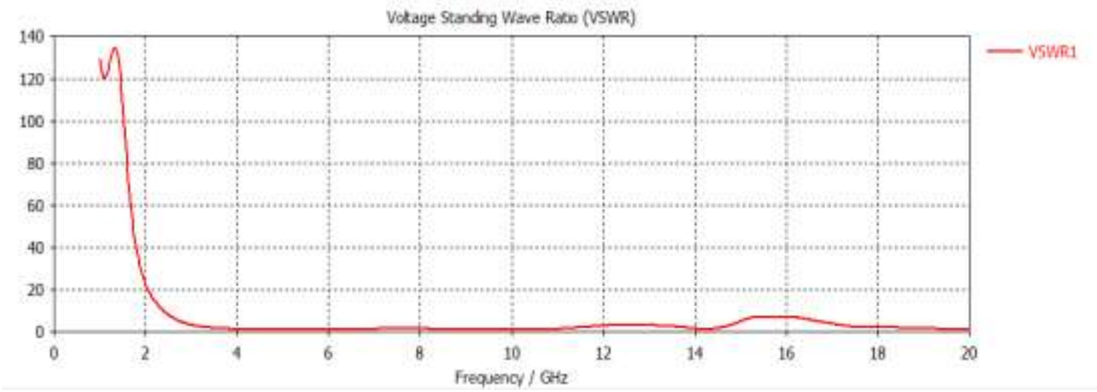

Fig.6.18 VSWR of Phase Shifter

6.5 INTEGRATED SYSTEM

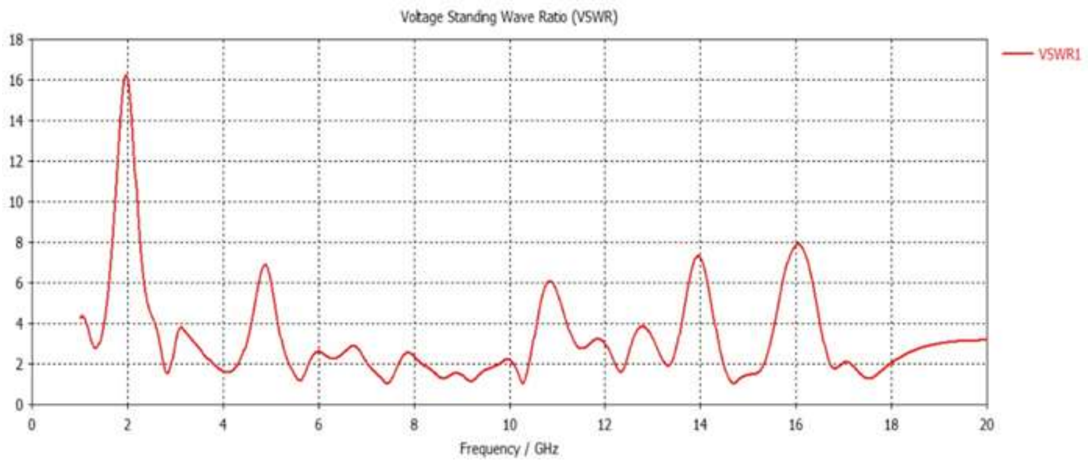

Fig.6.19 VSWR of Integrated system

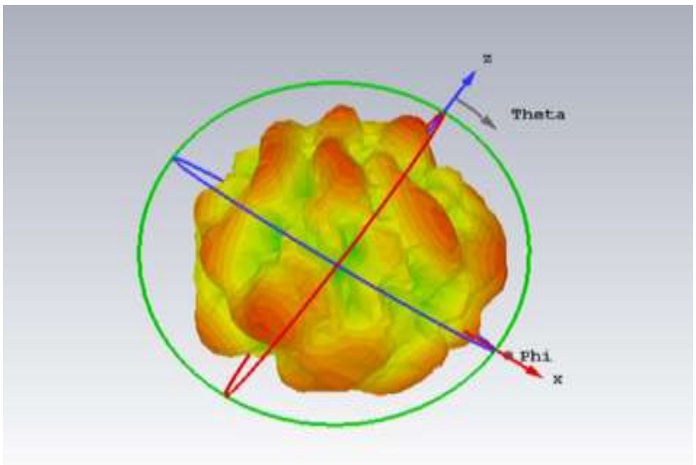

Fig. 6.20 Far Field Radiation at design frequency

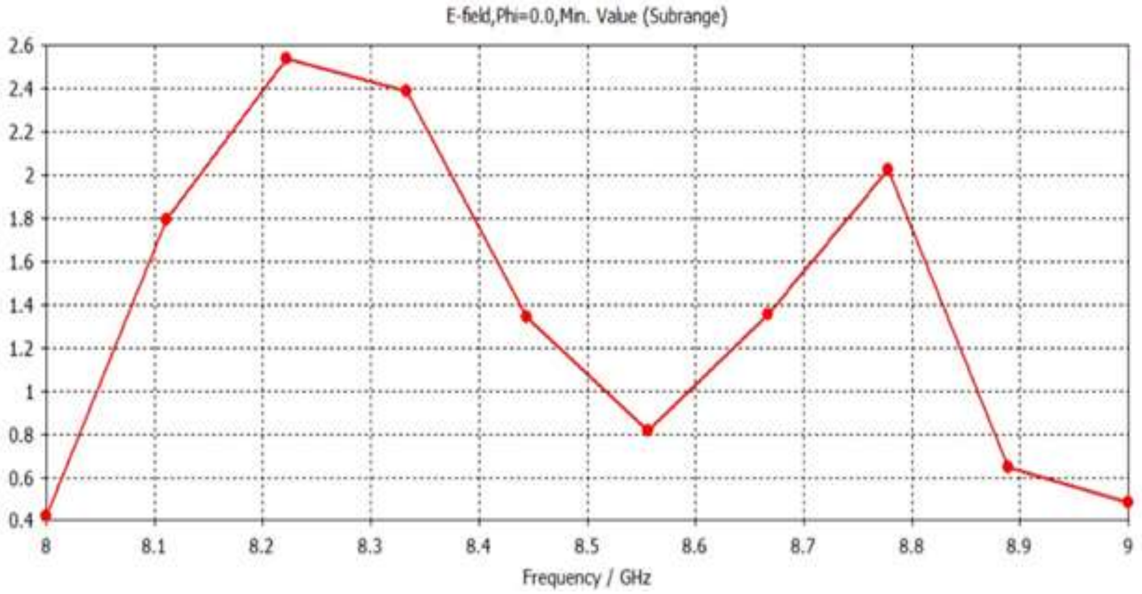

Fig.6.21 Axial Ratio

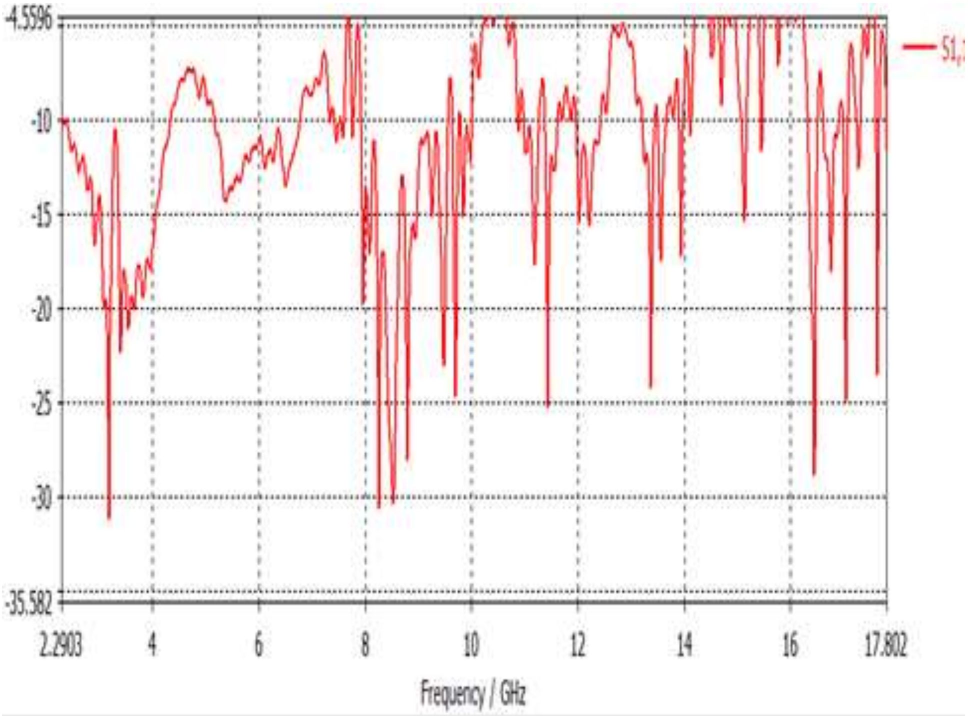

Fig.6.22 Return Loss of the Integrated System

6.6 KEY OBSERVATIONS

WILKINSON CHARACTERISTICS

- Design Frequency- 8.57 GHz
- Return loss - 25.91 dB
- VSWR- 1.1 dB
- Bandwidth- 2-10 GHz
- Model Parameters- see Table

PHASE SHIFTER CHARACTERISTICS

- 90-degree phase shift at design frequency
- Operating range 2-10 GHz
- Design Frequency- 8.57 GHz
- Return loss - 19.71 dB
- VSWR- 1.2 dB
- Bandwidth- 10 GHz
- Model Parameters - Slots-- Minor axis-3.2mm, Major axis -7.9mm
  Patches- Minor axis- 2.41mm, Major axis -7.9mm

SLOTTED ANTIPODAL

- Design Frequency-8.57GHz
- Return loss -35.51
- Gain - 9.16 dB
- Directivity - 9.55 dB
- VSWR-1.053 dB
- Bandwidth- 3.2 - 20 GHz (Test Limit)
- Model Parameters- 90mm x80mm

TOTAL SYSTEM

- Design Frequency- 8.57 GHz
- Return loss - 17.5 dB
- VSWR- 1.308 dB
- Bandwidth-4.5GHz
- Axial ratio- 0.098 dB

CHAPTER 7 CONCLUSION

We have successfully implemented the design the Circularly Polarized Vivaldi Antenna array at the center frequency of 8.57 GHz. This integrated structure works in the lower X band range of 8 GHZ and 9 GHz and is applicable for 5G applications along with added advantages of Circular Polarization such as better linkages between transmitter and receiver and combating noise issues. We did a thorough research on various antennas like the quasi-Yagi antenna, UWB antenna, Vivaldi antenna, antipodal Vivaldi antenna etc. depending on various parameters such as bandwidth, return loss, VSWR, Gain, Directivity and radiation efficiency and implemented them on CST design studio. Adding slots to the antipodal Vivaldi antenna to increase bandwidth and using Meta materials which have better electrical and non-electrical properties are key takeaways from the research on different antennas. Research on various power splitters also helped in strengthening the performance of the overall integrated system. Broadside coupling technique applied on phase shifter to have a 90 degrees phase shifter in array antenna is a novel concept, which is the most important thing in achieving Circular Polarization. The key Points of all the individual structure like the optimization of the Wilkinson power splitter to be a six-stage power splitter to have better isolation, analysis of the phase shifter as a four-port device, placing the antennas at an optimized distance and at a right angle so that their phase centers are close are some key notes which can be further be utilized for other researches. The whole purpose of this research was to achieve circular polarization in the target frequency range and the property used is axial ratio. The calculation of axial ratio is the last step and we successfully achieved an axial ratio of less than 1 dB in the target frequency range of 8 GHz to 9 GHz, with an axial ratio of 0.098 dB at the center frequency of 8.57 GHz. Such an axial ratio close to 0 dB at such a high frequency is novel and this will help 5G application when it will be deployed in satellite communication.

APPENDIX

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Design Of High Bandwidth Circularly Polarised Antipodal Vivaldi Array for 5G Applications

Anirudh Nakra
Dept. of Electronics and Communication
Delhi Technological University
New Delhi, India
anirudhnakra4@gmail.com

Abhijeet Vats
Dept. of Electronics and Communication
Delhi Technological University
New Delhi, India
abhijeetvats01@gmail.com

Asok De
Professor,
Dept. of Electronics and Communication
Delhi Technological University
New Delhi, India
asok.de@gmail.com

Abstract— **In this paper, a circularly polarized antenna array is proposed that has high gain and excellent axial ratio properties. The array is composed of multiple UWB antipodal slotted Vivaldi antennas that have been designed for a resonant frequency of 8.5 GHz and using orthogonal excitations to the array, circular polarization has been successfully achieved. Modified Wilkinson power splitter has been utilized to work over the range of 4-12 GHz and phase shifting has been achieved using aperture coupling techniques. The S parameters for the constructed system are excellent with return loss as low as -25 dB and an axial ratio of almost 0.098 dB at the resonant frequency.**

Keywords—Circular Polarization, Antipodal Vivaldi Antenna, Wilkinson divider, Axial ratio

I. INTRODUCTION

Circularly polarized antennas provide many advantages over a classical arrangement. For one, it allows a greater possibility of a good link between the transmitter and the receiver. It allows good LoS linkages and therefore is an important way forward for the antenna world. Recently with the proliferation of UWB circularly polarized antennas, there has been a rise in research in such areas. Good outputs and axial ratios can be observed over large bandwidths and this has made the demand for an antenna array that much more pivotal.

Some great research has been done on integrating aperture coupling techniques with UWB antennas to create antennas that work better than those using delay line circuits. Narbudowicz et all have employed a fusion system of good isolation power splitters with UWB phase shifters and antipodal Vivaldi antennas.

5G and further generations will benefit from CP antennas due to their extreme resistance to reflection, absorption and other interferences and mismatched polarization. In the paper, we have used an antipodal Vivaldi antenna with slots to maximize the bandwidth while improving isolation between the various

Components using a six stage power divider. We have also compared various different planar antennas such as a rectangular microstrip antenna and Quasi-Yagi antenna before finally landing on the antipodal Vivaldi antenna due to its better bandwidth and antenna efficiency results.

II. DESIGN

We chose the antipodal Vivaldi antenna as our working piece due to its high bandwidth. We achieved a gain of 7.6 dB with an antenna efficiency of 98.7% while also having a practical bandwidth of 7.8 GHz. This all round excellence and relative ease of fabrication made it an obvious choice over the Quasi Yagi antenna which had a slightly better efficiency but compromised on the bandwidth. Furthermore, research on antipodal Vivaldi has come to a point where its characteristics are quite suitable for 5G applications and creating a circularly polarized system would be beneficial for future work.

Two power splitters were tested in the feed network: a 3 stage Wilkinson power splitter and a 6 stage Wilkinson power splitter. The 6 stage Wilkinson power divider designed on a substrate of thickness 0.508 mm and dielectric constant 2.2 and it showed better isolation between the output ports compared to the 3 stage divider.

A Multi Sectional structure with different impedances were used to achieve the operation of the power divider in the required frequency range. The values of the resistances were calculated by the formulas given in [6]. Using the LineCalc tool provided in the schematic interface of Keysight ADS, we were able to define our control parameters to calculate the optimal length and width of the different stages. After calculating the characteristic impedances of the various stages mathematically and using TX line, we calculated, and fine-tuned the dimensions to those that gave us the best results. These widths and lengths were then translated into a 3d model in CST design studio using a delta separation of 1.3mm between the two isolated arms. By analyzing the S parameter curves, we saw that we were able to achieve an isolation greater than 28 dB which was better than the isolation from the splitters in both [3] and [4], two studies we chose as our standard.

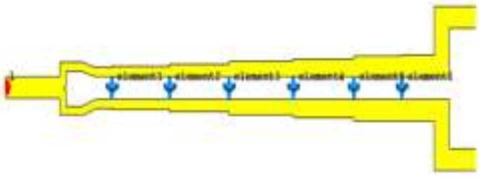

Fig. 1. Wilkinson Power divider

1

TABLE I. WILKINSON POWER SPLITTER DIMENSIONAL PARAMETERS AND RESISTOR VALUES

Resistors	Dimensional Parameters of Wilkinson power divider		
	Resistor values	*Width(mm)*	*length*
R1	153	W1=0.42	L1=5.20
R2	166	W2=0.53	L2=5.14
R3	258	W3=0.66	L3=4.99
R4	351	W4=0.75	L4=5.32
R5	299	W5=1.09	L5=4.78
R6	481	W6=1.14	L6=4.27

The phase shifter used in the model is based on broadband aperture coupling technique. The analysis of the Phase shifter is done using the conventional approach done for coupled microstrip line- treating it as a four port device with two of its ports open circuited[2].Previous research has been done on creating microwave phase shifters. However these works have often been non usable on high bandwidth equipment. Edge coupled and Schiffman phase shifters are popular but they suffer from issues such as high fabrication costs and difficulties. The design proposed in [2] has been optimal because of its relative ease to design for own purpose and high bandwidth. Three major steps have been utilized in creating this broadband phase shifter. The first step is to mathematically solve for the even and odd mode characteristic impedances for the proposed ellipses. After solving for them, an elliptical integral of the first kind was calculated for finding out the dimensions of the elliptical slots.

This calculation was complex and has been succinctly described in [2]. The length calculation however is a relatively straightforward process with quarter wave formula being used at the resonant frequency of design. The modelling of these patches is the next major step. Using the calculated dimensions, we cut two nearly circular slots with the size of length 7.9mm and minor axis of 3.2mm in the ground plane. The ground was then sandwiched between two substrates of thickness 0.508mm and dielectric constant 2.2. Above and below the slots, we designed elliptical patches of the same length (7.9 mm) and minor axis 2.41mm.

The two elliptical patches placed below the lower substrate were joined using a microstrip line of characteristic impedance 50 ohms. The topmost patches were joined to the output port and the Wilkinson divider output respectively. The last step we undertook was to optimize the dimensions of both the slots and the elliptical patches to give us a 90 degree phase shift in the lower X band between 8 to 9 GHz. Fine tuning the dimensions was a largely cumbersome process and was solved using trial and error.

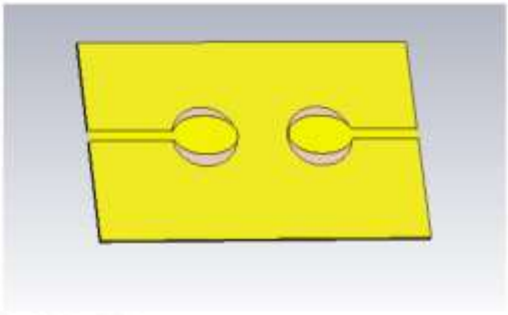

Fig. 2. Phase Shifter

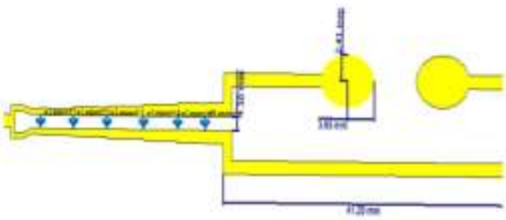

Fig. 3. Wilkinson power splitter and phase shifter combined

The output of the phase shifter and the reference line were fed to the slotted antipodal Vivaldi antenna The Vivaldi antenna was designed using a substrate of dielectric constant 2.98 and thickness 1.5 mm. Using standard design equations in [4], we were able to model the curve as an exponential taper of the type Y=Ae^(Rx). The width and length of the antennas were calculated using the lower limit of the frequency of operation and material parameters like dielectric constant of the substrate, width of the substrate, etc. Our Vivaldi antenna has a width of around 83 mm and a length spanning 91 mm. The microstrip feed line that was tapered was designed for a characteristic impedance of 50 ohms and its width can be calculated easily using software such as Txline or solving equations given in [4].

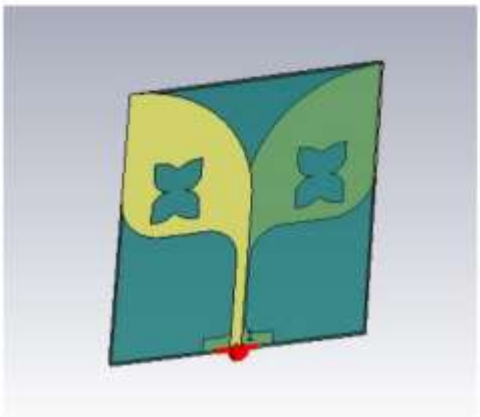

Fig. 4. Antipodal Vivaldi Antenna

The curves were optimized using a heuristic approach and the changes in the S parameters in CST Studio Suite 2019 were observed to create a broadband and compact antenna design. After the design of the radiators as well as the balun in the Vivaldi antenna, we moved on to the procedure of creating slots to enhance bandwidth. The antenna was already operating with great characteristics at 8.5 GHz but the bandwidth was only 1.2 GHz. Using techniques suggested in [4], we aimed to create floral pattern based slots in the antenna to effectively increase its bandwidth.

The slots introduced in the antenna were constructed by trial and error. The trial and error approach considered the overall impedance of the system. The slots were first designed as rectangular slots by fixing one end and using arbitrary lengths to define the rectangle and then tapering the ends to create a floral structure [4]. To achieve circular polarization, both the antennas must be kept in such a way that their phase centers are close to each other, but factors like size and the space required to prevent coupling counters it. So, for optimization, the antennas are kept at right angles to each other.

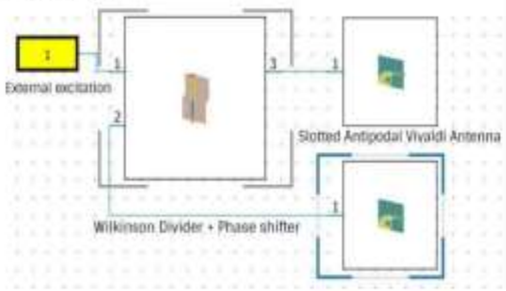

Fig. 5. Schematic of the system in CST design studio

III. RESULTS

At first, we analyzed the results of Wilkinson power divider, the phase shifter and the antipodal Vivaldi antenna individually followed by the analysis of the system. The power divider showed maximally flat response for S21 and S31 while giving great isolation (−30 dB) between the two ports.

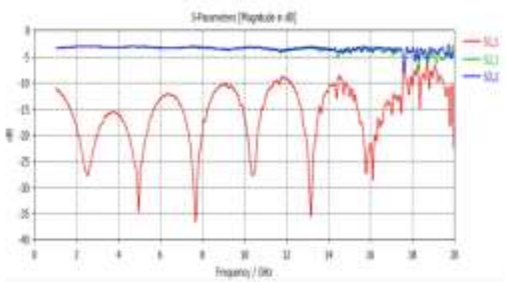

Fig. 6. S11, S21 and S31 of Wilkinson Power splitter

The Phase shifter in the 8-9 GHz band gave 90 degrees phase difference with the reference line. The slotted antipodal Vivaldi antenna showed high bandwidth.

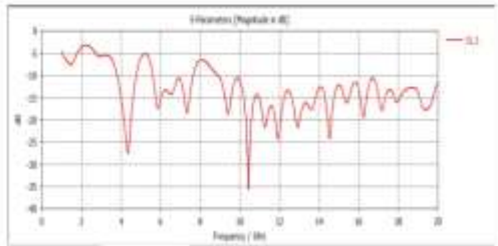

Fig. 7. Return loss of Antipodal Vivaldi Antenna

The combined array's frequency response showed the return loss below 10 db and the axial ratio below 1db for the frequency range of 8-9 GHz. Performance peaked for 8.57 GHz which showed -25 db return loss and an axial ratio of 0.098db.

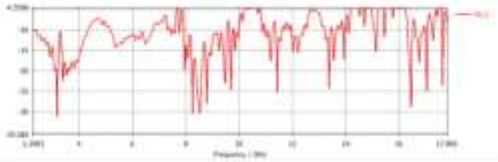

Fig. 8. Return loss of the system

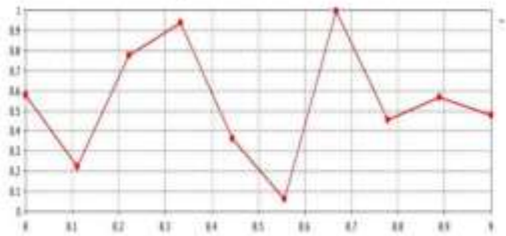

Fig. 9. Axial Ratio v/s Frequency

IV. CONCLUSION

The design of a circularly polarized antipodal Vivaldi antenna array has been presented. This array with CP gives a higher probability of successful link at even higher frequencies than presented before and eliminates the line of sight problem of linear polarization at frequencies above 2.5GHz. Vivaldi antenna in itself has been highly miniaturized and is extremely portable while giving a bandwidth of more than 7 GHz. A high isolation six stage Wilkinson divider has been employed to give maximal isolation of more than 30 dB while not being very loss. An ultra-wideband phase shifter has been designed and optimized to work at low X band frequencies to generate a phase shift of 90 degrees in the feed of the Vivaldi array and the system gives axial ratios (0.098 dB) that are much lower than those in previous literature especially in the target lower X band range.

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