PEOPLE’S DEMOCRATIC REPUBLIC OF ALGERIA

MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH

Mohamed El-Bachir El-Ibrahimi University - Bordj Bou Arreridj

Faculty of Science and Technology

Department of Electronics

Master’s Dissertation

Presented for the fulfilment of MASTER degree

FILIERE: Telecommunications

Specialty: Telecommunication Systems

By

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Entitled

Design of Beamforming Antenna for sub-6 GHz Wireless Applications

Presented on: …/…/……

Before the jury composed of:

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College year 2023/2024

بسم الله الرحمن الرحيم

Acknowledgements

I hereby express my gratitude for my supervisor, Mr Masoudane Idris , whose insightful observations have allowed the pages of this dissertation to come together beautifully. I also recognize the panel of examiners, Ms. …….and Mr. …………, for assessing my work with discernment, for their pertinent remarks, as well as their kind words about this modest work. I would also like to thank the rest of the teachers at the Department of Electronic, whose relentless help and selfless advice offer the students a well-rounded learning experience at our University. We owe you a great deal. Thank you all very much.

Dedicated

I dedicate this modest work to:

My mother, who cherished my success, because of her Love, his Support, all the sacrifices made and his precious advice, for all his assistance and his presence in my life. May God give her good health and long life.

My father, who can be proud and find here the result of long years of sacrifice and deprivation to help me advance in life.

To my relatives and brothers, for their unconditional support in difficult times, their encouragement and their presence always at my side

"For my dear pet, who sat by my side as I wrote this memoiry.

"To you, dear reader, for making this journey worthwhile."

IMENE

Dedicated

Thank God who succeeded us for this and we would not have got if not for God's gift.

To those for whom words and letters cannot do justice, to those whose satisfaction is linked to God's satisfaction, and whose prayers are the secret to my success, no words can fully express their worth…

To my dear mother and my kind father, may God have mercy on them and grant them the highest place in paradise. To those who have accompanied me throughout the years, sharing both joys and sorrows, to my dear brothers (ousssma and abdelraouf and salah-eldin I miss you ,you still in our mind .), and to the one who supported and encouraged me throughout my academic journey, my friend kahina I'm going to go through life holding hands because you're my best friend, on which I rely when I'm tired.

Everyone gave a helping hand to get to where I am.

I want thank me for believing in me , i want thank me for doing all this hard work , i want thank me for try do more right than wrong. I want thank me for never quitting.

Souhila

Abstract

beamforming technology together with antennas array technologies is expected to play a key role in next-generation wireless communication systems (5G), the main objective of this thesis is to discuss the latest research on the best types of beamforming techniques, and to illustrate the importance of beamforming techniques to remove and solve the many technical obstacles faced by these systems. The antenna array is designed associated with Rotman's lens and leaky wave antennas array .These two technologies are the most prominent techniques used to achieve the beamforming

من المتوقع أن تلعب تقنية التشكيل مع تقنيات مصفوفة الهوائيات دورًا رئيسيًا في أنظمة الاتصالات اللاسلكية والهدف الرئيسي لهذه الأطروحة هو مناقشة أحدث الأبحاث حول أفضل أنواع تقنيات تشكيل الأشعة، وتوضيح أهمية تقنيات تشكيل الأشعة لإزالة وحل العديد من العقبات التقنية التي تواجهها هذه الأنظمة.

تم تصميم مصفوفة الهوائي المرتبطة بعدسة روتمان ومصفوفة هوائيات الموجات المتسربة. هذان التقنيان هما أبرز التقنيات المستخدمة لتحقيق تشكيل الحزم

la technologie de formation de faisceaux avec les technologies de réseau d'antennes devrait jouer un rôle clé dans les systèmes de communication sans fil de prochaine génération (5G), l'objectif principal de cette thèse est de discuter des dernières recherches sur les meilleurs types de techniques de formation de faisceaux, et illustrer l'importance des techniques de formation de faisceaux pour éliminer et résoudre les nombreux obstacles techniques rencontrés par ces systèmes .Le réseau d'antennes est conçu pour être associé à la lentille de Rotman et aux antennes à ondes perméables . Ces deux technologies sont les techniques les plus utilisées pour réaliser le beamforming

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Chapter 1 : : Beamforming Antennas and Technologies

Chapter 2: Discusion and Results

Liste of abbreviations:

UMTS	**U**niversal **M**obile **T**elecommunication **S**ystem
3GPP	**3**rd **G**eneration **P**artnership **P**roject
LTE	**L**ong **T**erm **E**volution
MIMO	**M**ultiple **I**nput **M**ultiple **O**utput
WIMAX	**W**orldwide **I**nteroperability for **M**icrowave **A**ccess
WIFI	**Wi**reless **Fi**delity
WPAN	**W**ireless **P**ersonal **A**rea **N**etwork
FIR filter	**F**inite **I**mpulse **R**esponse filter
IIR filter	**I**nfinite **I**mpulse **R**esponse
LMS	**L**east-**M**ean-**S**quare
RLS	**R**ecursive-**L**east-**S**quare
SMI	**S**ample **M**atrix **I**nversion
CMA	**C**onstant **M**odulus **A**lgorithm
LCMV	**l**inearly **C**onstrained **M**inimum **V**ariance
MVDR	**M**inimum **V**ariance **D**istortionless **R**esponse
BS	**B**ase **S**tation
DOA	**D**irection of **A**rrival
RF	**R**adio **F**requency
BFNS	**B**eamforming **N**etwork
TTD	**T**rue **T**ime **D**elay
ECM	**E**lectronic **C**ounter **M**easure
SSPS	**S**urface **P**lasmon **P**olariton**s**
PEC	**P**erfect **E**lectric **C**onductor
LWA	**L**eaky **W**ave **A**ntennas
MLWA	**M**icrostrip **L**eaky **W**ave **A**ntennas

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General Introduction:

Antenna arrays have a long history spanning over 100 years and have evolved alongside electronic and information technologies. They have played a crucial role in wireless communications and are indispensable. However, with the rapid increase in communication requirements, traditional single-antenna transmission faces challenges in meeting the urgent demands for high capacity, large data rates, long distances, low latency, energy efficiency, and strong robustness. To address these ever-growing requirements, it is promising to utilize different types of antennas combined with various beamforming technologies in wireless communication systems. This approach brings several advantages, including significant antenna gains, multiplexing gains, and diversity gains.

Utilizing high-frequency bands, such as millimeter-wave frequencies, with abundant spectrum resources has become a popular choice for advancing broadband communication. Despite the benefits, these bands also come with increased propagation losses. To address this issue, antenna arrays have emerged as a viable solution to achieve high directional gains through the collaboration of multiple connected antenna elements. By focusing the radiation energy towards specific directions, antenna arrays offer significant gains to offset propagation loss, facilitating high-frequency broadband communication.

Antenna arrays are expected to play a crucial role in wireless communication utilizing millimeter-wave frequencies due to the short wavelength of these signals, allowing for a large number of antenna elements to be packed into a small area. However, the implementation of large-scale antenna arrays poses challenges such as compact circuit design, costly RF chains, and high power consumption. Factors like antenna layout, system integration, and power control must be carefully considered to ensure the effectiveness of antenna arrays in high-frequency communication Utilizing a large-scale antenna array allows for the implementation of beamforming technology to meet quality of service requirements and compensate for signal propagation loss. Through effective beamforming, beams can be directed towards specific directions, enhancing signal power for intended users while minimizing interference for others. Antenna arrays offer higher beam gains and greater flexibility in beamforming compared to traditional directional millimeter-wave antennas and integrated antennas. Beamforming architectures for antenna arrays can generally be categorized into three types: digital beamforming, analog beamforming, and hybrid beamforming, based on the hardware structure.

Hybrid beamforming is a preferred solution for achieving both energy efficiency and spectrum efficiency. It combines the benefits of fully digital beamforming and analog beamforming. In fully digital beamforming, each antenna has its own independent Radio Frequency chain, allowing for simultaneous transmission of multiple data streams. However, this architecture is costly and consumes a significant amount of energy, especially in the millimeter-wave-band with large antenna arrays.

On the other hand, analog beamforming is an energy-efficient alternative where the antennas share only one Radio Frequency chain. However, this limits the system's ability to support multiple data streams, reducing spectrum efficiency.

To strike a balance between energy efficiency and spectrum efficiency, hybrid beamforming was introduced. It involves connecting a small number of Radio Frequency chains to a large number of antennas. This configuration allows for beam gain and interference management while minimizing hardware cost and energy consumption. By combining the advantages of both fully digital and analog beamforming, hybrid beamforming offers an optimal solution for efficient signal processing in baseband.

In our these , we will study beam forming and its techniques. in order to understand the operating principle and behavior of this technology. This study will be followed by an in-depth practical study using the cst program, which allows us to fully understand the parameters and characteristics of each these techniques (Rotman lens and leaky wave antennas). and a preliminary theoretical study to understand the concept, fundamentals and types as well as the advantages and disadvantages of each technique This dissertation is organized as follows: In the first chapter, this is the theoretical chapter we will discuss about beamforming and their various techniques with its operating principles and its applications and some basic notions. and its advantages and disadvantages and in the end we talk about the future of its techniques.

In the second chapter, the practical chapter, we will see the design and simulation on the cst program of the Rotman lens with an antenna array and the leaky-wave antenna, and we will validate the results found At the end, we end with a general conclusion.

Chapter 01: Beamforming Antennas and Technologies

1 Introduction :

Beamforming is essentially a specialized type of antenna radiation pattern that focuses the omni-directional radiated power of an antenna into one or more specific directions. In the context of 5G technology, beamforming involves transmitting a signal in a narrower beam from a base station to a receiver, allowing only the intended user to receive the information while rejecting interference from other directions. During transmission, the main lobe of the antenna pattern is steered towards a specific direction by adjusting the phase and amplitude of each antenna element in an array, resulting in constructive interference in the wavefront. When receiving, the individual responses of each antenna element are combined to obtain the desired signal in the desired direction Figure 1.1 illustrates a typical beamforming scenario in the context of cellular technology.

In this part we will study the fundamentals of beamforming and its most important types and history across generations, types, uses, advantages, disadvantages and future of this technology.

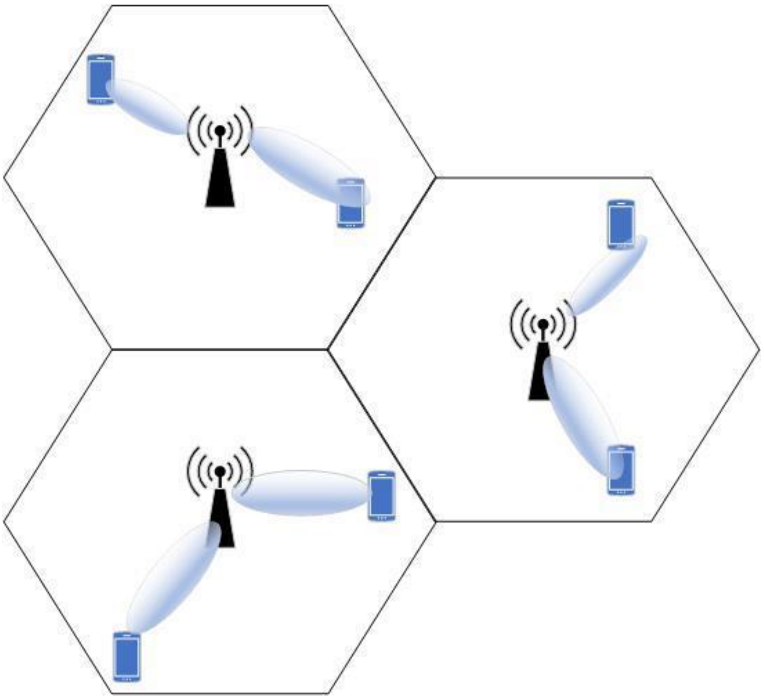


Figure 1.1: Typical beamforming scenario inside a cell **[1]**.

1.1 The importance of beamforming:

Beamforming is a technique that aims to concentrate energy towards a receiver. In the past, access points used omni-directional antennas, which emit energy in all directions. This meant that receiver antennas did not have to track each client individually, but it also had its drawbacks. An alternative approach is to focus the energy specifically towards the intended receiver, which is the concept behind beamforming. By directing the signal in a specific direction, the receiver can receive a higher quality signal, resulting in faster data transfer and fewer errors, without the need to increase the broadcast power. Additionally, beamforming can also be used to minimize or eliminate broadcasting in other directions, reducing interference for users attempting to receive other signals [1]. Represent omnidirectional and directive antennas.

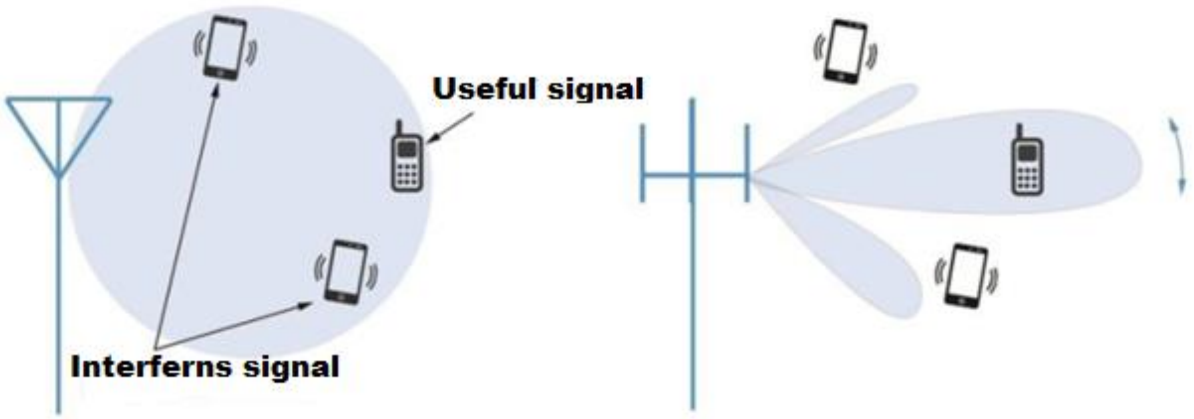


Figure 1.2 : Omnidirectional antennas and directive antennas **[2]**.

1.2 Beamforming History in Wireless Communication Standards :

Beamforming techniques in cellular phone standards and other wireless communication standards have evolved over time to support high density cells and increased throughputs. Initially, beamforming was implemented at the baseband in traditional cellular communication systems.

- During **the second generation** of cellular standards:
  digital technology was introduced, allowing for basic beamforming methods to select specific receiver antennas. However, limitations such as weaker digital signals at higher

frequencies and reduced sound range were addressed in the third generation technology [3].

- **The third generation cellular standard UMTS, introduced by 3GPP**: supported elementary beamforming methods. Different modes of beamforming were specified, including flexible and fixed beam patterns [4].
  - **The fourth generation, LTE/LTE-Advanced** ,was developed to meet the high bandwidth and speed demands of users, incorporating technologies like MIMO and carrier aggregation [5].
  - **In indoor networks,** beamforming is crucial to mitigate multipath effects and improve signal-to-noise ratio. Standards like WiMAX, Wi-Fi, and WPAN have adopted beamforming techniques. The 802.11ac standard standardized beamforming.
  - **In the 5th generation** .The use of millimeter wave bands in beamforming allows for highly directional beams with large array gains. Advanced hybrid beamforming algorithms combining analog and digital methods are used to focus signals in desired directions. Beamforming is expected to play a significant role in future wireless technologies, especially in indoor networks and short-distance communication [6].

1.3 Why the beamforming in 5G :

The principle of 5G is to direct the wave beams directly to the users. This makes it possible to limit interference between waves, to have a more reliable signal, and to save energy. These three conditions are part of the imperatives that 5G must meet. Since the waves of 5G signals have high frequencies, they can carry more information faster. This system avoids congestion in hotspots, that is, there will be no problems with throughput in places where there are many connections simultaneously. Also, the network can be more diversified locally: there can be completely different services used on the same network at the same time.

1.4 How are beams targeted at users and how are they then tracked?

The signal of the user’s position is received by different parts of the 5G antennas. On each of these parts, there is an offset of the moment of the arrival of the signal, according to the angle with which it touches the antenna. With mathematical models that integrate these different time shifts, it is possible to locate the user and target the beam in its direction.

Then you have to follow the users, and it’s more complicated. Base stations use fixed beam sets that point to pre-established angles. There is a mechanism that allows the user’s device to measure the power of the received beam in relation to the adjacent beams. The device sends this information back to the base station, which allows the base station to choose the best beam.

1.4.1 **Beams :**

The sectors are further divided into several low-resolution and high-resolution beams. Among these beams, the transmitter and receiver select the best pair of beams. The **Figure 1.3** represente Low-resolution beams and High-resolution beams respectively .

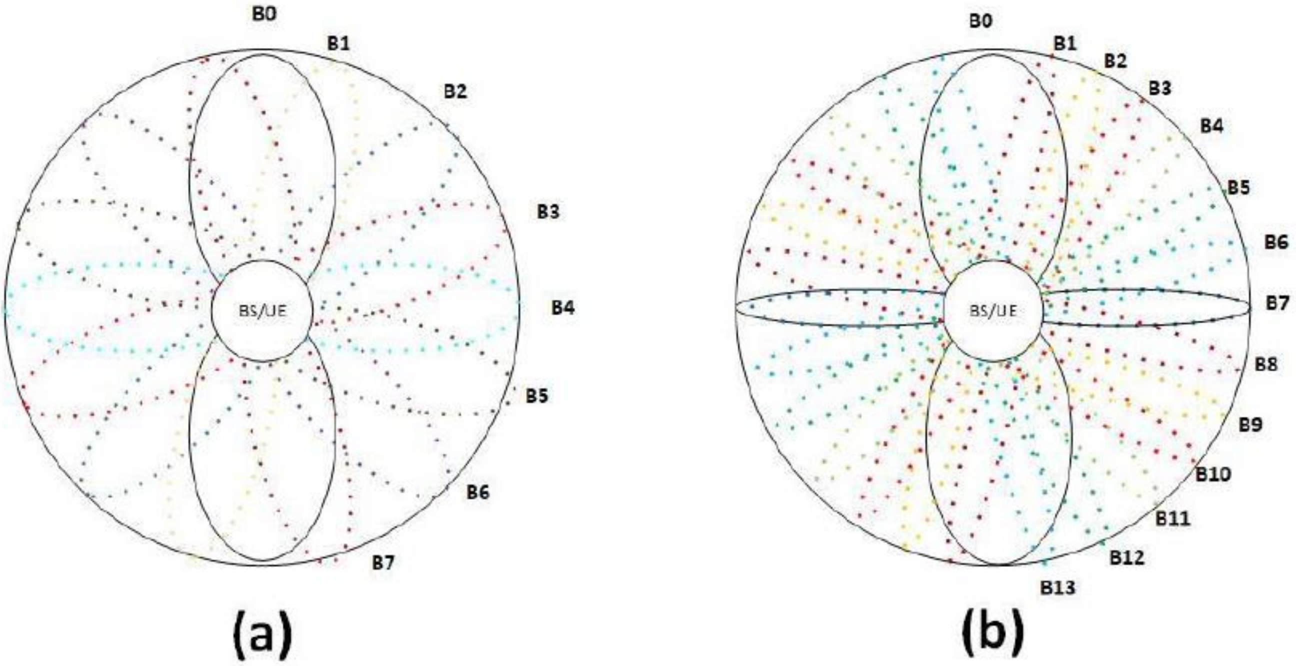


Figure 1.3 (a)Low-resolution beams (b)High-resolution beams

1.5 <u>Clasification of beamforming :</u>

Beamforming can be divided into two types based on signal bandwidth: narrowband beamforming and wideband beamforming. Narrowband beamforming operates through an instantaneous linear combination of arriving array signals. However, when the signals are wideband, an additional processing dimension is required for optimal operation, such as tapping delay lines (or FIR/IIR filters) or the recently proposed sensor delay lines, which result in a wideband beamforming system (Liu and Weiss, 2010). The majority of current wireless communication applications still rely on narrowband beamforming; however, wideband beamforming is becoming an important topic for future wireless communication applications due to 5G requirements for high-frequency band signals in order to achieve extremely high data rates. The best example of wideband beamforming that can be used in 5G to achieve exceptionally high speeds and capacities is mm-wave beamforming. Section 5 provides a comprehensive overview of mm-wave (wideband) beamforming [2].

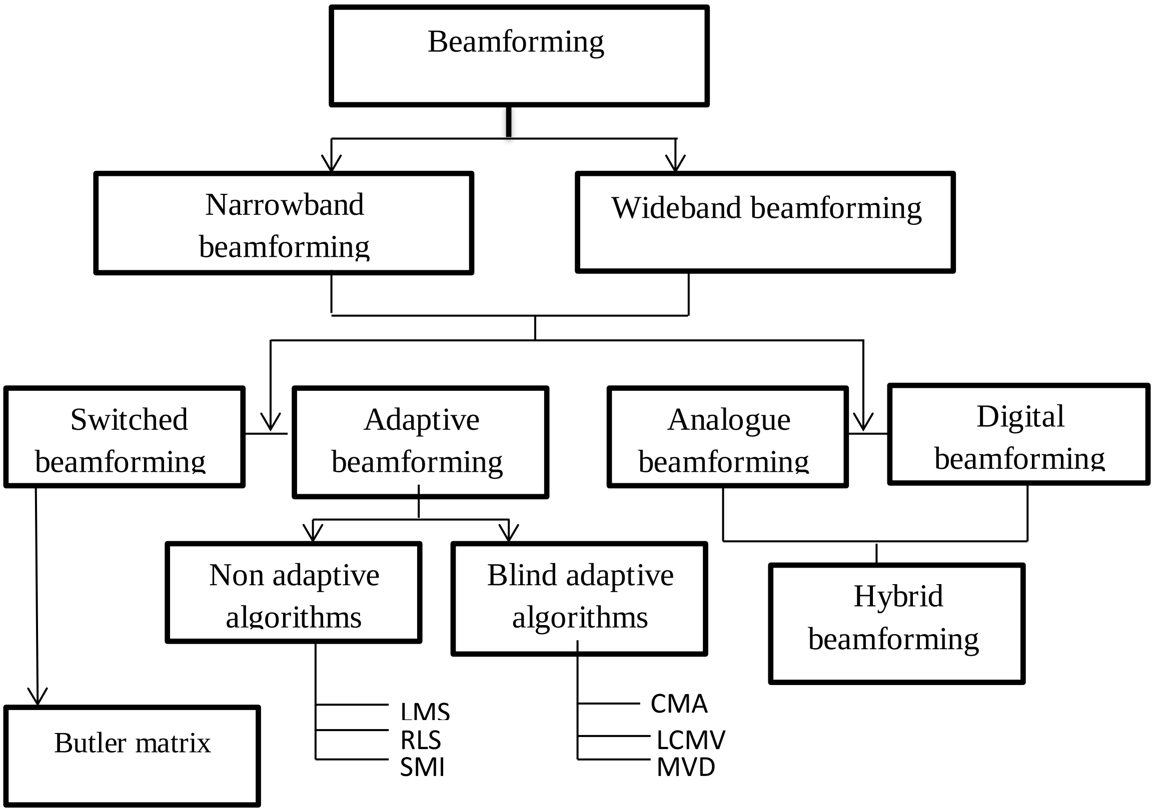


Figure 1.4: General beamforming classification [6].

1.5.1 Switched array beamforming versus adaptive array beamforming

Beamforming schemes are often characterised as switched-beam or adaptive array systems. A switched-beam system relies on a fixed beamforming network to generate predetermined beams. The Butler matrix, created by Butler and Ralph in 1961, is perhaps the most prevalent technique for fixed beamforming. A Butler matrix is made up of hybrid couplers and phase shifters. Additionally, a beam usually sBy contrast, adaptive array systems have the option to formulate a singular beam for each user. This option is realised by weight vectors that are applied via adaptive array processors to detected signals with the objective of controlling phase changes between the elements of the antenna array and their amplitude spreading In this technique, specific beam shapes can be formed, and the directions toward a preferred mobile station are given by the main lobe remote sensing and consequently null toward the interfering sequences. Adaptive beamforming assumes that the BS modernizes the localization of the mobile station. However, accurate localization is a difficult task because a large number of real-time mobile stations may overload the process. Therefore, estimating the DOA (socalled direction-of-arrival) of received signals impinging on an antenna array is a main issue for wireless communication systems. It is considerably more difficult to put an adaptive beamforming system into practice than a switched- beamforming system. By contrast, perfect adaptive beams attempt to reduce the interference between users and achieve considerably improved offered power resources (Huang et al., 2015; Sivasundarapandian, 2015; Wu et al., 2015). Regardless, there are advantages and disadvantages to both categories, which must be considered in implementation for massive MIMO(Masive Multi Input Output) systems., which illustrates that although adaptive beamforming is difficult to implement, the majority of recent studies and simulations related to massive MIMO prefer this technique to switched beamforming because of its reliability for 5G requirements.erves more than one mobile station [7], the following Table 1.1 represents a comparison between Switched beamforming and Adaptive beamforming.

Parameter	**Switched beamforming**	**Adaptive beamforming**
Coverage and capacity	Better coverage and capacity compared to conventional antenna systems. The improvement ranges from 20% to 200%	Covering a larger area and being more uniform compared to switched beamforming at the same power level
Interferences elimination	Suffering from a problem in differentiating between the desired	Offering more comprehensive interference rejection

complexity and cost	signal and an interferer signal Offering more comprehensive interference rejection Complexity and cost – Easy to implement in existing cellular systems – Inexpensive – Using simple algorithms for beam selection	Complexity and cost – Easy to implement in existing cellular systems – Inexpensive – Using simple algorithms for beam selection – Difficult to implement – Expensive - Requiring more time and more accurate (highly complex) algorithms to steer the beam and nulls

Table 1.1: Comparison between the two approaches in terms of coverage area, capacity, interference suppression, and complexity Parameter [2].

Beamforming Algorithm	**Element weight update equation**	**Disadvantages**	**Advantages**
Least mean squares (LMS)	$w(n +1 = w(n) - \mu\nabla(E\{ [d - y]2\})$	Always converges	May take long time to converge
Constant modulus algorithm (CMA)	$w(n+1) = w(n) - \mu x(n)\varepsilon * (n)$ $\varepsilon(n) = [1 - \lvert y(n) \rvert 2]y(n)x(n)$	No reference signal is need	May not converge

Table 1.2: popular adaptive beamforming algorithms [8].

1.5.2 Classical Beamforming System Architectures and Approaches

Traditionally, beamforming is a spatial filtering method that is using an array of radiators to capture or radiate energy in a given direction along an aperture. The transmit/receive gain represents an improvement over omnidirectional transmission/reception. Modern communication systems use smart antenna systems, which can combine array gain, diversity gain, and interference mitigation to further increase.

The capacity of the communication link. This can be done through electrical beam steering with a phased array, which is a multi-element radiation device with a unique geometric design.

The output spatial power distribution, known as the array radiation pattern, is determined by the vector sum of the fields radiated by each element. It can be described in terms of the individual element radiation pattern and the array factor, which is a function of the array geometry and amplitude/phase shifts applied to individual elements represents the common system configurations for antenna beamforming utilising phased arrays [9].

a) Fixed Weight Beamforming :

In general, fixed beamforming refers to a traditional method in which the antenna array pattern is determined by fixed element weights independent of the signal environment.

Fixed weight beamforming directs the main beam by applying constant antenna weights (amplitude and/or phase) to array elements in the analogue or digital domain

There are three main categories of beamforming based on architecture and hardware implementation: analog beamforming, digital beamforming, and hybrid beamforming [10].

b) Analog beamforming :

The most basic technique is analogue beamforming, which involves changing the signal phase in the analogue domain. The output of a single RF transceiver is divided into multiple paths, one for each of the array's antenna elements. Each signal path is sent through a phase changer and amplified before reaching the antenna [11]. utilizes one Radio Frequency chain and multiple phase shifters across antenna elements to control the phase of each element and steer the beam. This type of beamforming is commonly used in long-range systems such as radar and short-range communication systems like IEEE 802.11 ad. Analog beamforming is advantageous due to its simple implementation and cost reduction, but it can only transmit one stream at a time with one RF chain. This is the most cost-effective technique to perform beamforming because it needs a minimal amount of hardware. However, an analogue beamforming system can only process one data stream and generate one signal beam, limiting its efficacy in 5G, when many beams are needed· Figure 1.5 represents analog beamforming.

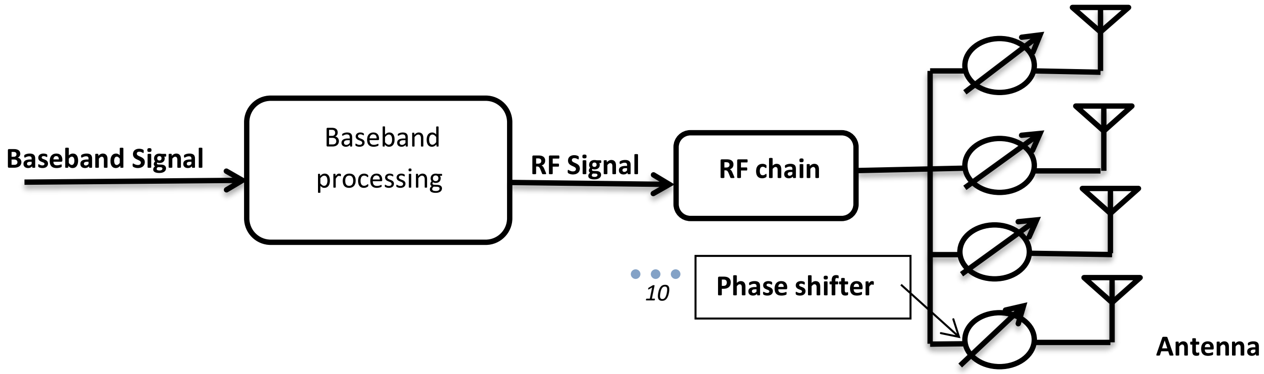


Figure 1.5: Analog beamforming scenario

c) How the analog beamforming work :

The following figure illustrates a baseband signal formation transmitter , in the first should modulated the signal. This radio signal is divided using a power divider and passes through the beam trainer which has the ability to change the amplitude (paths leading to a stack of antennas. The power divider depends on the number of antennas used in the antenna array This radio signal is divided using a power divider and passes through the trainer) This radio signal is divided using a power divider and passes through the beam formatter which has the ability to change the amplitude (a_k) and phase (θ_k) of the signals in each of the paths leading to an antenna stack. The power divider depends on the number of antennas used in the antenna array.the Figure 1.6 and Figure 1.7 represente the analog beams in emission and reception respectively.

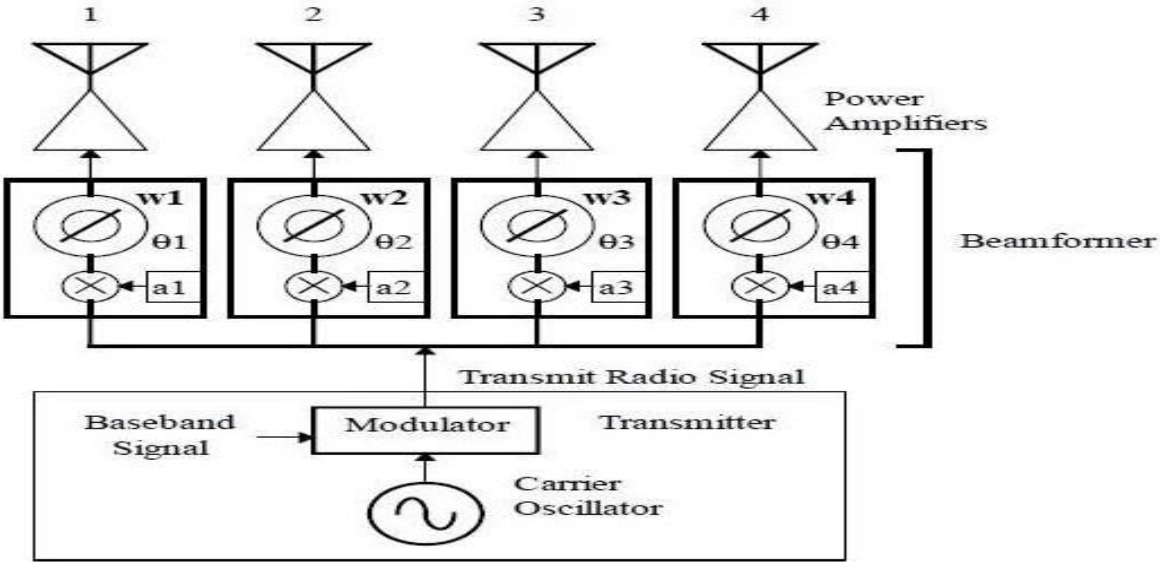


Figure 1.6: Formation of analog beams in emission [12].

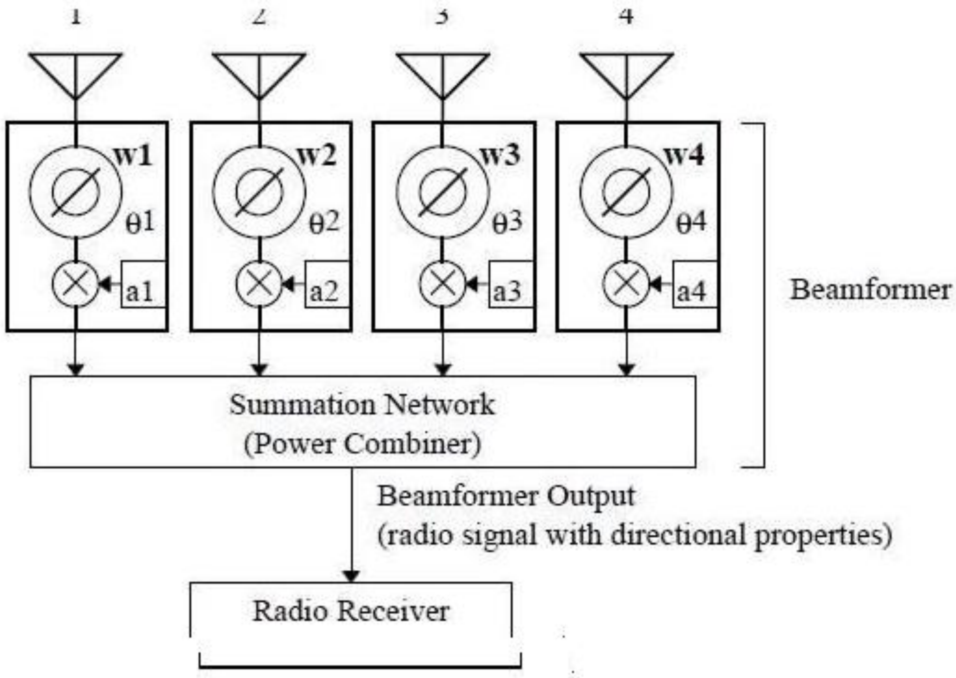


Figure 1.7: depicts analog beamforming receiver [12].

As indicate , the baseban signal to be transmitted is modulated first. The radio signal is split using a power divider and routed via a beamformer, which can modify the amplitude (a_k) and phase (θ_k) of the signals in each path leading to the stack of antennas. Power divider depends on number of antennas used in antenna array for example 4 way power divider is needed to address the need of 4 antenna array.

Beamforming equations used in analog type:

Wk= $ak \; * \; e^{jsin(\theta k)}$ **(1)**

Wk= $ak * cos(\theta k\;) + j * ak\, sin(\theta k)$ **(2)**

Where, Wk represents complex weight for kth antenna in the array.

ak is relative amplitude of weight.

θk is phase shift of weight.

➨Weights are being applied to analog signals in analog beamforming [13].

d) Digital beamforming :

In fully digital beamforming, each antenna element is paired with its own RF chain and phase shifter, resulting in a one-to-one ratio between the number of RF chains and antenna elements. While digital beamforming is considered the most effective architecture in theory, the practical implementation of a large number of RF chains and analog-to digital converters can be challenging .Figure 1.8 represents a fully digital beamforming structure.

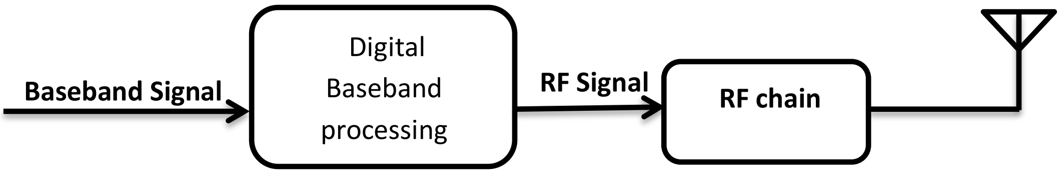


Figure 1.8 : digital beamforming scenario

In digital beamforming, each antenna element is fed by a different transceiver and data converters, and each signal is pre-coded (with amplitude and phase changes) in baseband processing before RF transmission. Digital beamforming generates and superimposes a number of signals onto antenna array elements, enabling a single antenna array to serve many beams and hence multiple users. Although this flexibility is ideal for 5G networks, digital beamforming demands additional hardware and signal processing, resulting in greater power consumption, particularly at mmWave frequencies, where several hundred antenna components are possible.the Figure 1.9 illustrate the digital beamforming receiver.

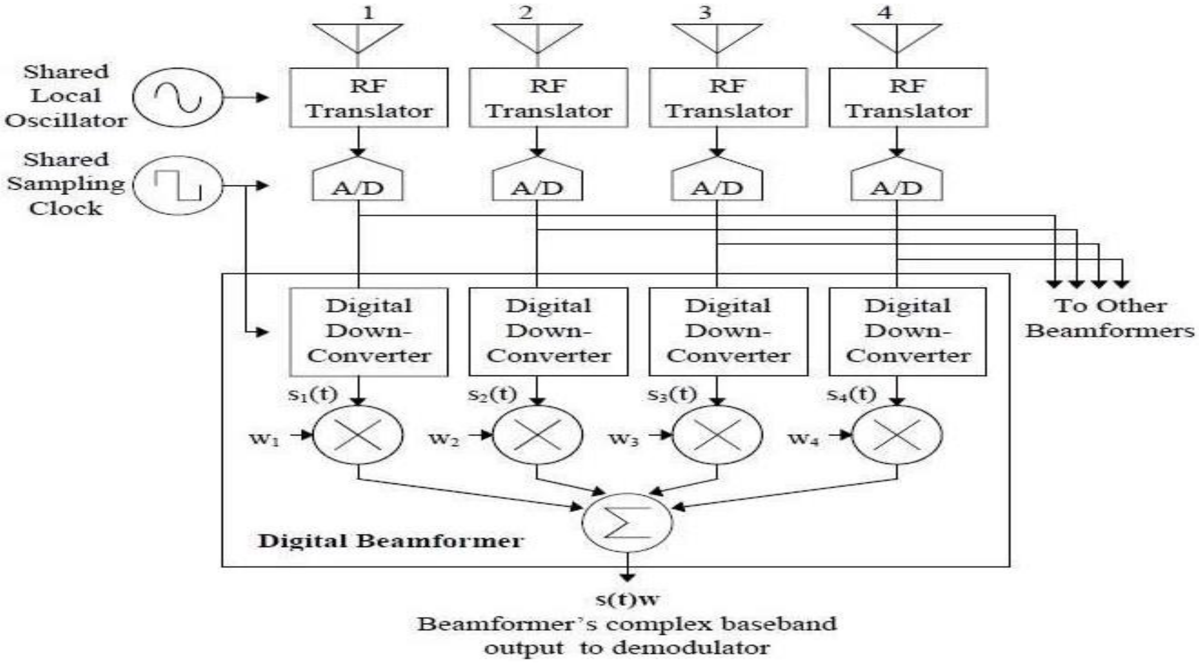


Figure 1.9: Digital beamforming receiver **[13]**.

e) Analog vs. Digital Beamforming :

The difference between analog and digital beamforming simply refer to the design of the RF front end that interfaces with the antenna array. Modern systems involve some fusion of analog and digital components, which is referred to as hybrid beamforming,

The principle factor that distinguishes digital and analog is the way in which the phase delay is applied to the signal sent to each feedline. For duplexed MIMO systems, digital beamforming is arguably the best choice to reduce component count and more precisely control the phase delay between feedlines. Analog beamforming involves use of some analog phase delay line, while in digital beamforming, the delay is applied by simply delaying the signal output from the transceiver.

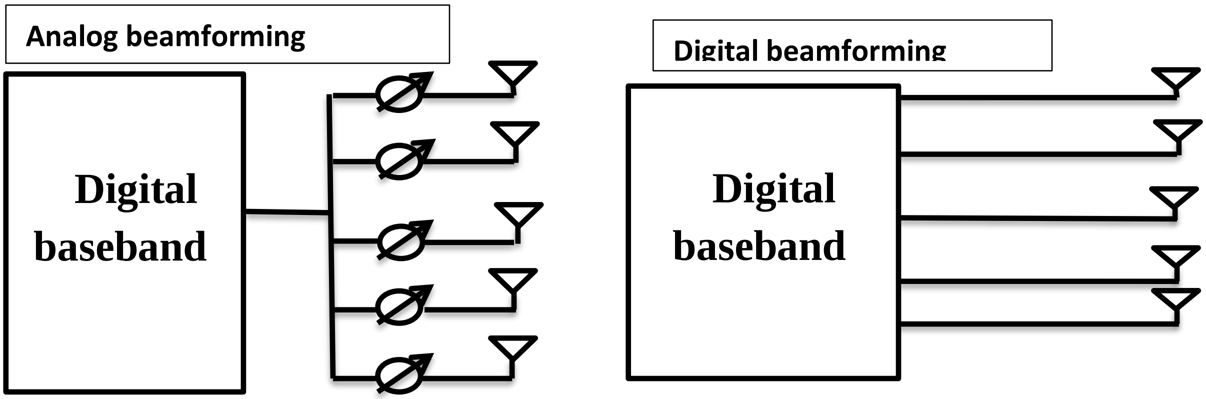


Figure 1.10: analog vs digital beamforming.

f) Hybrid beamforming :

The objective of hybrid beamforming is to combine the benefits of digital and analogue beamformers. A sub-array module is created by combining several arrays to create a hybrid beamforming architecture . Hybrid beamforming maintains a good balance between cost and flexibility, making it a viable technology for 5G NR deployment. There are other categories into which hybrid beamforming structures can be further subdivided, including switching matrix, virtual sectorization, full-connected hybrid beamforming, and sub-connected hybrid beamforming. Every structure has advantages and disadvantages of its own.

Error! Reference source not found. represents a full-connected hybrid beamforming structure. In full-connected hybrid beamforming, each RF chain is connected to a respective number of phase shifters and to all antenna. Full-connected hybrid structure has a higher beamforming gain.

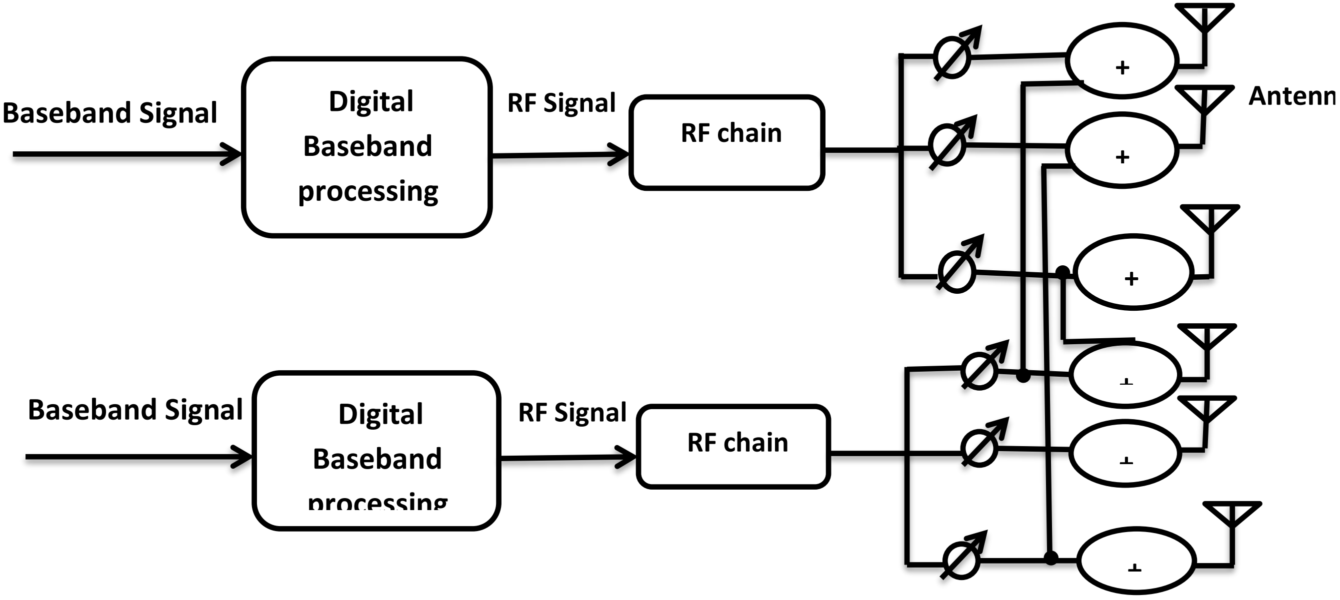


Figure 1.11: Hybrid beamforming scenario, full-connected structure.

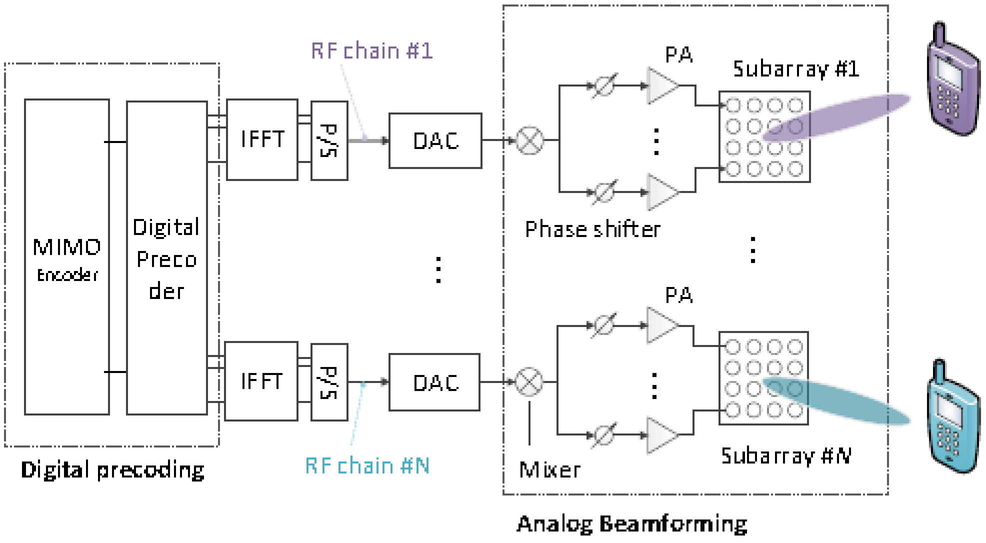


Figure 1.11: hybird beamforming.

- **The advantage of this topology :**

The advantage of this topology is that digital beamforming methods generate digital signals good enough to allow good quality DOA estimation, while the analog beamforming method reduces the number of RF chains required for beamforming. This ultimately makes it possible, in principle, to develop cost-effective hardware for the entire system. The analog parts of the beam trainer include digital-to-analog conversion and power-to-transmit amplification and low-noise amplification in reception. Hybrid beamforming is usable not only at less than 6 GHz, but also in the mmWave spectrum.

1.6 Time delay Beamforming :

Time delay beams using time sampled sensor signals have been widely used in acoustic receivers for many years. The transition period dictates the accuracy with which the desired beam formation time for each sensor can be approached (unless interpolation is used). This is shown in **Figure 1.12** for a linear array of uniformly spaced sensors where the desired inter-sensor delay is a half-sampling interval (T/2). The set of points around each inclined line represents the two-dimensional (space-time) sampling points used in the weighted sum that forms a beam output [14].

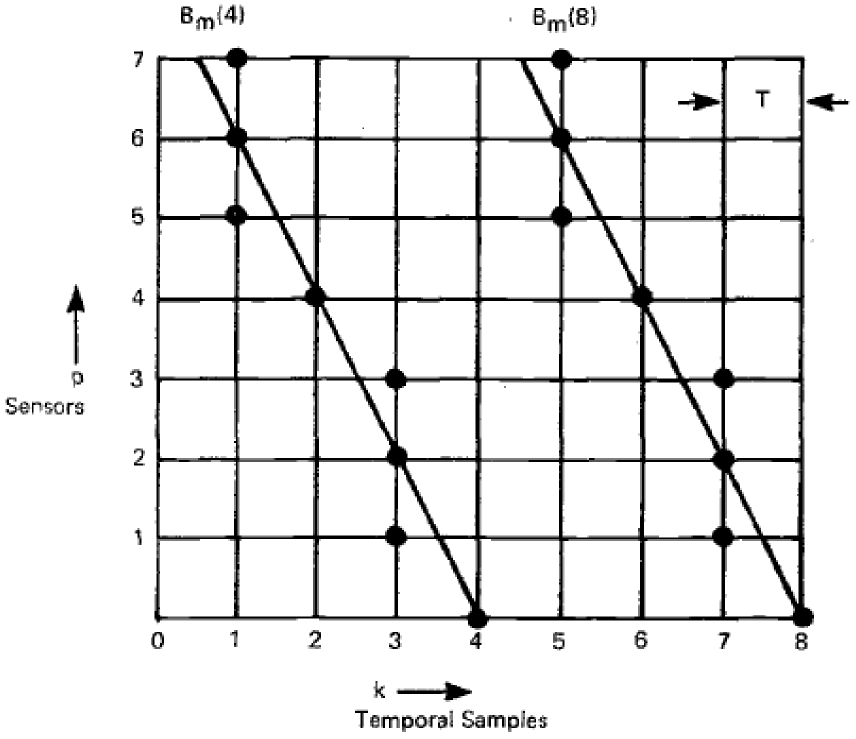


Figure 1.12: Time Delay Beamforming **[14]**.

$$\boldsymbol{BM(K) = \sum_{p=0}^{M-1} Wp\, Xp(k - Dm, p)} \qquad \textbf{(3)}$$

Where : Wp : is the aperture shading coefficient.

Xp : is the sensor signal.

Dm,p: represents the beamforming delay for the mth beam and the pth sensor .

expressed as the neares integer number of sample intervals.

The distribution of delay errors across the network is illustrated in **Figure 1.13** . Delay errors are periodic or systematic across the network and the net effect can be considered as the formation of a new network in which each periodic group of sensors is equivalent to a single sensor. These equivalent elements are no longer omnidirectional and have a much greater separation distance (ds vs. d).

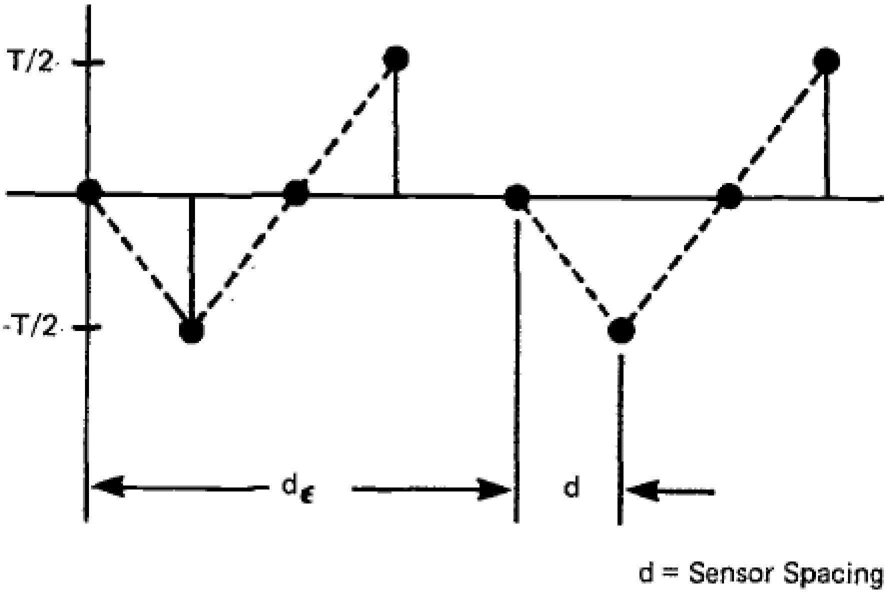


Figure 1.13:. Delay Error Distribution Across Array **[14]**.

This increased effective sensor spacing is not limited to less than half a wavelength, although the initial sensor spacing has been appropriately selected. Therefore, the network lobes are developed in real angular space, but they are attenuated by the spatial response scheme associated with the group of periodic sensors, as shown in **Figure 1.14**.

The levels of the lateral lobes are no longer controlled by the shading coefficients of the aperture; they are also a function of the ratio of sampling frequency at the frequency of the received signal. Therefore, sensor signals must be sampled at a much higher rate than the Nyquist rate in order to minimize lateral lobe degradation in narrow band linear beam models. This high sampling rate of the sensor can cause problems in transferring and managing internal data in programmable signal processors.

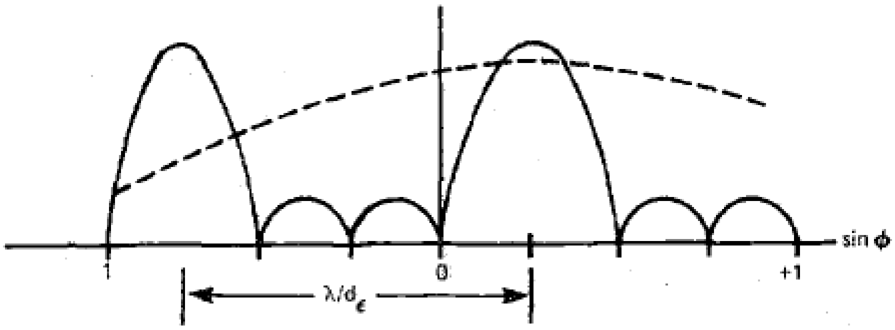


Figure 1.14: Influence of Delay Errors **[14]**.

1.7 What are the main difficulties encountered in implementing beamforming :

Today the 5G network still cannot function without the 4G network because of the short range of the beams, making its use only efficient and useful in the urban environment and especially in hotspots. In more remote environments, 4G takes over. Beamforming cannot be done for a mobile user located several hundred metres from the antenna—or even a few kilometres in the countryside. Another difficulty is the movement of users from one base station to another. Algorithms are developed to anticipate these movements.

1.8 Applications of Beamforming :

Beamforming is a versatile widely used networking technology with applications in a number of domains. Here are the top applications that are most relevant for businesses today.

1.8.1 Beamforming in 5G :

5G can use beamforming to overcome interference and range limits. 5G beamforming allows for more targeted signal delivery to a receiving device, such as a smartphone. The approach reduces interference among individual beams. Massive MIMO and hybrid beamforming are popular competitors for 5G. For example, huge MIMO may use spatial multiplexing and multi-antenna arrays to broadcast several independent signals. One of the core 5G techniques is beamforming, which combines cutting-edge antenna technologies on mobile devices and network base stations to direct a wireless signal in a specific direction rather than broadcasting it over a huge area.

1.8.2 Beamforming in Wi-Fi :

Instead of having the wireless signal spread out in all directions, as it would from a broadcast antenna, beamforming concentrates the signal towards a single receiving device. The resulting direct link is quicker and more dependable than it would be without beamforming.

When beamforming is enabled, signal strength can improve in previously difficult-to-reach areas, such as the edge of the house or next to the closet. Using beamforming, your router may create a stronger signal for your mobile devices. Wi-Fi must feature multiple-input multiple out (MIMO) technology to transmit the many overlapping signals required for beamforming.

1.9 Advantages of beamforming :

- Boosts the power of electromagnetic waves by concentrating them in a signale beam, thus extending the travel of a signal.
- minimizes frequency interference caused by surrounding electromagnetic radiation from external sources because signals are focused on specific locations.
- assures the transmission of a higher signal quality, which reduces errors and increases data transmission speeds and efficiency.
- helps the use of next-generation wireless communication applications, such as mass IoTs, driverless cars, and virtual and augmented reality.

1.10 Disadvantages of beamforming :

- Hardware Hardware complexity higher due to use of multiple complexity is higher antennas and other hardware systems.
- Concerns over energy efficiency because power consumption is considerably higher than omnidirectional broadcasting and communication .
- The End using devices will need larger battery capacitie a cause of the power-hungry and processing-intensive requirement of beamforming.

With the rapid development in the field of communication systems, the need to control the beam direction of large area antennas is becoming much more important. To meet this need, several feeding techniques try to improve to obtain a perfect spatial distribution of the beams, seeking a feeding circuit with a wide scanning capacity, low cost and simple design.

The Butler matrix, the Blass matrix, the Nolen matrix, and the Rotman lens are some of the most popular power circuits. In our work, we are interested by Rotman lens because of several favorable characteristics. Before approaching in the context of the Rotman lens, we will see, in this chapter part, deferential type of intelligent antennas These techniques are known by the formation of beams.

1.11 Types of smart antennas

Smart antennas can be classified into three main categories, which are the phased array, the switchable beam array and the adaptive array, also known as the smart antenna The first two categories use analog circuits to modify the phase and amplitude of the excitations of network elements while the last category is digital. As show in **Figure 1.15**

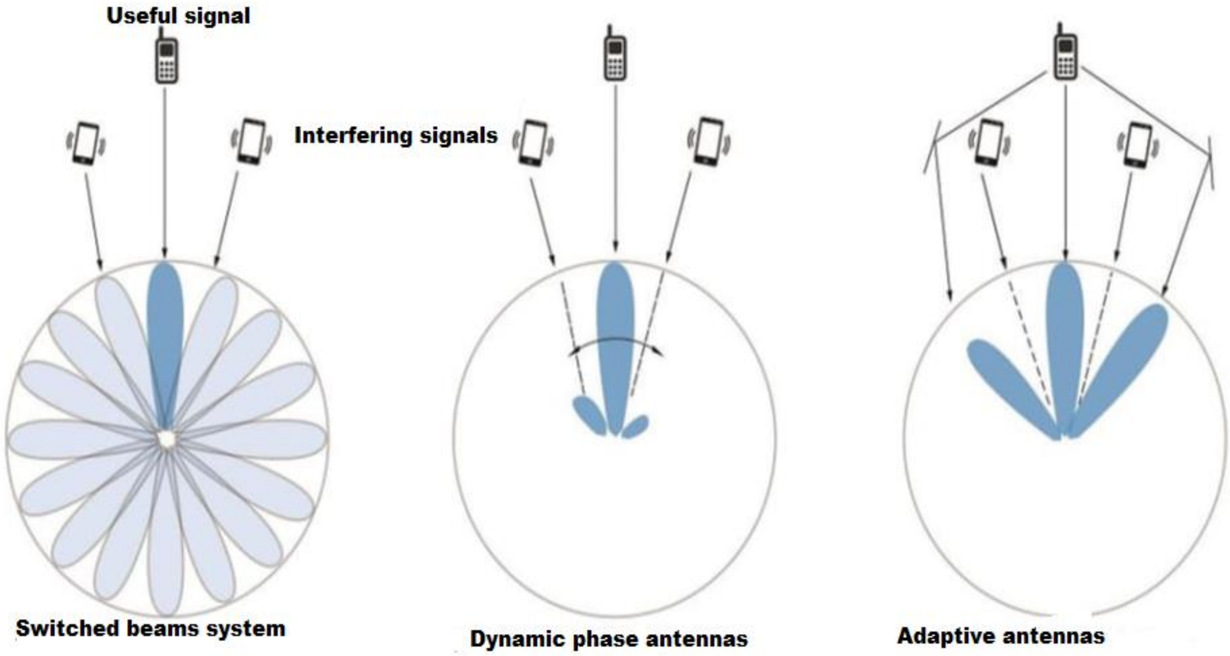


Figure 1.15: Type of smart antennas.

1.12 Phased Array

An out-of-phase network is a network generally equipped with a phase shift. Upstream of each elementary source, a phase shift is used to modify the phase applied to the source. Dynamically phased array in English can be achieved by adding transmission lines (elementary structure not radiant), of varying lengths, to each element of the network. The delay of propagation on these lines (delay) causes the required phase shift between the elements, which makes it possible to orient the lobe towards a given direction. In this type of design, the lattice is static and it does not allow the orientation of the main lobe to a direction other than the one initially chosen. So, instead of these transmission lines, diode phase shifters are generally used . Figure 1.16 : Phased array consisting of a power divider and 4 phase shifters.

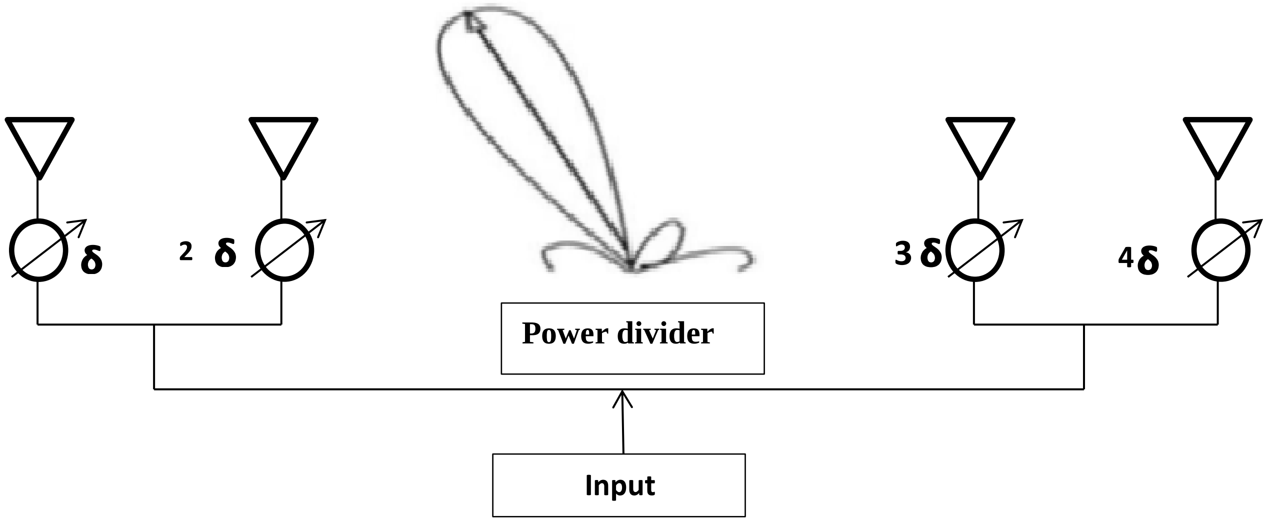


Figure 1.16 : Phased array consisting of a power divider and 4 phase shifters.

1.13 The Beamforming Networks :

High penetration losses, inherent free space path losses, and other atmospheric losses make wireless transmission at such high frequencies difficult High-directional transmission is required to get around issues, using multi-beam antennas with effective beamforming networks (BFNs). An appealing passive microwave lens-based BFN with wide adjustable beam scanning ranges, structural and operational simplicity, and dependability is the Rotman lens

A beamforming network is the apparatus that generates dynamic feeding information for an aperture (BFN). Beamforming networks often have a certain number of input ports and a certain number of output ports that are fed a certain number of array elements. To send quality beams into various angles, a BFN generates desired amplitude and phase distributions across the aperture for each input port. There are several ways of designing and categorizing the BFNs. They are the digital BFNs, network BFNs, and microwave lens BFNs. The Rotman lens antenna design falls in the regime of lens BFNs. Table 1.3 Show some number of BFN and there advantage and disadvantages.

S. number BFN	**Features**	**Advantages**	**Disadvantages**
Digital beamforming networks	They use a computer or processor to form precise amplitude and phase for different channels of array elements by controlling electronic components.	They have zero phase error, flexible amplitude tapering, and infinite number of scanning steps.	They are limited to low microwave frequencies due to low bit-bandwidth of current A/D devices
Microwave lens beamforming network	It uses a path delay method to produce the desired phase front at the array input. Each input is connected to a beam port, and the 3 Microwave lens beamforming network radiates a semicircular phase front within the lens cavity. The energy is then directed into the output array via an array of receiving elements that operate as receivers	The properly designed beam, receiving port positions, transmission line length, correct phase, and acceptable amplitude distributions can be achieved across the aperture.	The transmission lines, fixed phase shifters, and hybrid couplers that make up the matrix cause finite insertion losses as well as inherent losses.The individual beam patterns must likewise be orthogonal in space for the Butler matrix passive beam forming

			antenna to function properly.
Network beamforming network	One of the earliest BFNs which originated from the Butler matrix. It consists of alternate rows of fixed phase shifters and hybrid junctions .	They are easy to construct and can be implemented using printed circuit boards.The produced beams are dependent on frequency	Crossovers between lines are required. The beam shift occurs as the frequency varies, which is undesirable in most communication systems since specified bandwidth information must be conveyed to the same area

Table 1.3: Different types of beamforming networks.

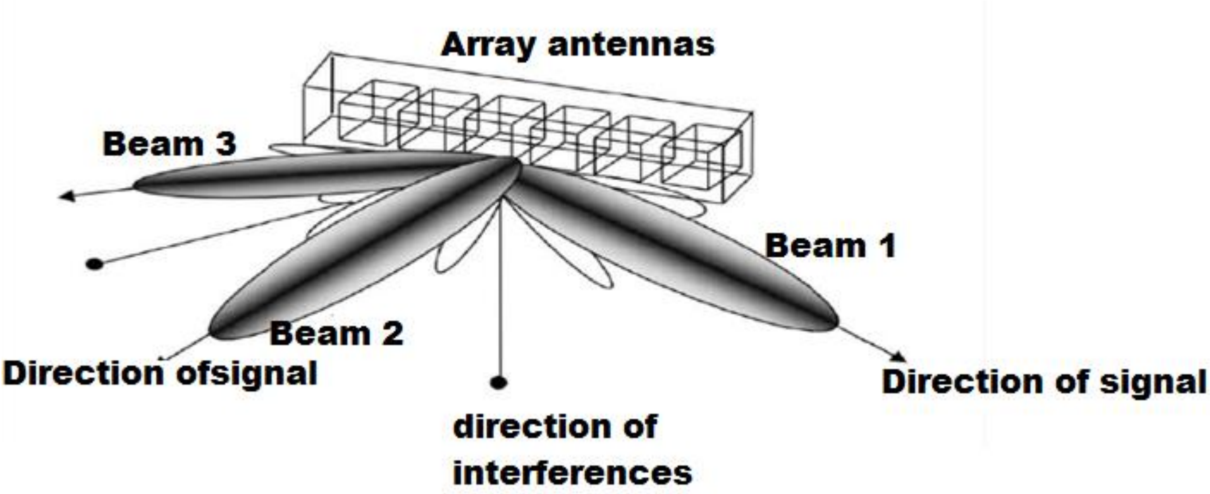


Figure 1.17:the beams by array antennas .

1.14 Rotman lens definition :

The Rotman lens aims to create a network of passive microwave beams due to its low cost, reliability, simple design, and wide-angle scanning capabilities. This device utilizes the wavelength of a signal injected into a geometrically configured waveguide to passively adjust the phase of the inputs in a linear antenna array, thereby allowing the beam to scan in any desired signal pattern. It features a carefully chosen shape and appropriately lengthened transmission lines to produce a phased wavefront at the output, determined by the time delay in the signal transmission. The Rotman lens performs beam scanning using equivalent time delays created by the different path lengths to the radiating elements. As a true time delay (TTD) device, the Rotman lens generates a beam direction that is independent of frequency, enabling it to operate across a wide bandwidth. This location determines the position of the structure's beam and matrix ports. As long as the path lengths maintain a constant time-delay behaviour across the bandwidth, the lens is insensitive to beam squinting generated by constant phase beams. Each input port generates a unique beam, which is angularly shifted at the system's output. A number of equations govern the lens design, determining focal points and array placements. System design input factors include the required number of beams, the number of primary elements, and the spacing between the elements.

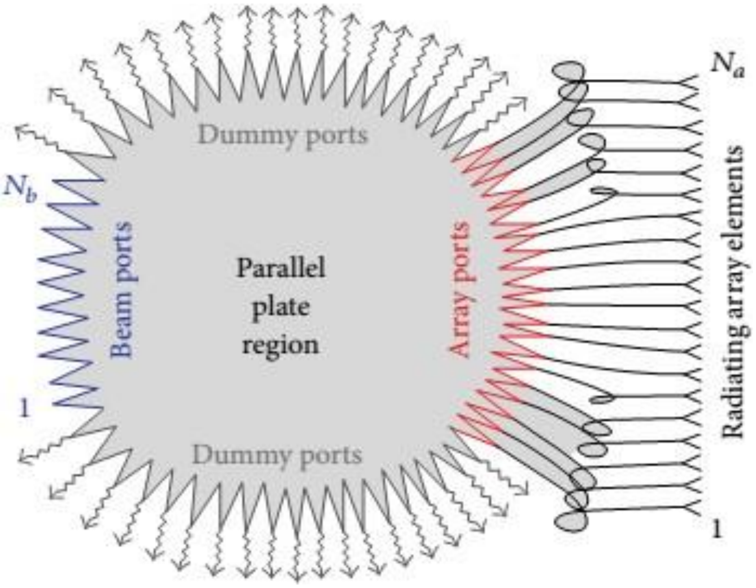


Figure 1.18 : Structur of rotman lens **[15]**.

1.15 Rotmman lens paramatere:

Using microstrip construction methods, a Rotman lens is constructed and fed into a patch antenna array. Its large scan angles, low cost, conformal geometry, and high gain meet the requirements for an antenna. Optimizing different parameters that are helpful in designing a Rotman-lens antenna has a lot of potential. The antenna can generate multiple beams that can be changed for steering without requiring a change in antenna orientation. It is made up of a series of arc-shaped input and output ports. It is made up of a parallel plate area with several beamports and array ports surrounding it.

In order to provide a parallel plate region with reflection-less termination, dummy loads can also be introduced the lens performance. The lens structure between both sets of ports functions as an ideal transmission line between the individual input and output ports. The signal applied to the input port is picked up by the output port.

The different electrical lengths between a specific input and all output ports generate a linear progressive phase shifts across the output ports of the lens.

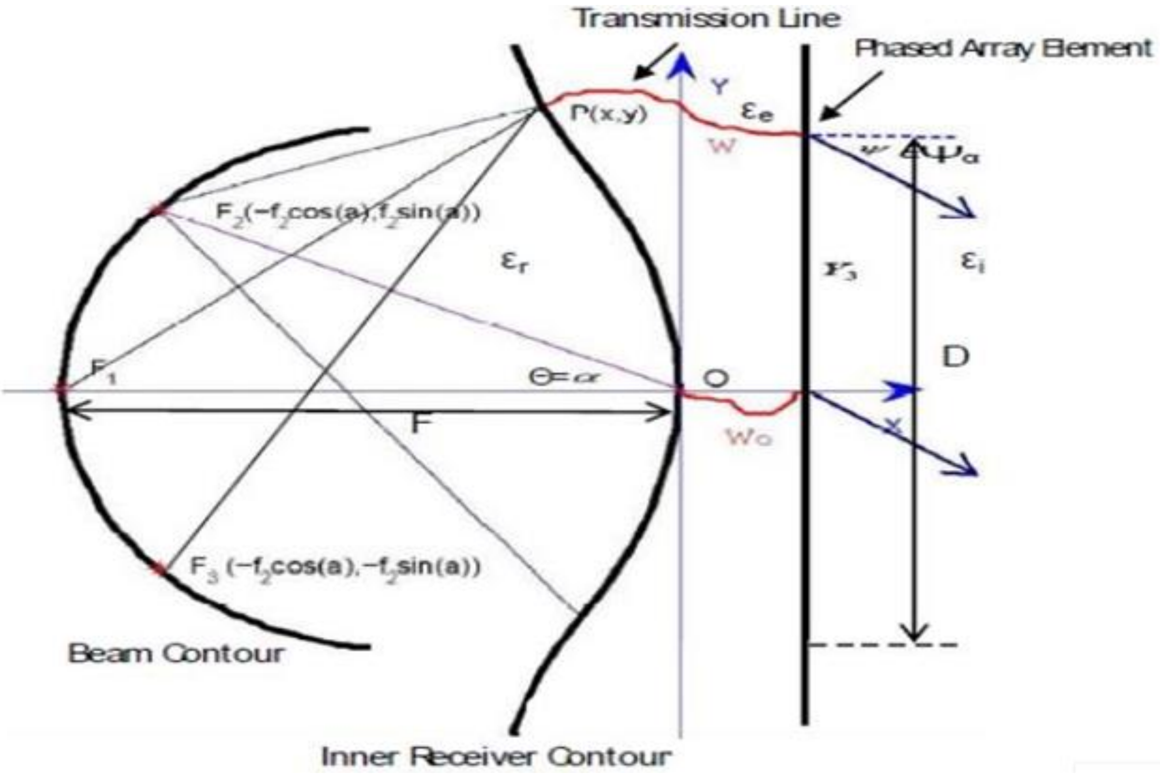


Figure 1.19: Geometric scheme of the Rotman lens **[16]**.

1.15.1 The different geometrical parameters :

α : off-center focal angle .

β : rapport focal , $\beta = OF_2 / OF_1$, $\beta = F_2/F_1$

ψ : Network scan angle

θ : underlying angle for beam port phase centers

γ: Radius/beam angle ratio, $\gamma=\sin(\psi_\alpha)/\sin(\alpha)$

OF_2: lateral focal length $f_{2;}$ OF_1 : central focal length f_1

□□□intermediate parameter, □□□□$Y_3\gamma/ f1$

Y_3 : Distance from any point on the array relative to the X-axis

W : length of the transmission line

e : Eccentricity of the beam contour

w: Normalized relative length of the transmission line, $w=(W-W_0)/f_1$

$\varepsilon_r,\ \varepsilon_e, \varepsilon_1$: Dielectric constants for the cavity region, transmission line,and environment

X,Y : Undetermined coordinates of the phase centers of the internal receiving port,normalized as X,Y.

The final equations for extracting the output contours (inner receiving contours) are listed below:

$$\mathbf{W_{12}}=\frac{\sqrt{\varepsilon e}}{\sqrt{\varepsilon r}}\,\frac{-b\pm\sqrt{b^2-4ac}}{2a} \qquad \mathbf{(4)}$$

1.16 Application of Rotman Lens:

- The main military applications of microwave lenses are airborne and maritime radar systems. For example, the self-protection ECM system AN/ALQ-184for the air force tactical.
- The Rotman lens has good performance, making it ideal for civilian applications such as remote controlled vehicles, satellite communication, collision radar, and ULB (Ultra Broadband) technology communications system
- In radar communication systems applications, it is desirable to have a wide area of coverage in a certain direction. In other words, a steerable electronic system with a wide aperture antenna is very necessary to follow the target quickly without making a

mechanical tilt in the antenna. In this situation, the Rotman lens forms a formidable solution to fulfill the task of tracking and detection in electronic defense systems.

1.17 Leaky wave antennas definition :

Leaky wave antennas are a type of traveling-wave antennas which a wave propagating along alonger than its wavelength .They resemble surfacewave antennas quite a bit like the majority of traveling wave antennas ,leaky wave antennas have a cross- section with dimension almost equal to the operating direction. A distinguished feature of these antennas is that the electromagnetically field is excited by a wave, which is incident on the interior or the exterior of the guiding structure, which produces currents that propagate along its longitudinal direction.

1.18 Classification of LWAs :

The classification of a leaky wave antenna is completely dependent on the guiding structure or geometry that propagates a wave in one direction, either unidirectionally or bidirectionally as shown Figure 1.22.

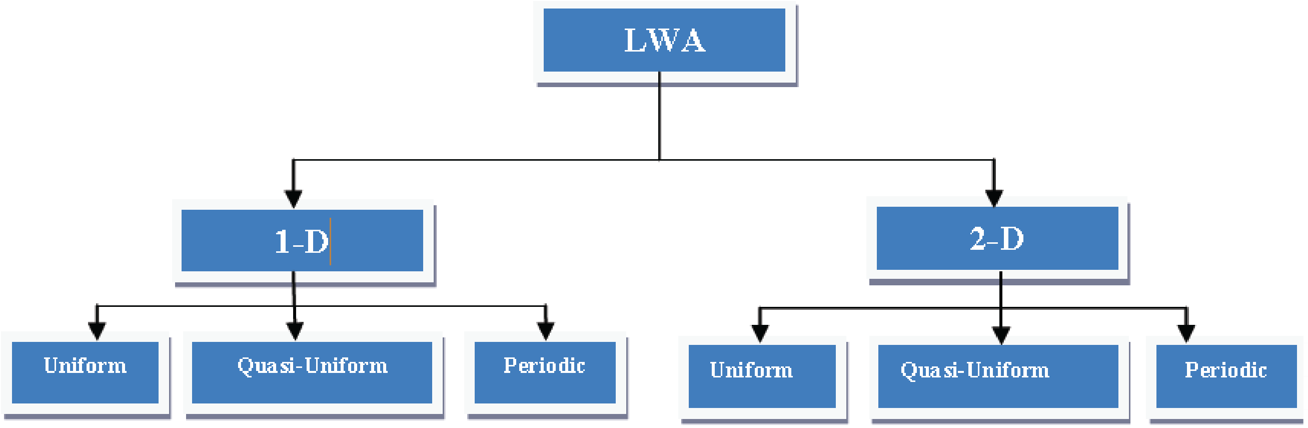


Figure 1.22: The classification of LWAS.

The source for a unidirectional leaky wave antenna is located at the structure's extremity. In bidirectional LWA, the source located in the center ofthe structure. LWAs further can be classified as uniform, quasi-uniform and periodic structures based on the mode of propagation.

In uniform leaky wave antenna, guiding structure is uniform along the length of the structure. These antennas utilize a higher order fast wave mode for leaking . The quasi-uniform leaky wave antennas is similar in all manners with uniform LWA. The guiding structure that supports the wave, which is slow with respect to free space, is called periodic leaky wave antenna.

LWAs can be divided into three types: uniform LWAs, periodic LWAs, and quasi-uniform LWA. A uniform LWA's cross section is constant throughout its guided wave structure. Because its fundamental mode is a fast wave (β0 < k0), it can emit when the guided wave structure is open. When a uniform LWA is fed, its main beam shifts from endfire to broadside direction as frequency increases. A periodic LWA generates an infinite number of space harmonics in its guided wave structure due to periodic modulations (β-1 < k0), allowing for backward to forward beam scanning [17]. However, due to periodic structures' open stop band, the performance of a periodic LWA degrades significantly when its beam is scanned near the broadside direction. As show in **Figure 1.20**.

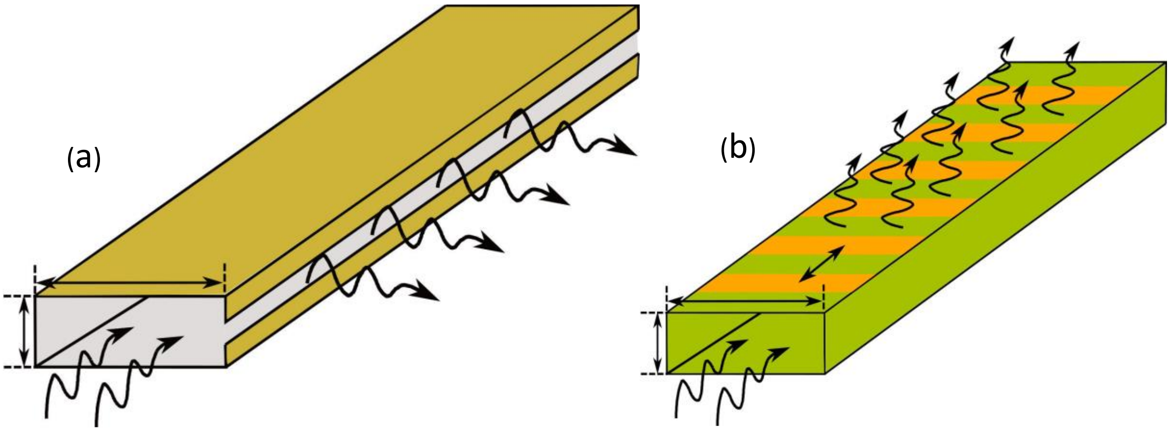


Figure 1.20 :(a) Aslotted air filled rectangular waveguide (b) Arectangular dielectric rod with periodic meta stripsl. **[17]**

It is difficult for a slotted air-filled rectangular waveguide LWA to scan in the broadside direction because the operating frequency corresponds to the waveguide's cut-off frequency. It is also difficult for a slotted air-filled rectangular waveguide LWA to scan to the endfire direction because the long slot of the rectangular waveguide corresponds to a magnetic current source, and the endfire direction corresponds to the radiation zero point of the magnetic current source. Compared with uniform LWAs, the fundamental mode of a periodic LWA is a slow wave. Thus, even if its guided wave structure is open, it cannot radiate. However, since a periodic LWA introduces periodic modulations along its guided wave structure, an infinite number of space harmonics are generated in the guided wave structure of the periodic LWA, where each space harmonic has a phase constant

$$\boldsymbol{\beta n = \beta 0 + 2\pi n/p} \qquad \textbf{(5)}$$

where β0 is the fundamental mode phase constant of the periodic LWA (slightly different from the fundamental mode phase constant when there is no periodic modulations), n is the harmonic order, and p is the period length. Although the fundamental mode of a periodic LWA is a slow wave, it is possible to obtain a space harmonic (usually the first space harmonic) that is a fast wave by designing a certain period length. As shown in **Figure 1.21**

A rectangular dielectric rod with periodic metal strips is a classic example of periodic LWAs. The fundamental advantage of a periodic LWA is that its phase constant can be negative (e.g., β-1 < k0), allowing the beam to scan from backward to forward. However, because periodic structures have an open stop band, the performance of a periodic LWA deteriorates significantly when its beam is scanned near the broadside direction. This is because the period length is equal to the periodic LWA's fundamental mode guided wavelength at the frequency corresponding to the open stop band Thus, the reflections from all periodic elements are superposed in phase, resulting in most of the energy being reflected back to the periodic LWA's input port. In recent years, a number of papers have presented various strategies for suppressing periodic LWA's open stop band. A quasi-uniform LWA, like periodic LWAs, uses periodic modulation to direct its wave form. Thus, it can generate limitless space harmonics. However, the quasi-uniform LWA's fundamental mode is a rapid wave, similar to uniform LWAs, and its period length is chosen to be short enough to ensure that radiation is limited to the fundamental mode. As a result, the period length of a uniform LWA does not directly affect the radiation mode. However, periodic modulations can be employed to modify the leaky mode's attenuation constant. Figure depicts a classic example of quasi-uniform LWAs, which emit light through closely spaced periodic perforations on the side wall of an air-filled rectangular waveguide.

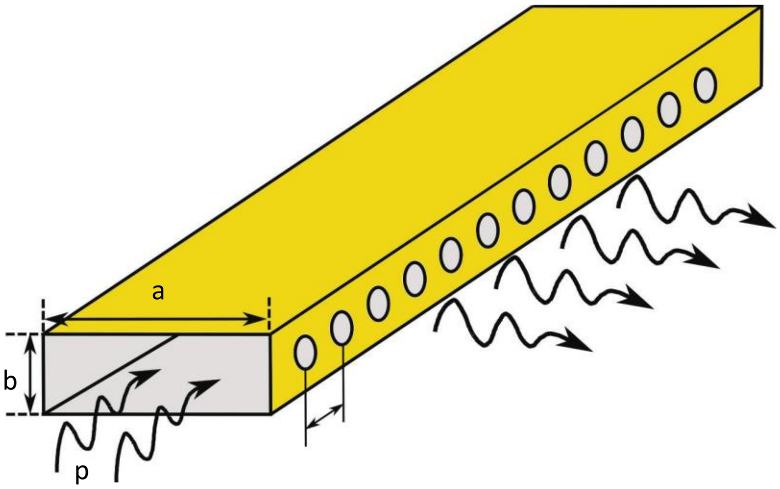


Figure 1.21 : An air-filled rectangular waveguide with closely spaced periodic holes

1.19 Surface plasmon polaritons (SPPs) in leaky wave antennas

Surface plasmon polaritons (SPPs) are highly localised surface waves that exist on the metal-dielectric interface at optical frequencies [The SPPs offer excellent performance at optical frequencies but cannot be generated naturally at microwave frequencies because metal behaves as a perfect electric conductor (PEC) at microwave frequencies. SPP structures called mimic structures have been proposed at microwave frequencies. These designed structures are known as spoof surface plasmon polariton (SSPP). Recently many SSPP-based structures have been used to design passive components such as filters, antennas and splitters but leaky-wave antennas (LWAs) based on SSPP have gained a lot of attention. The leaky-wave antenna is a type of travelling wave antenna having outstanding properties These leaky-wave antenna structures have high directivity and wide frequency scanning and require a simple feeding network The SSP TLs used in the realisation of LWAs have gained attention due to their high field confinement.

1.20 Application of leaky wave antennas :

1.20.1 5G Communication Systems

5G systems are the most recent additions to Various antenna techniques were utilised to improve the performance of this cutting-edge technology, which is still being developed. In addition to traditional channels, 5G requires high frequency bands in the millimetre wave region to achieve a greater bandwidth. constructed an antenna that took advantage of LWA's beam steering advantage. This antenna design is based on HIS and partially reflecting surfaces (PRS), which are extremely beneficial in millimetre wave applications. The integration of beam steerable LWA and PRS layers makes them suitable for 5G mobile communication.

1.20.2 Low cost radars :

Different types of radar are developed over the course of many years which are used in detecting and locating different objects that may be space crafts or ships. For the improvements in radars efficiency many types of antennas are developed which also includes certain LWA Inherent beamforming property with frequency sweep of LWA make them a good choice for the frequency scanning radar. For the development of a cost-efficient radar, Karamokar et al presented a planar leakywave antenna. The designed antenna was low profile hence proved useful for low-cost radars systems.

1.20.3 Human tracking :

One of the most important uses for antennas is human tracking. Tracking a human body has important applications in security and surveillance services. Because of this relevance, technological improvements are being produced and will continue to rise. One of the key challenges that occur during the human tracking is the variations in indoor and outdoor environments that affect the performance. Multi strip LWA are employed in the tracking process because of their capacity to estimate and range in a single frequency sweep. Yang et al. proposed an antenna design that tracked in the range-azimuth plane and generated images at a high refresh rate. Human tracking employs a wide range of microstrip leaky-wave antennas (MLWA) with modifications such as radar cross section and transverse resonance approaches. Aside from these applications, LWA is employed in automobile radars, imaging, and MIMO systems. MLWAs are widely utilised in spacecraft due to their tiny size and ease of production.

This can be effectively used in technology for identifying disaster-affected areas where rescue efforts are to be carried out. Disaster relief efforts rely on cutting-edge technology, which can be performed by using the LWA to follow persons performing rescue duties while simultaneously gathering data on the number of people trapped in an area.

1.21 Challenges and Future Research Directions of LWAs:

Leaky-wave antennas are essential components of 5G/B5G mmW mobile communication systems, with a significant impact on the system's performance. A high-performance transceiver antenna can greatly enhance transmission quality. To achieve a high gain beam to get around the increased path loss of mmW propagation in free space, 5G/B5G mmW antennas should be high directivity and low loss. Furthermore, for improved data transmission rate, 5G/B5G mmW antennas should have a larger bandwidth. Based on these requirements, fixed-beam and frequency-fixed beam-scanning LWAs continue to face the challenges of low loss, simple structure, and broadband. Feed LC Substrate DC via A Ground length (Ls) x P Connecting line. Varactor diodes A, DC via B Shorting through B Ld Wc. Main Patch Inductor shorting vias A (a). Varactor diodes B DC via A Inductor Substrate LWAs are ideal for creating mmW antennas due to their excellent directivity, low loss, and structural simplicity. However, due to LWAs' dispersion characteristics, their beams scan.

1.22 Conclusion:

In this chapter we studied the theoretical side which contains the definition of beamforming with its types and we devoted two of his most advanced techniques to researchers in futre generation : the rotman lens and leaky wave antennas . in the next chapter we represent the pratical side.

Chapter 02: Results and discussion

2. Introduction :

After studying and applying beamforming, its types and applications in wireless communications, we have divided this chapter into two parts

in the part one describes an advanced 6 GHz antenna array that can form multiple beams for use in applications such as 5G network base stations. The system consists of three parts: a Rotman lens beamformer with seven input ports and ten output ports, a standard-fed rectangular microstrip patch array. The system produces seven focused beams with a 3 dB beamwidth of approximately 14.5 degrees and a gain of greater than 17 dBi, covering a range of +/- 30 degrees. The design process consists of three separate phases: the creation of the Rotman lens beamformer, the design of the rectangular microstrip patch array , and the combination between the Rotman lens and series feed. The Rotman lens is designed as a microstrip device using the Antenna Magus software. The patch array are designed for CST STUDIO SUITE 2019. This example describes the creation of each stage of the device and evaluates the performance of each stage and the entire device .

in the part two a leaky-wave antenna (LWA) array based on hole array spoof surface plasmon polaritons (SSPPs) is proposed, which can realize wide frequency beam-scanning angle.

By etching periodic hole arrays on the upper metal of the defective ground structure, the SSPP structure is formed and the frequency scanning beam is generated by using its higher order radiation mode characteristics. The radiation mechanisms of the design are explained by using the dispersion relationship, electric field

distributions, and space harmonics . The LWA array is fed by a 1 to 4 power divider and achieves good impedance matching within 6–16 GHz bandwidth.

The average peak gain value of the proposed LWA antenna array is about 16.86 dBi and the frequency beamscanning range is 91.

1.1 Part 01 : Rotman lens

2.1.1 parameters of Rotman lens

Antenna Magus designs a trifocal (α1 = 0) Rotman Lens for minimum phase error across all beam ports. The centre focal angle, α1, however, can be adjusted. The effect of an increase in the lens parameters obtained from [Ibbotson] can be summarised as follows in **Table 0.1**:

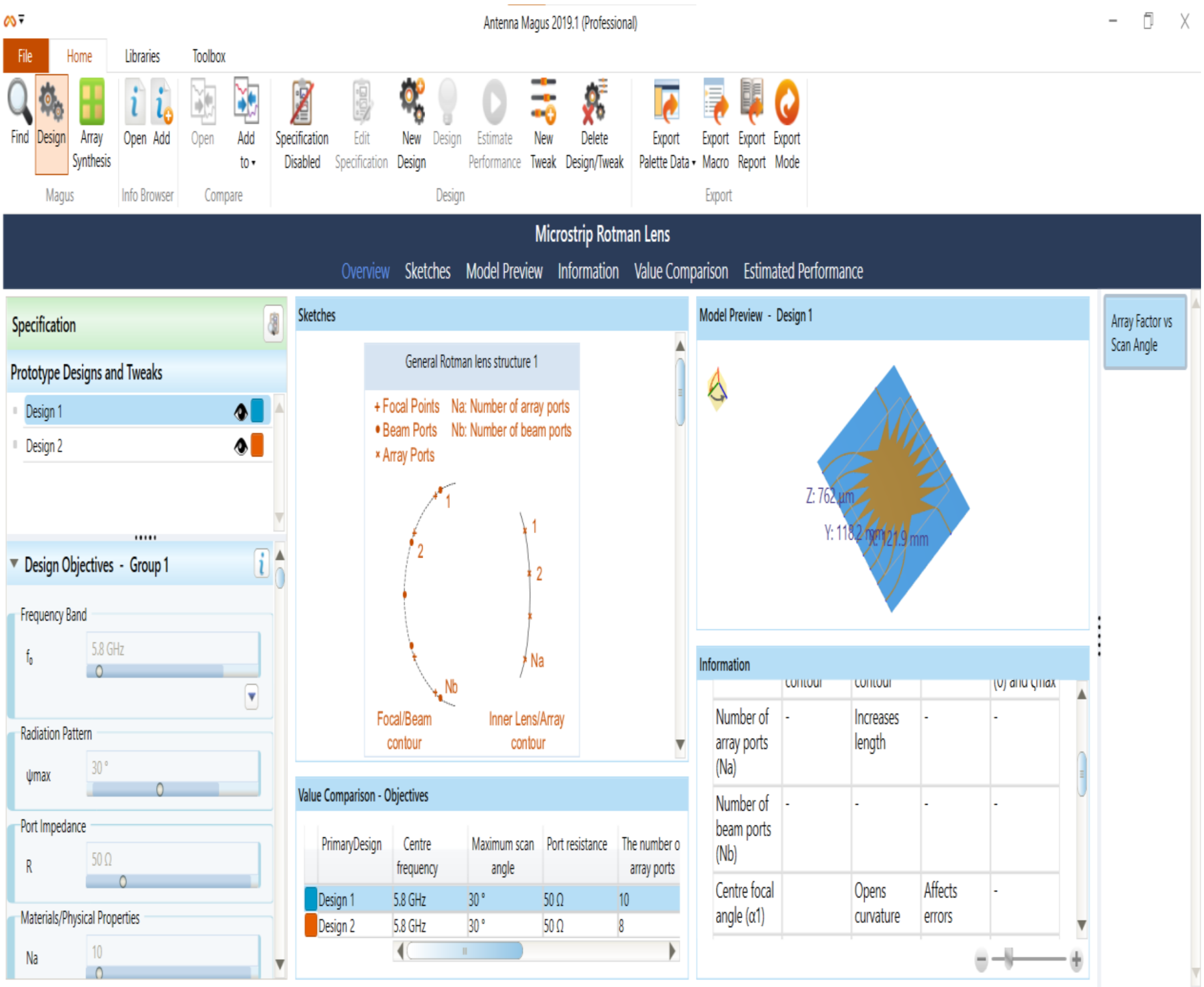
Model name	**Short name**	**Description**	**value**
lens_angle	θ	Angle of edge beam port	28.21°
Angle of edge beam port	L1	Length of the centre focal point	68.21 mm
focal_angle_centre	α1	Angle of the centre focal point	0°
focal_angle_edge	α2	Angle of the edge focal point	40°
focal_ratio	β	Edge focal length to centre focal length ratio (L2/L1)	970e-3
lens_angle_ratio	γ	Ratio relating maximum scan angle to edge focal angle (sinψ/sinα2)	1.05
array_element_spacing	Se	Spacing between array elements	20 mm
focal_arc_ellipticity	p	Ellipticity of the focal arc (contour)	1
array_port_length	La	Length of array port tapered lines	27.017 mm
beam_port_length	Lb	Length of beam port tapered lines	27.02 mm
dummy_array_port_length	Lda	Length of dummy port tapered lines on the array side	27.02 mm

dummy_beam_port_length	Ldb	Length of dummy port tapered lines on the beam side	27.02 mm
port_width	Wp	Port line widths	1.668 mm
load_impedance	Zl	Load impedance at dummy ports	50 Ω
substrate_height	Hs	Height of the substrate	0.762 mm
relative_permittivity	εr	Relative permittivity of the dielectric	3.66
tan_delta	tanδ	Loss tangent of the dielectric	0.004
frequency_centre	f_0	Centre frequency	6 GHz
Frequency_min	F min	Frequency minimum	5.5 GHz
Frequency_max	F max	Frequency maximum	6.5 GHz

Table 0.1: prametres of Rotman lens .

2.1.2Device Design :

The Rotman lens beamformer is desired to operate at seven beams +/- 30 degrees through ten array ports. A 50-ohm microstrip design is chosen which uses a circular contour shape and an overall width that is just under 5 wavelengths. The sidewalls are curved and include two dummy ports per side for absorbing any reflected fields. A suitable dielectric is chosen for the substrate with a relative permittivity of 3.66 and a thickness of 0.762 mm. The basic design is shown in **Figure 0.1** where the Antenna Magus software used to create the lens is shown. The output ports at the ends of the transmission lines are spaced a half-wavelength apart. The transmission lines are of varying lengths as determined by the equations of the Rotman lens. The Rotman lens is generally used with one or more beam ports active to produce a linear phase shift across the array ports due to the time delay in the signal propagation to reach the output. These devices are often referred to as “true time delay” systems and do not rely on phase shifters to steer beams.



Frequency Band

f₀ 5.8 GHz

Radiation Pattern

ψmax 30 °

Port Impedance

R 50 Ω

Materials/Physical Properties

Na 10

Value Comparison - Objectives

PrimaryDesign	Centre frequency	Maximum scan angle	Port resistance	The number o array ports
Design 1	5.8 GHz	30 °	50 Ω	10
Design 2	5.8 GHz	30 °	50 Ω	8

	contour	contour		(θ) and ψmax
Number of array ports (Na)	-	Increases length	-	-
Number of beam ports (Nb)	-	-	-	-
Centre focal angle (α1)		Opens curvature	Affects errors	-

Figure 0.1: The initial Rotman lens design is shown in the Antenna Magus software. The seven beam ports and the ten array ports .

After the lens shape is adjusted, **Figure 0.2** plots the seven output beams—one for each input port—to confirm the beam positions and sidelobe levels. At scan angles of +/-30, +/-20, +/10, and 0 degrees, the beams are evident. The goal is to have consistent aperture distribution array ports.

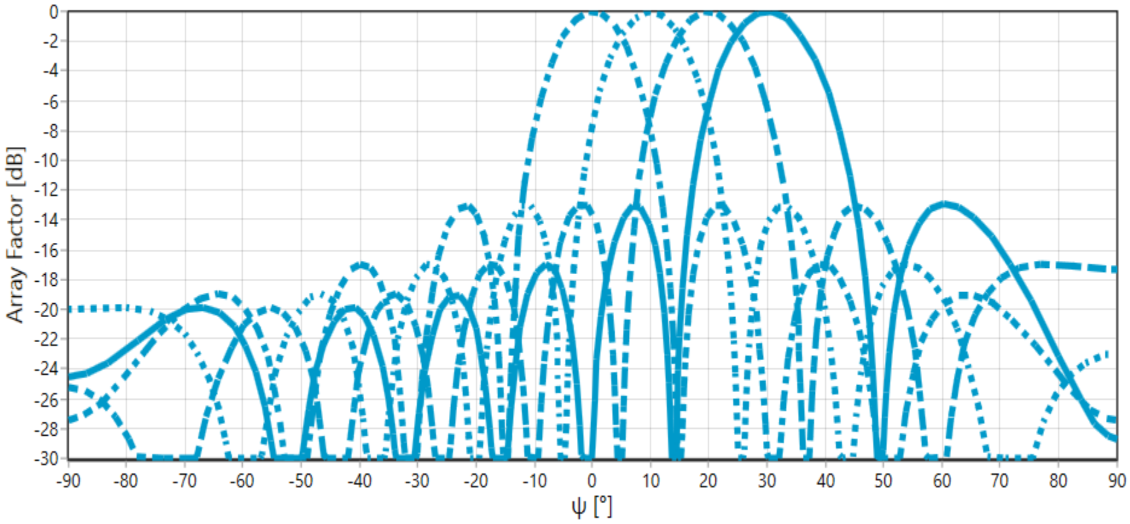


Figure 0.2: The Array Factor, a measure of the expected radiation pattern produced by a beam port due to the phase across the array ports, is shown for all seven beams of the Rotman lens designed in Antenna Magus.

2.1.3Devise simulation :

For usage in the 2019 CST Studio Suit, the Rotman lens design from Antenna Magus was exported. The geometry shown in **Figure 0.3** was created after the ports were imported into CST and terminated with a 50-ohm load on each port.

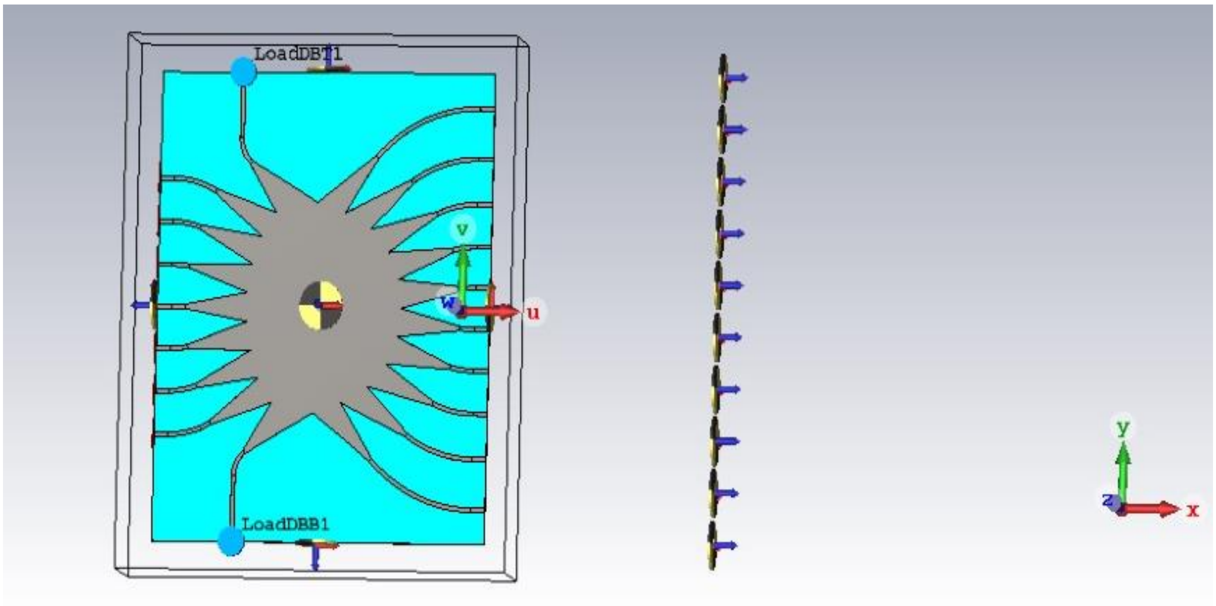


Figure 0.3: The Rotman lens design is shown in CST following was generated by the Antenna Magus software program. The lens is done in microstrip on a 0.762 mm substrate with permittivity of 3.66.

The simulated (S) reflection coefficients for each beam port of the Rotman lens are displayed in **Figure 0.4**. The extended Rotman lens has reflection coefficients in the 5–7 GHz range that are less than −10 dB for every beam port, indicating good beam port matching. The outcomes of the simulations for symmetric beam ports, like beam ports 1 and 7, 2 and 6, and 3 and 5.

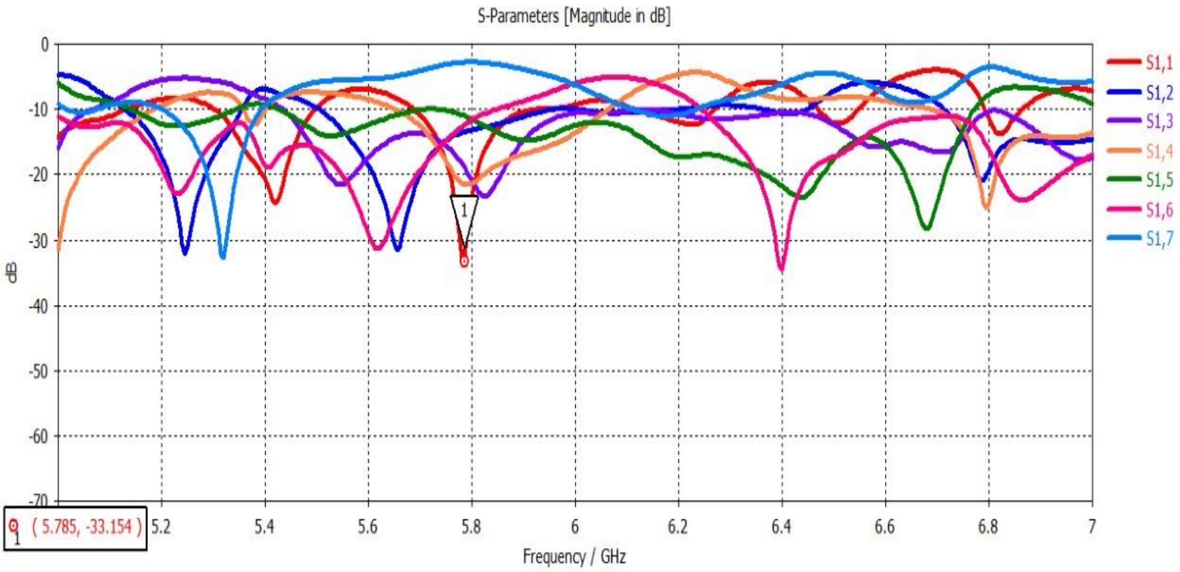


Figure 0.4: The return loss for beam port number 1 of the Rotman lens is plotted over a frequency range around 6 GHz.

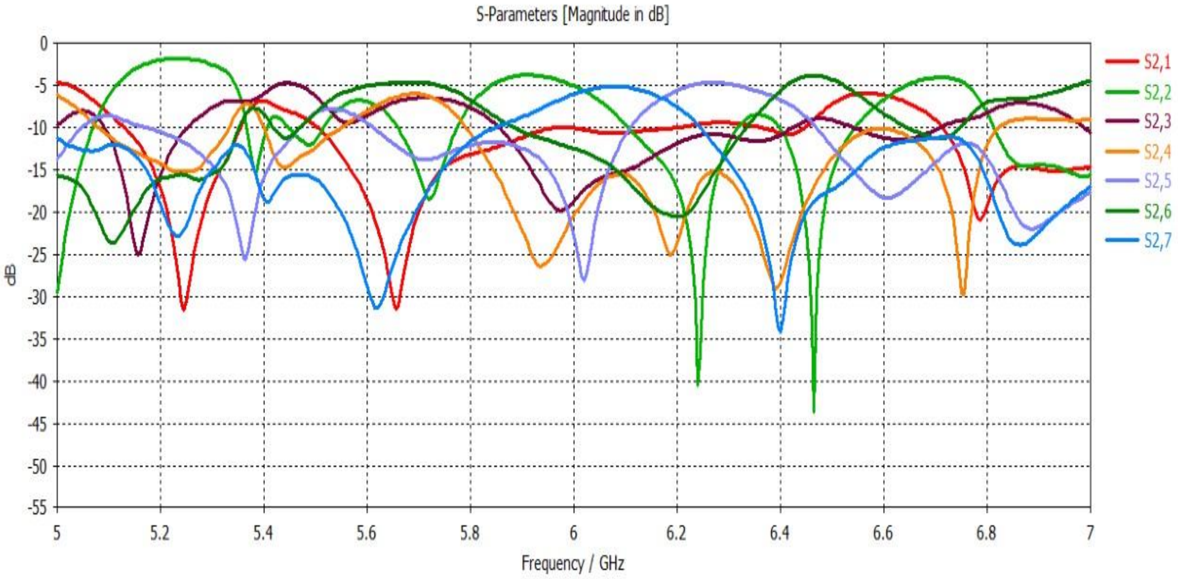


Figure 0.5 : The return loss for beam port number 2 of the Rotman lens is plotted over a frequency range around 6 GHz.

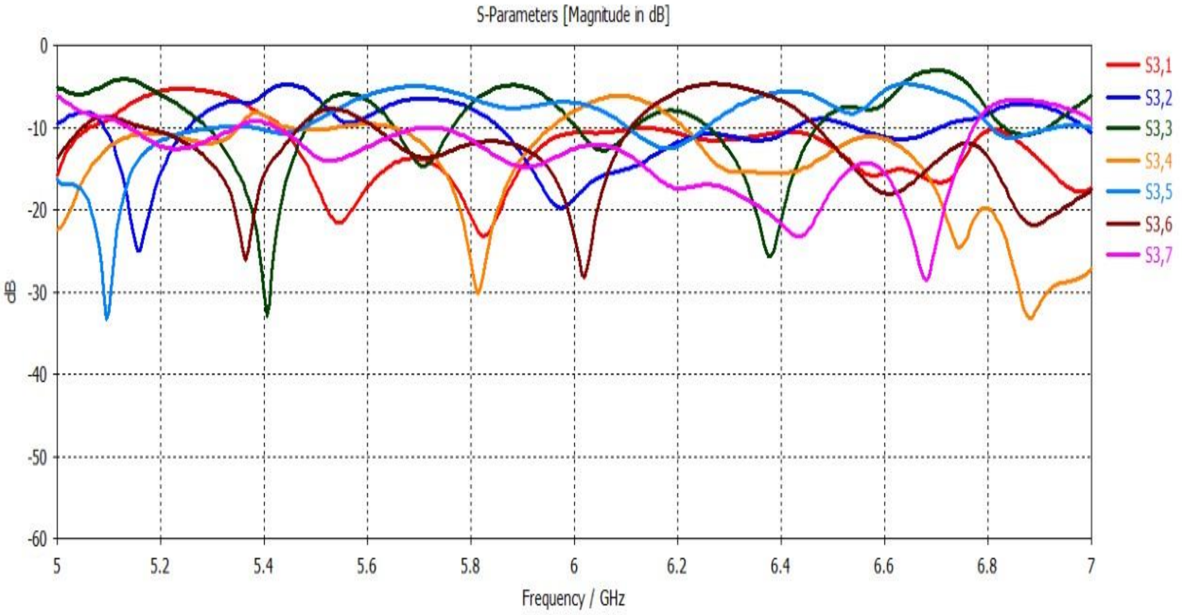


Figure 0.6: The return loss for beam port number 3 of the Rotman lens is plotted over a frequency range around 6 GHz.

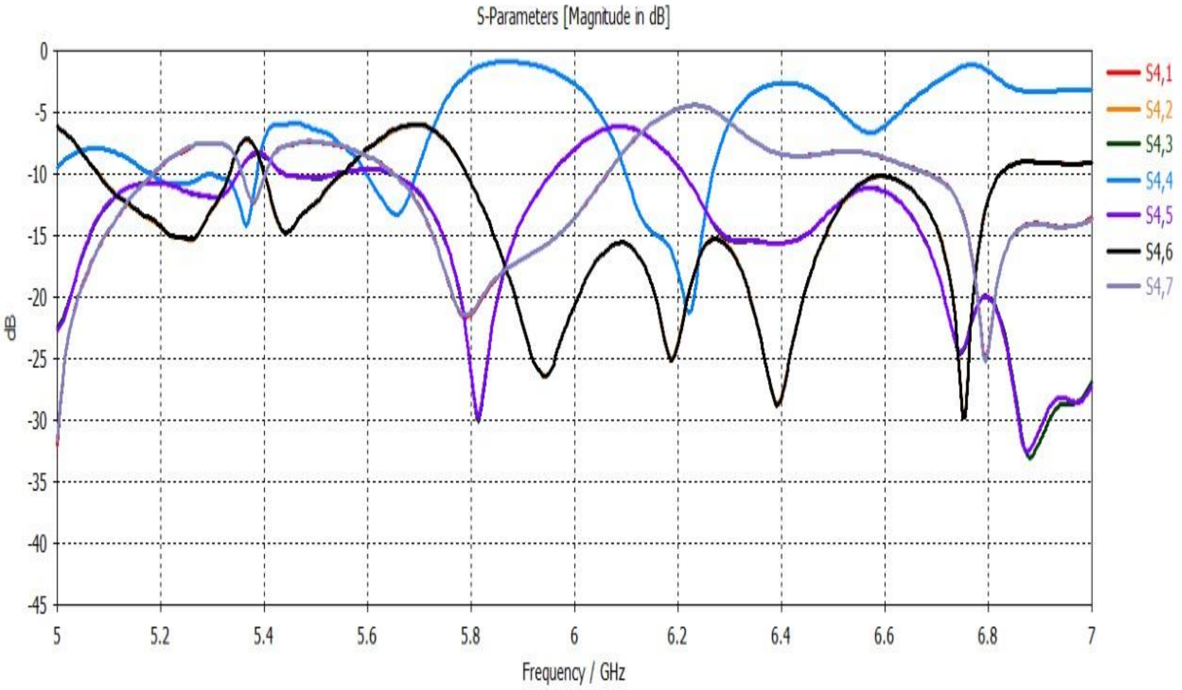


Figure 0.7:The return loss for beam port number 4 of the Rotman lens is plotted over a frequency range around 6 GHz.

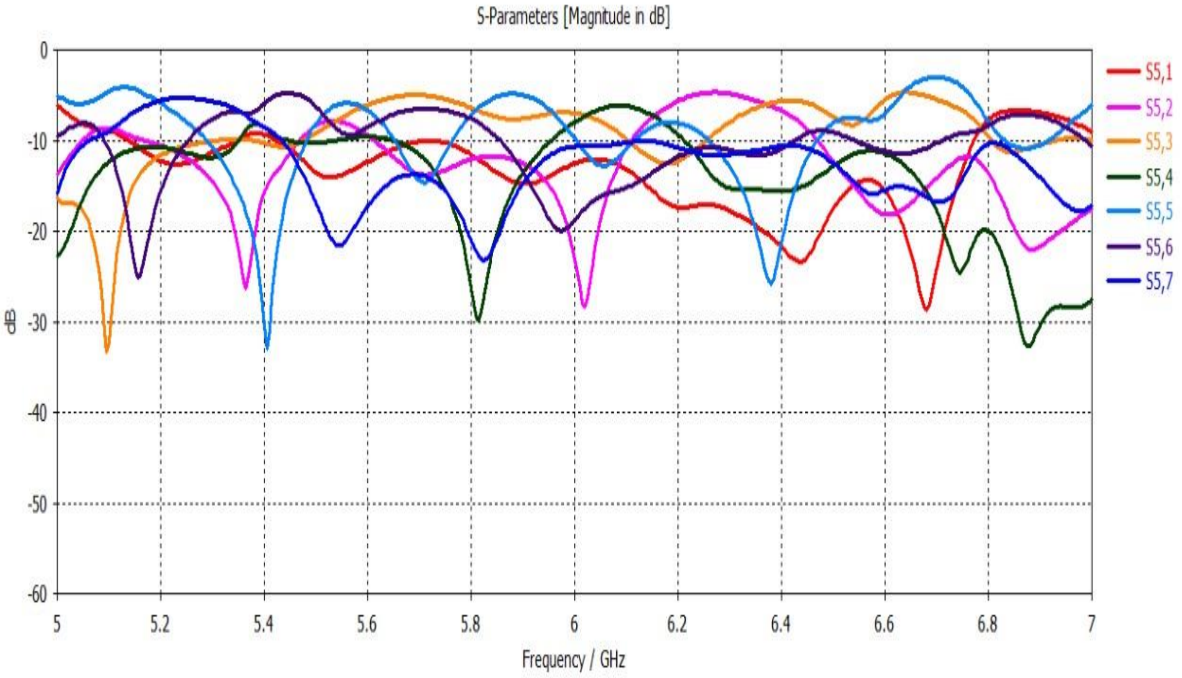


Figure 0.8: The return loss for beam port number 5 of the Rotman lens is plotted over a frequency range around 6 GHz.

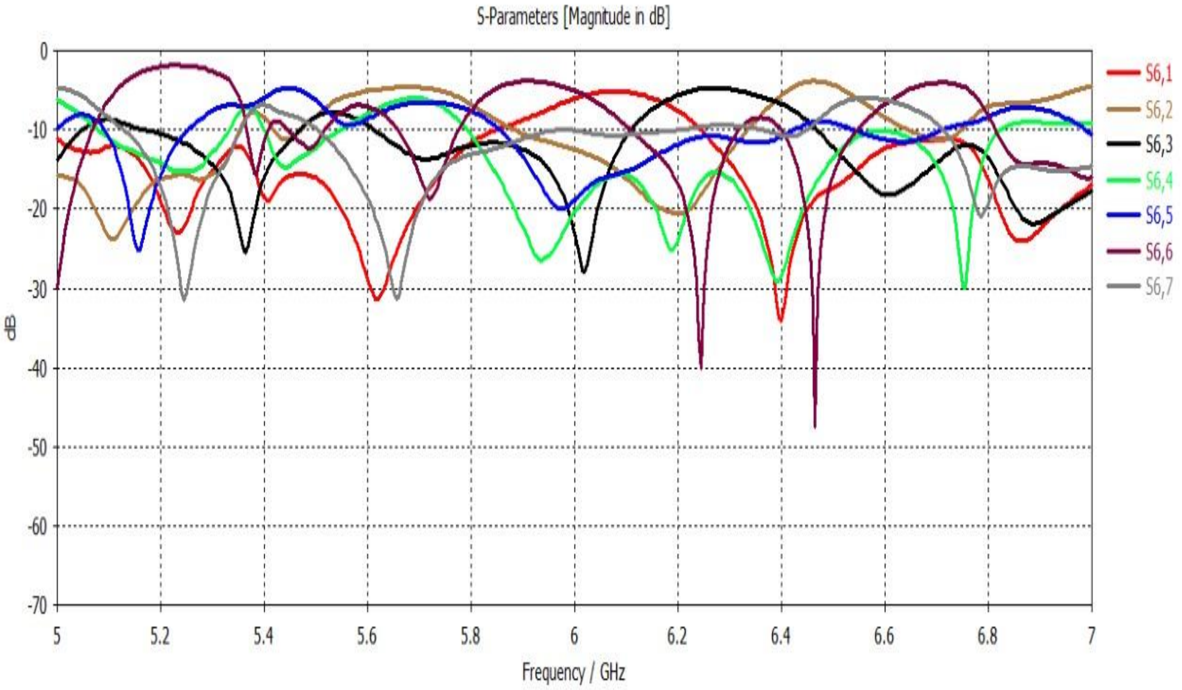


Figure 0.9: The return loss for beam port number 6 of the Rotman lens is plotted over a frequency range around 6 GHz.

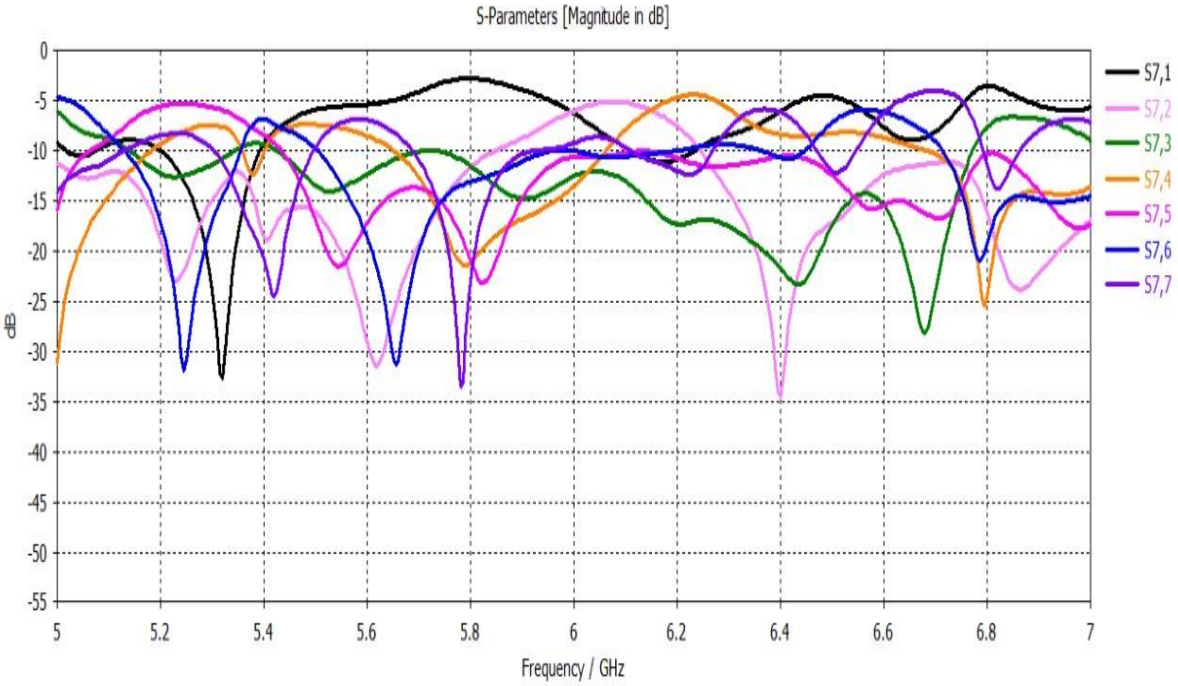


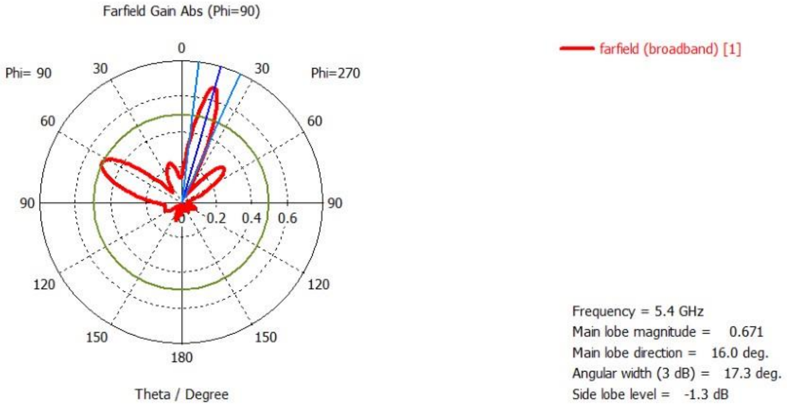
Figure 0.10: The return loss for beam port number 7 of the Rotman lens is plotted over a frequency range around 6 GHz.

2.1.4 Radiation Patterns and Discussion

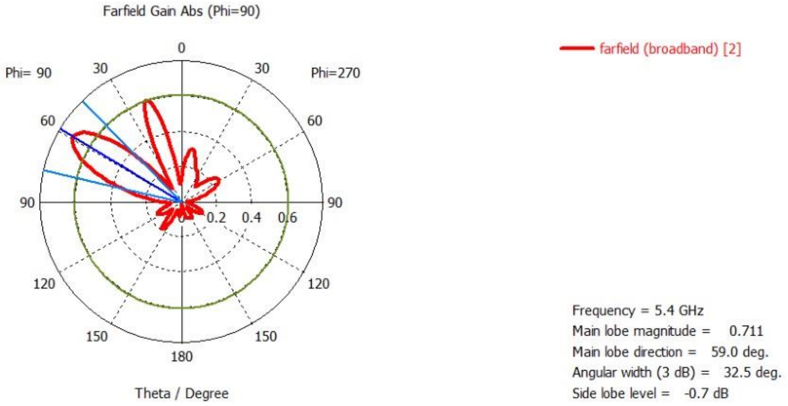
Figure 0.11 displays the fabricated prototype's normalized radiation pattern results with an antenna array at 5.4 GHz. 8. The simulated beam pointing angles produced by the antenna array when the beam ports 1, 2, 3, 4, 5, 6, and 7 are excited are 16°, 59°, 39°, 0°, -39°, -59°, and -16°, respectively. These are consistent with the preset beam pointing angles of θ1 = 16°, θ2 = 59°, θ3 = 39°, and θ4 = 0°. **Table 0.2** provides a summary of the simulated beam pointing angle results at the three frequency points.

Frequencies GHz	**Beam Port 1**	**Beam Port 2**	**Beam Port 3**	**Beam Port 4**	**Beam Port 5**	**Beam Port 6**	**Beam Port 7**
5.4 GHz	16°	59°	39°	0°	-39°	-59°	**-16°**
5.8 GHz	22°	68°	31°	24°	-31°	-68°	**-22°**
6 GHz	27°	60°	57°	56°	-57°	-60°	**-27°**

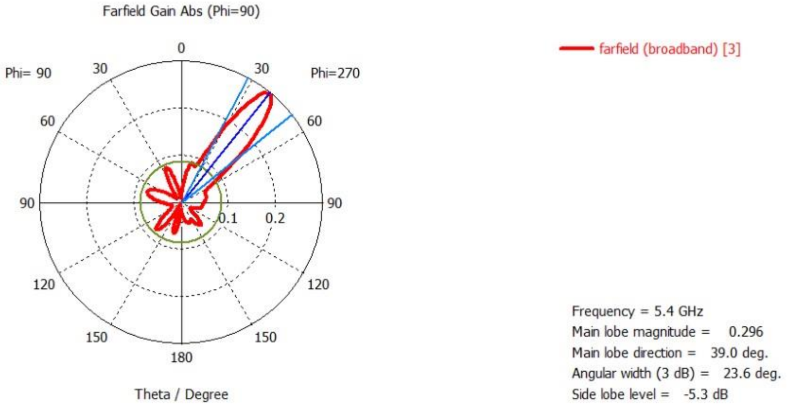
Table 0.2 : Beam pointing angles at three frequency points.



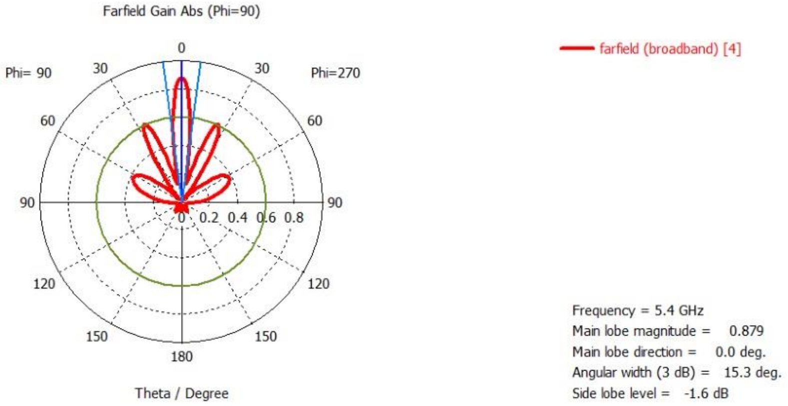
Frequency = 5.4 GHz
Main lobe magnitude = 0.671
Main lobe direction = 16.0 deg.
Angular width (3 dB) = 17.3 deg.
Side lobe level = -1.3 dB



Frequency = 5.4 GHz
Main lobe magnitude = 0.711
Main lobe direction = 59.0 deg.
Angular width (3 dB) = 32.5 deg.
Side lobe level = -0.7 dB



Frequency = 5.4 GHz
Main lobe magnitude = 0.296
Main lobe direction = 39.0 deg.
Angular width (3 dB) = 23.6 deg.
Side lobe level = -5.3 dB



Frequency = 5.4 GHz
Main lobe magnitude = 0.879
Main lobe direction = 0.0 deg.
Angular width (3 dB) = 15.3 deg.
Side lobe level = -1.6 dB

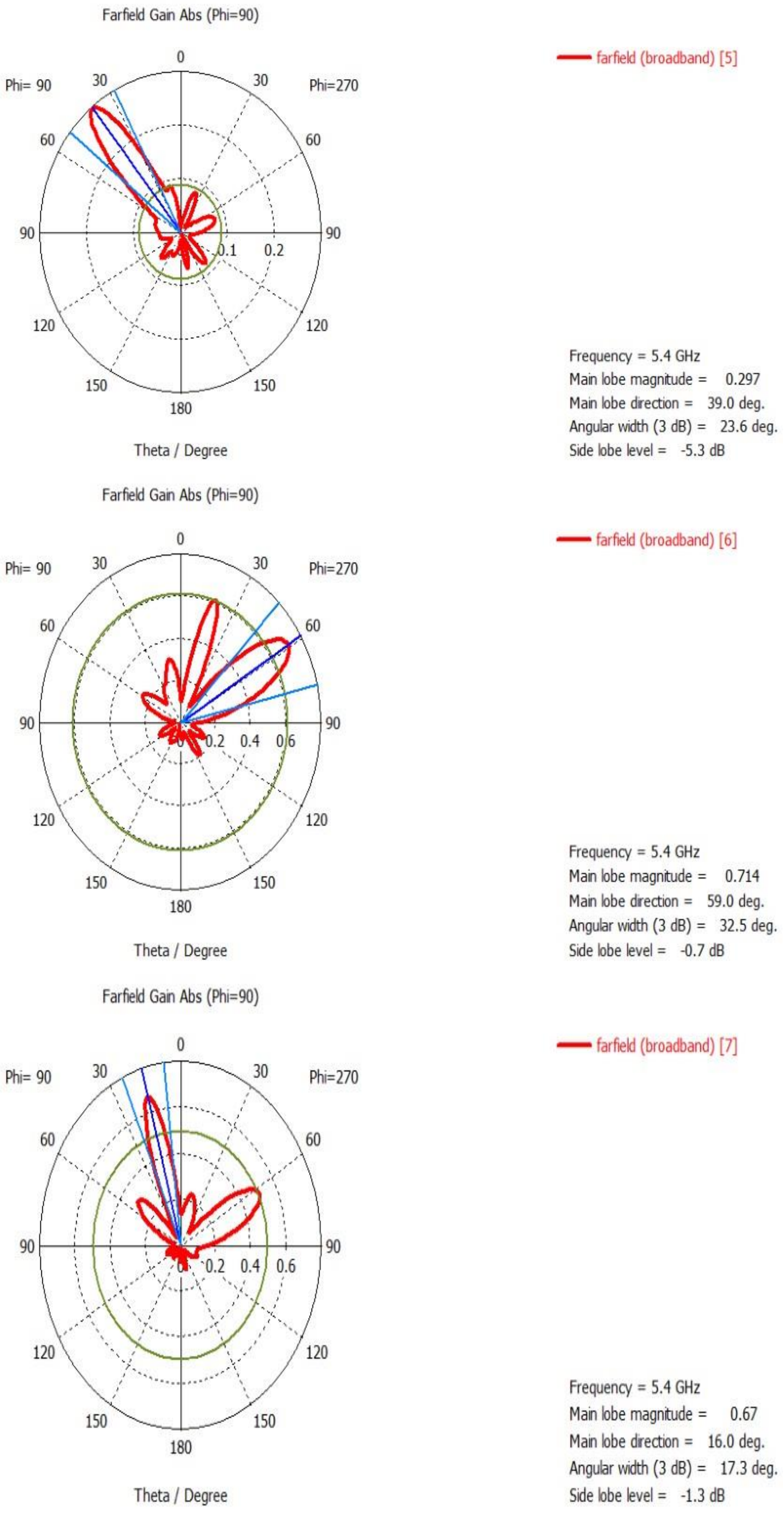


Figure 0.11: radiation patren of the Rotman lens of each ports respectively .

2.1.5 Series_ fed rectangular microstrip patch array

The series_ fed rectangular microstrip patch array is designed using the same dielectric (epsilon = 3.66) as for the Rotman lens. The thickness of the stripline substrate is 0.762 mm and the traces are 50 ohms. As show in **Table 0.3**

Parameters	**Short name**	**Description**	**Value**
frequency_centre	f_0	Centre frequency	5.8 GHz
num_elements	N	Number of elements	5
line_length	Ll	Line length	15.08 mm
line_width	Wl	Line width	1.668 mm
patch_length	Lp	Patch length	13.08 mm
patch_width_*	Wp*	Patch * width	16.92 mm
substrate_height	Hs	Substrate height	0.762 mm
relative_permittivity	ε_r	Relative permittivity	3.66
tan_delta	$\tan\delta$	Loss tangent of the substrate medium	0.004
Metal	PEC	PEC	

Table 0.3:parameter of Series_ fed rectangular microstrip patch array.

The series-fed patch array consists of rectangular half-wavelength patches which are connected with narrow microstrip lines. The widths of the patches may vary to achieve a specific excitation distribution.

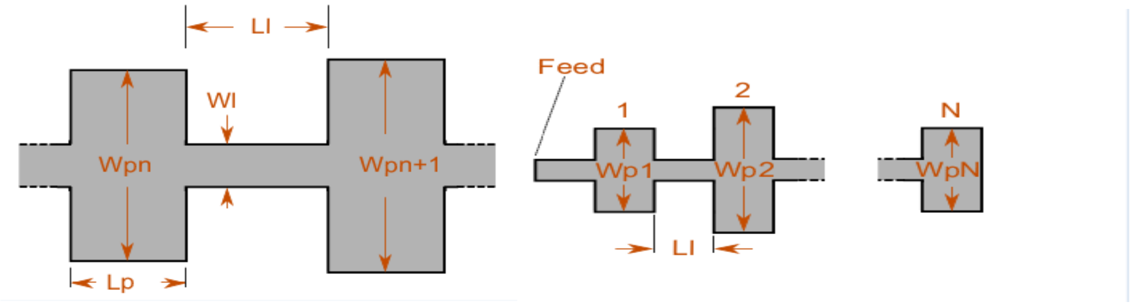


Figure 0.12: shows the structure of the series_ fed rectangular microstrip patch array.

2.1.6 Device design and simulation :

The resonant series-fed patch array is terminated in an open circuit to achieve standing wave excitation of the patch edges. It is intrinsically narrow band, but when properly designed is capable of a broadside fan-beam with gain around 20 dBi, close-in side-lobes below 25 dB, and 1.5 % pattern and impedance bandwidth about the resonant frequency.

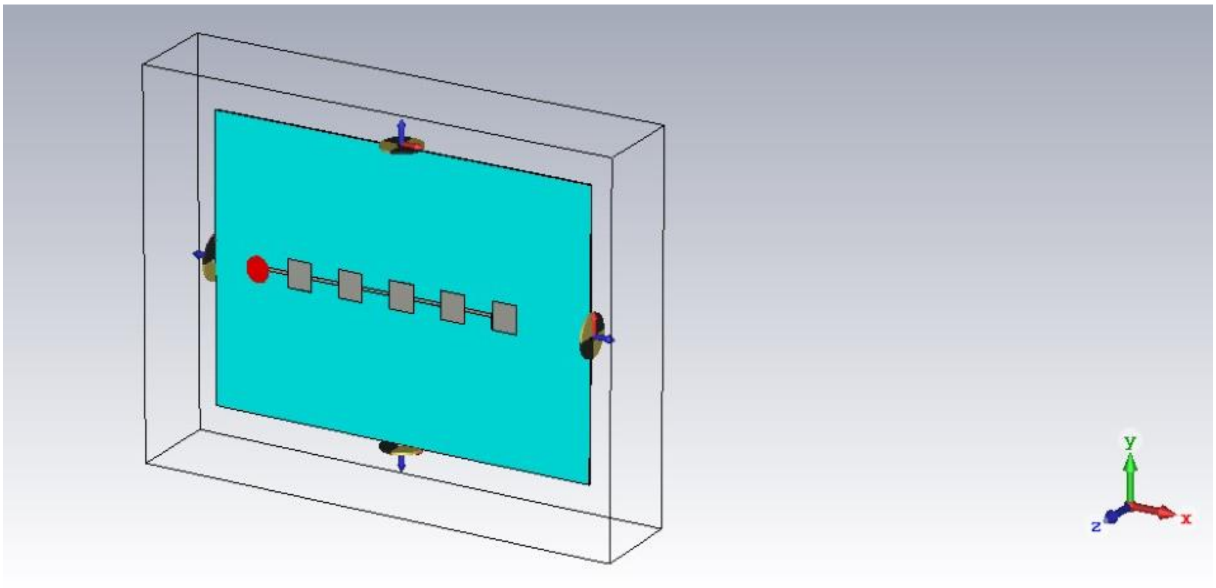


Figure 0.13: The series_ fed rectangular microstrip patch array design is shown in CST following was generated by the Antenna Magus software program. The series is done in microstrip on a 0.762 mm substrate with permittivity of 3.66.

The combined series_ fed rectangular microstrip patch array part was simulated with waveguide ports . The resulting return loss plots for each subarray are shown in **Figure 0.14** and good performance is seen at 5.73 GHz. The ports are fed with phase shifts varying from +90 degrees between elements (beam 1) to -90 degrees between elements (beam 7) in 30 degree increments to produce seven distinct beams.

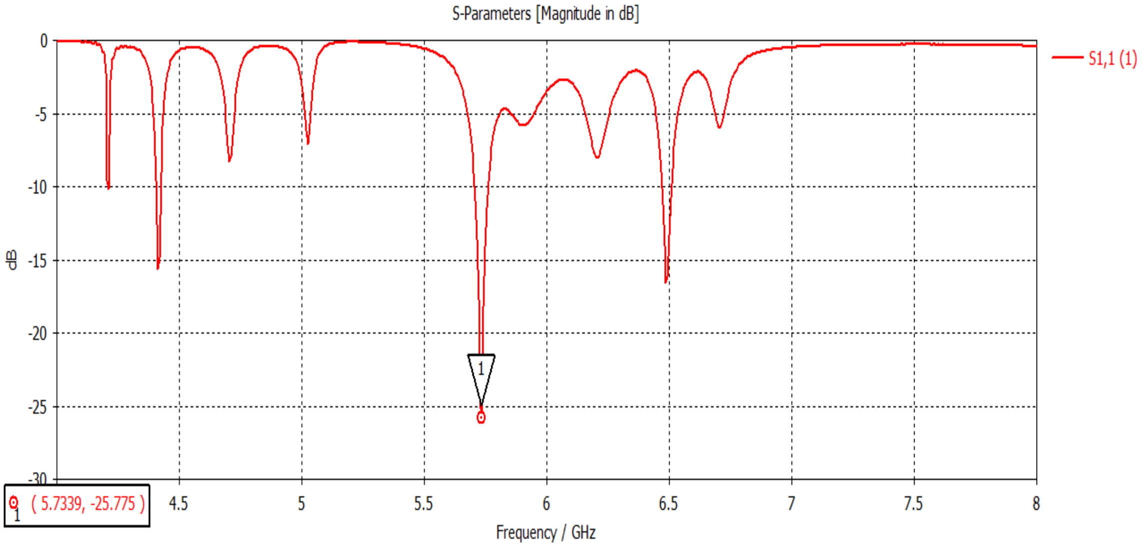
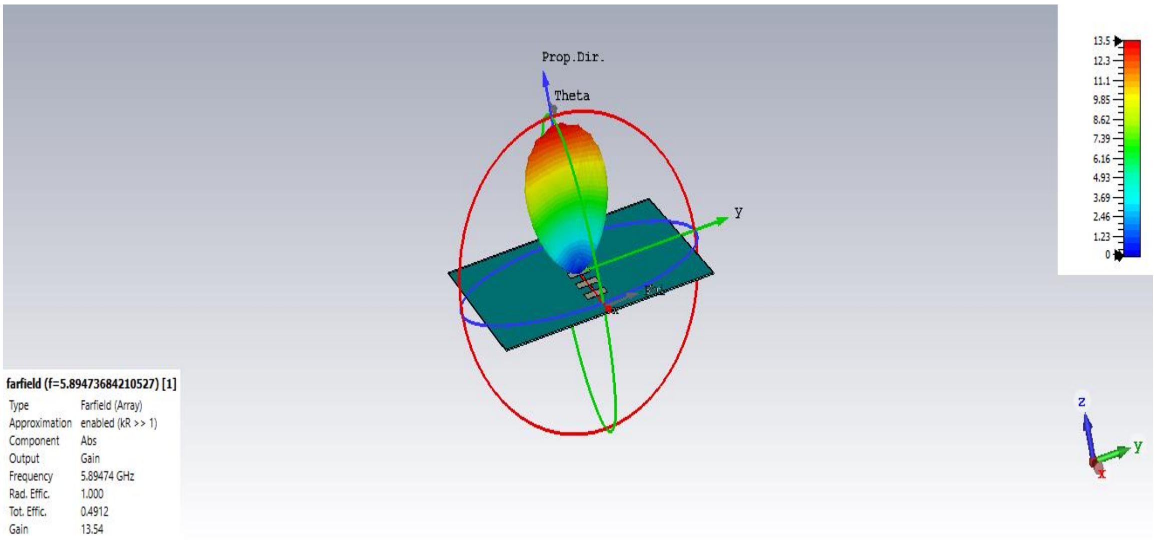


Figure 0.14: The return loss for each beam port of the series_ fed rectangular microstrip patch array is plotted over a frequency range around 6 GHz.



farfield (f=5.89473684210527) [1]

Type	Farfield (Array)
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	5.89474 GHz
Rad. Effic.	1.000
Tot. Effic.	0.4912
Gain	13.54

Figure 0.15: This is an alternate view of the three-dimensional beam patterns of series_ fed rectangular microstrip patch array.

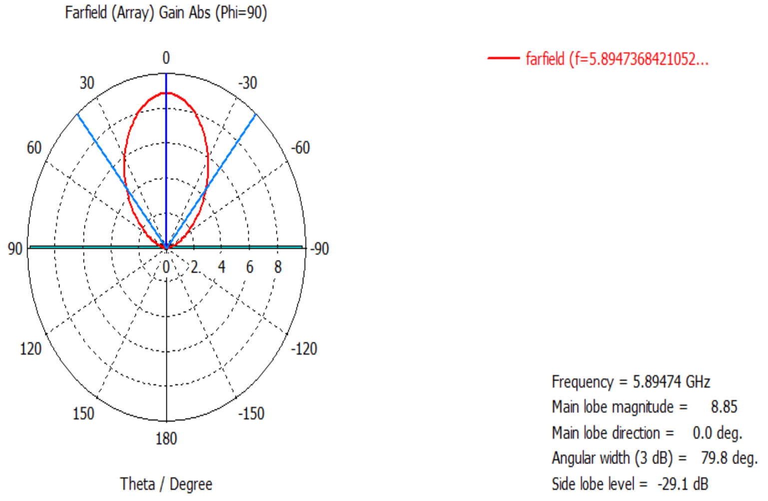


Figure 0.16:Simulated and normalized radiation patterns at 5.8 GHz.

The final step of the design is to combine the Rotman lens beamformer with the series_ fed rectangular microstrip patch array . This structure is shown as a three-dimensional model in Figures **Figure 0.17** and **Figure 0.18**. Here, waveguide ports matched to 50 ohms are used at all open connections including the seven beam ports and two dummy ports for reflection reduction in the lens.

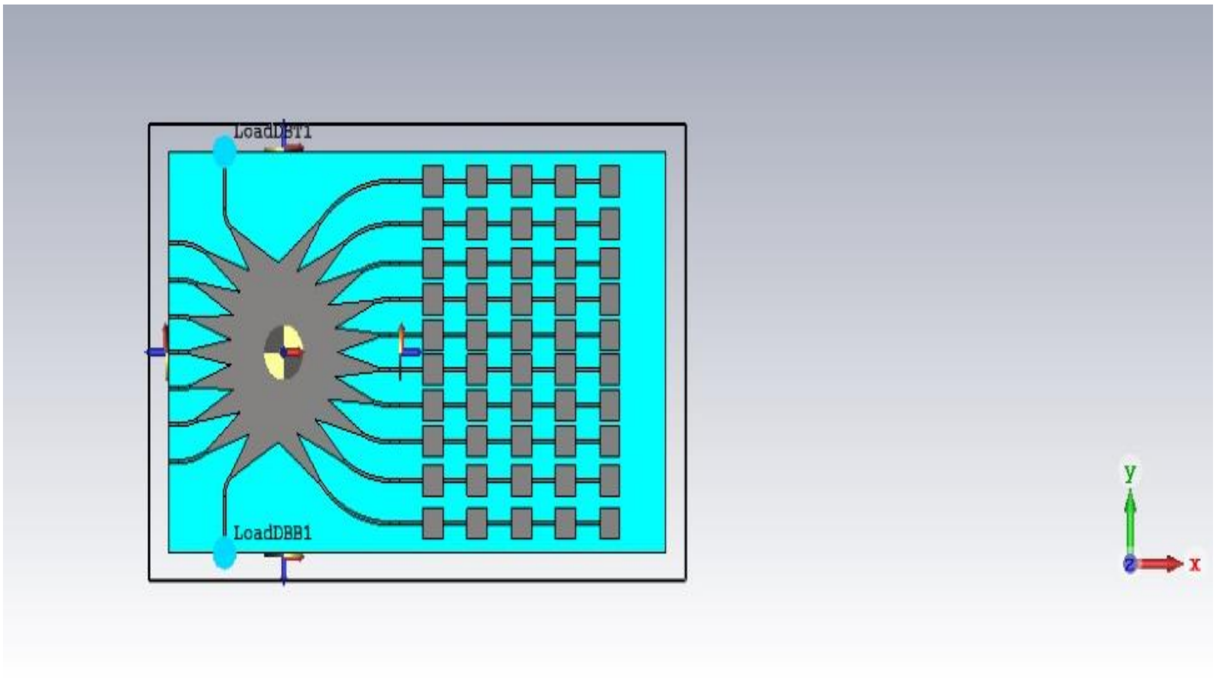


Figure 0.17: This is a top view of the entire system where the Rotman lens and array transmission lines are more clearly visible.

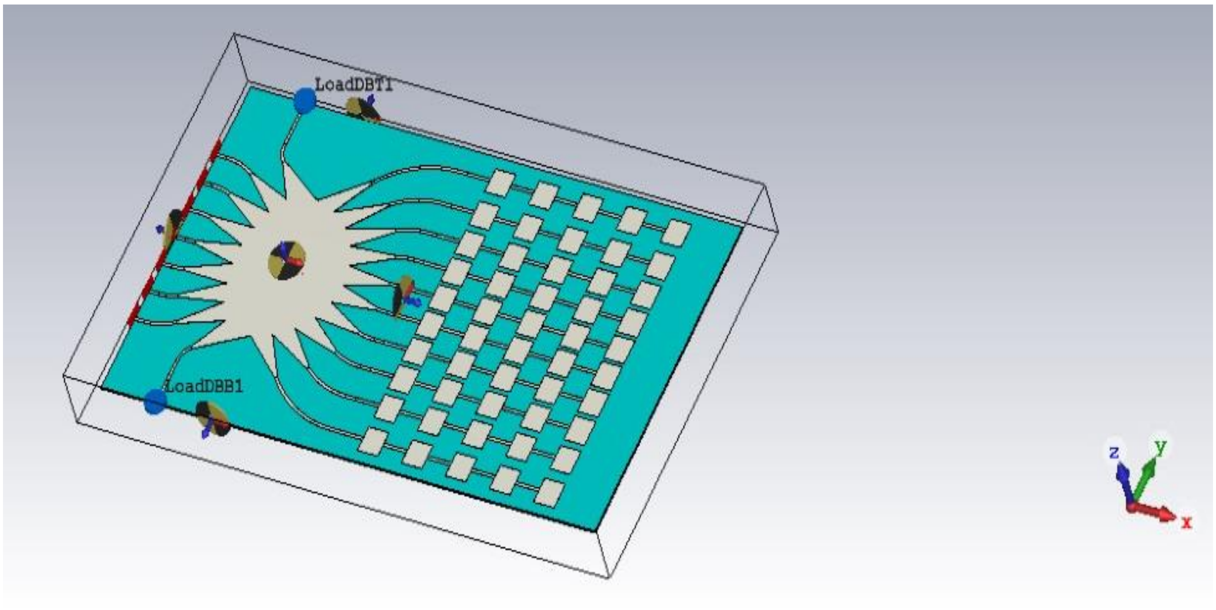


Figure 0.18: Here the complete system of the Rotman lens input, and 5x10 series_ fed rectangular microstrip patch array are shown as a three-dimensional model.

The simulated (S) reflection coefficients for each beam port of the Rotman lens are displayed in Fig. 2.(13.14.15.16.17.18.19) The Rotman lens shows reflection coefficients in the range of −10 dB for every beam port in the 5.5–6.5 GHz range, indicating good beam port matching. The symmetrical beam port simulation results.

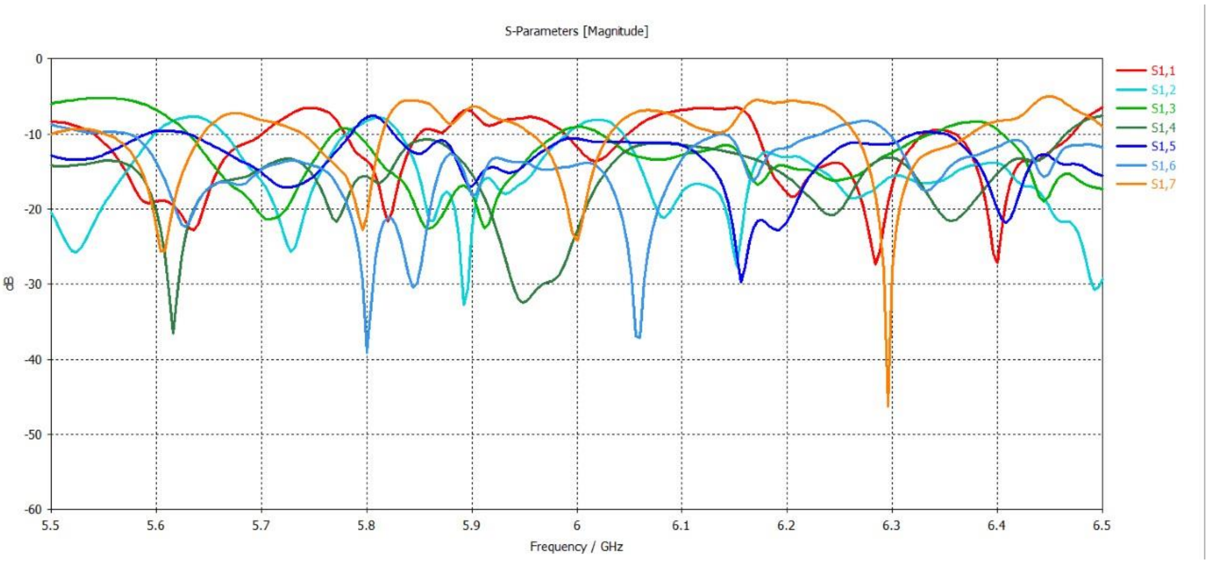


Figure 0.19: The return loss for first beam port of the Rotman lens is plotted over a frequency range around 6 GHz.

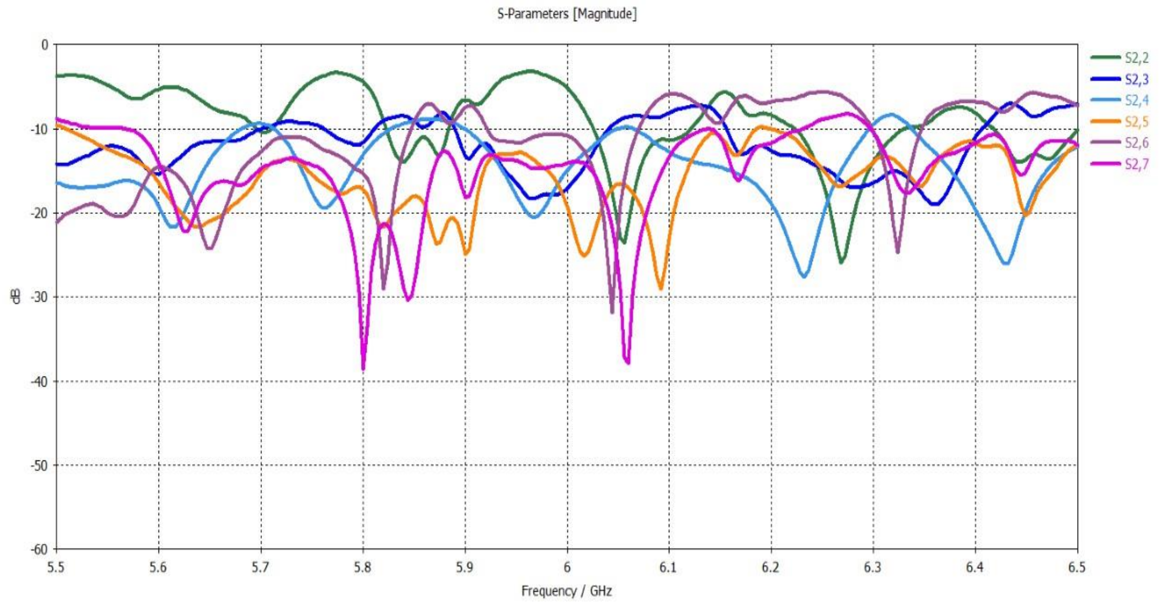


Figure 0.20: The return loss for second beam port of the Rotman lens is plotted over a frequency range around 6GHz.

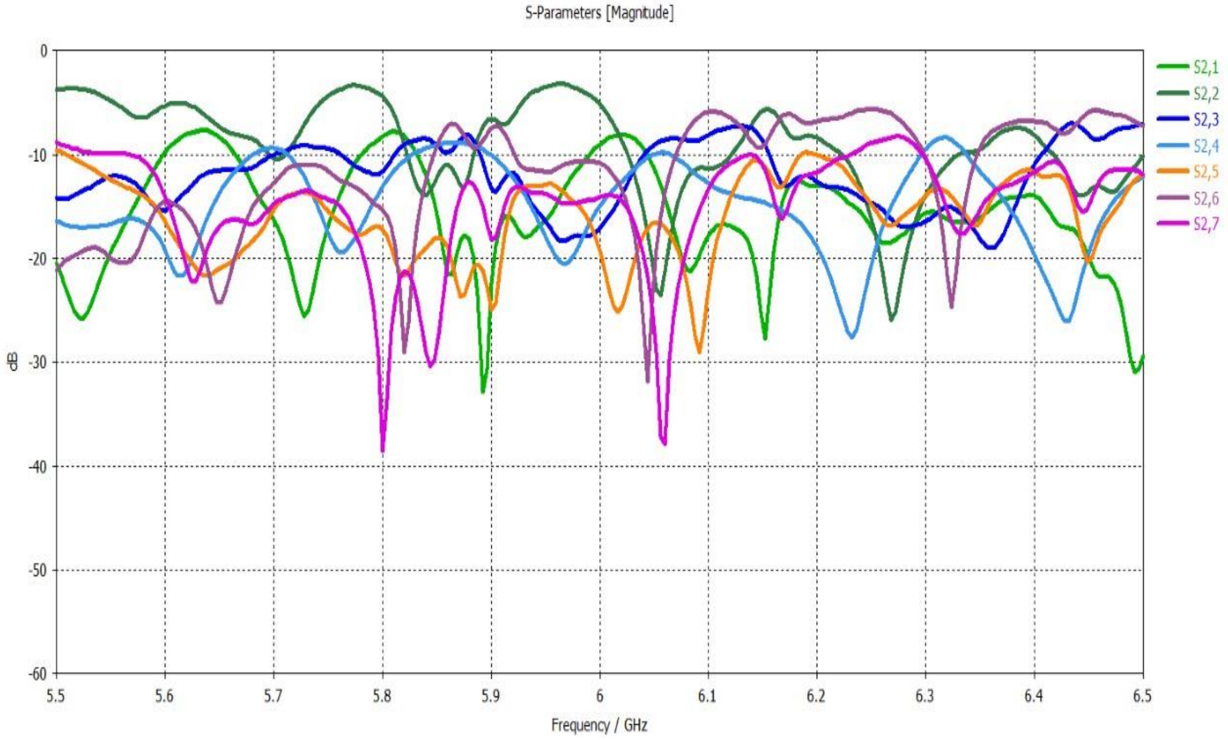


Figure 0.21: The return loss for third beam port of the Rotman lens is plotted over a frequency range around 6GHz.

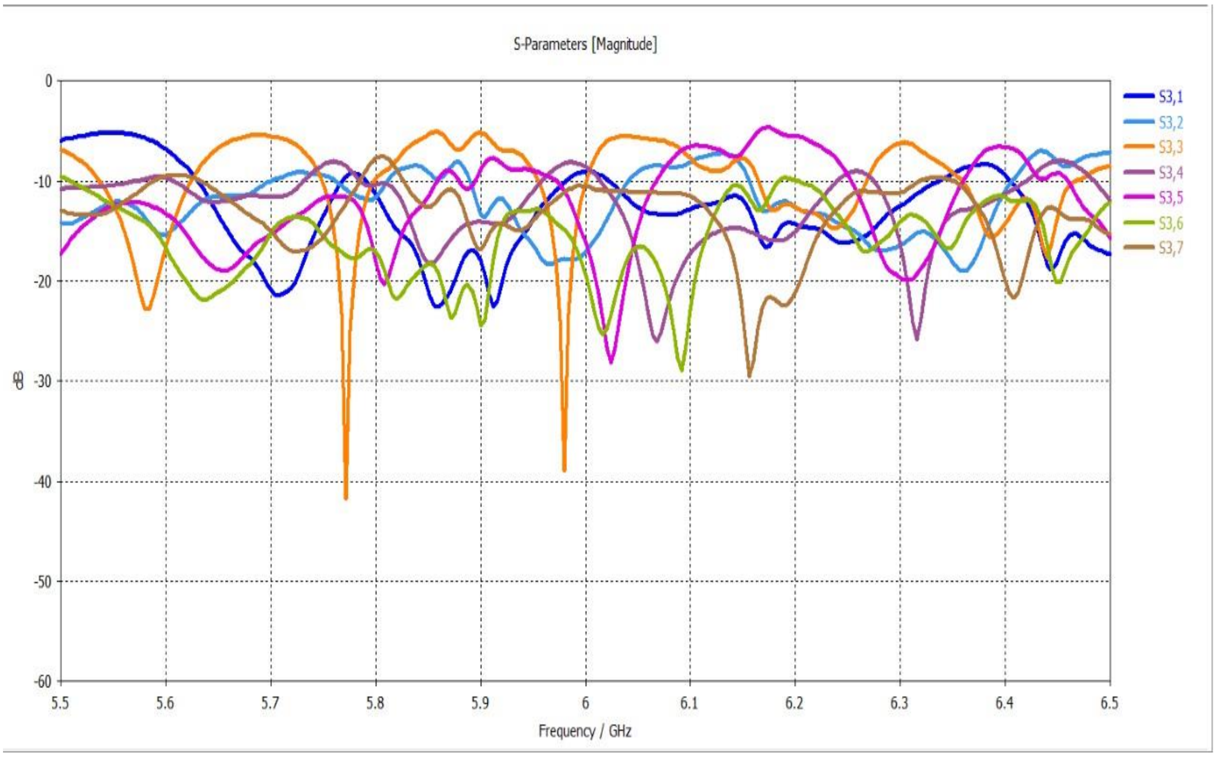


Figure 0.22: The return loss for beam port number 4 of the Rotman lens is plotted over a frequency range around 6 GHz.

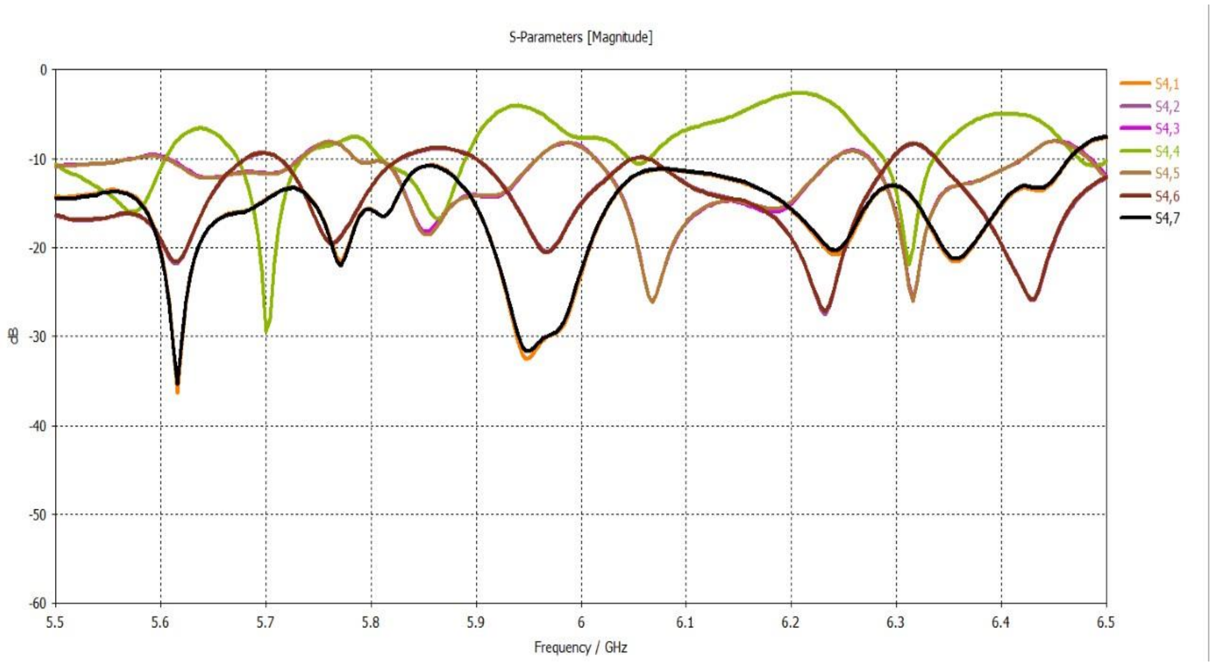


Figure 0.23: The return loss for beam port number 4 of the Rotman lens is plotted over a frequency range around 6 GHz.

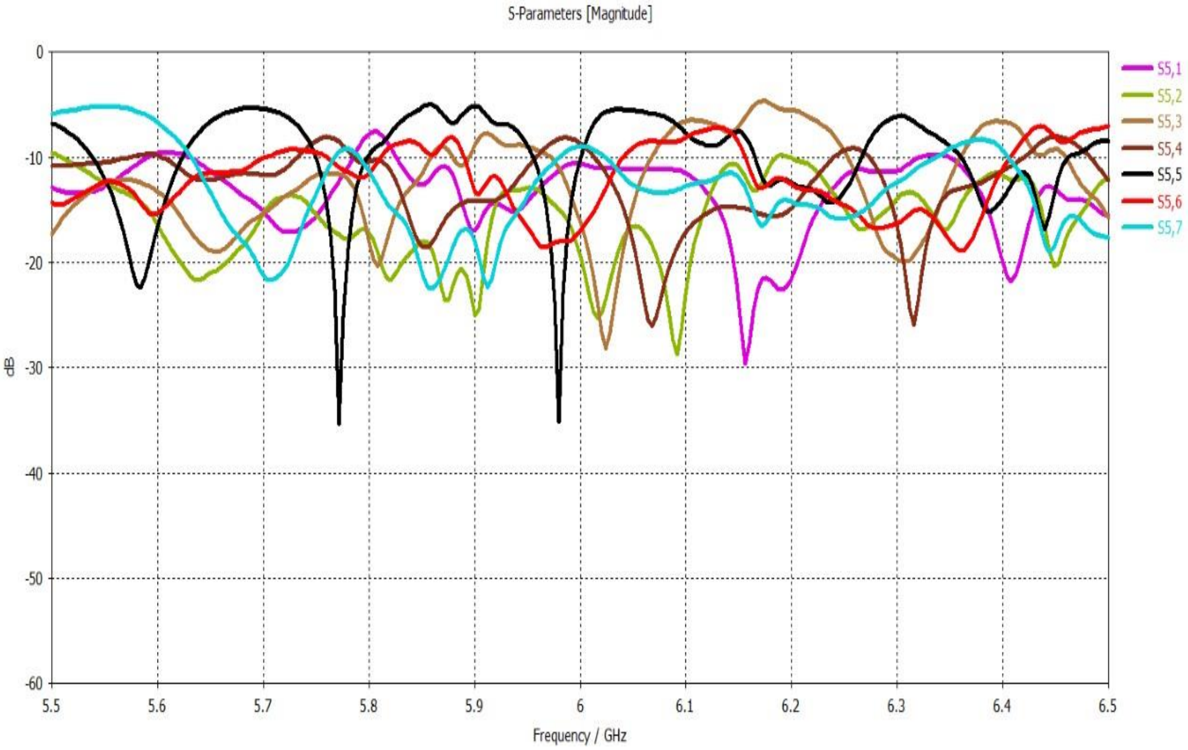


Figure 0.24: The return loss for beam port number 5 of the Rotman lens is plotted over a frequency range around 6 GHz

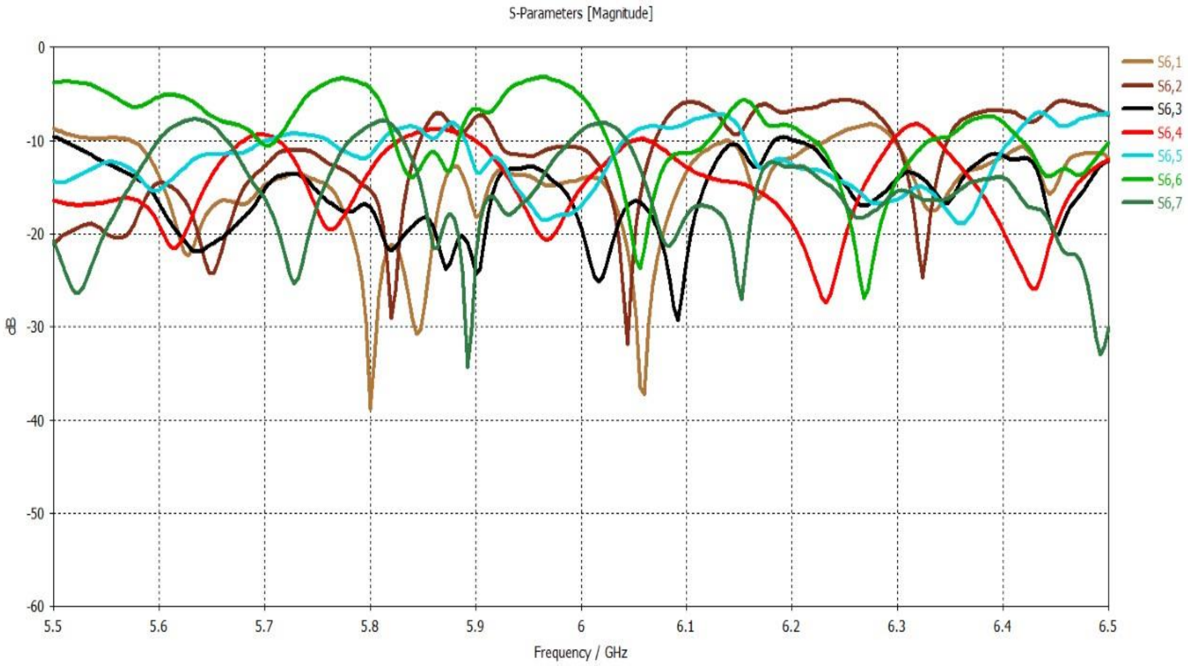


Figure 0.25: The return loss for beam port number 6 of the Rotman lens is plotted over a frequency range around 6 GHz.

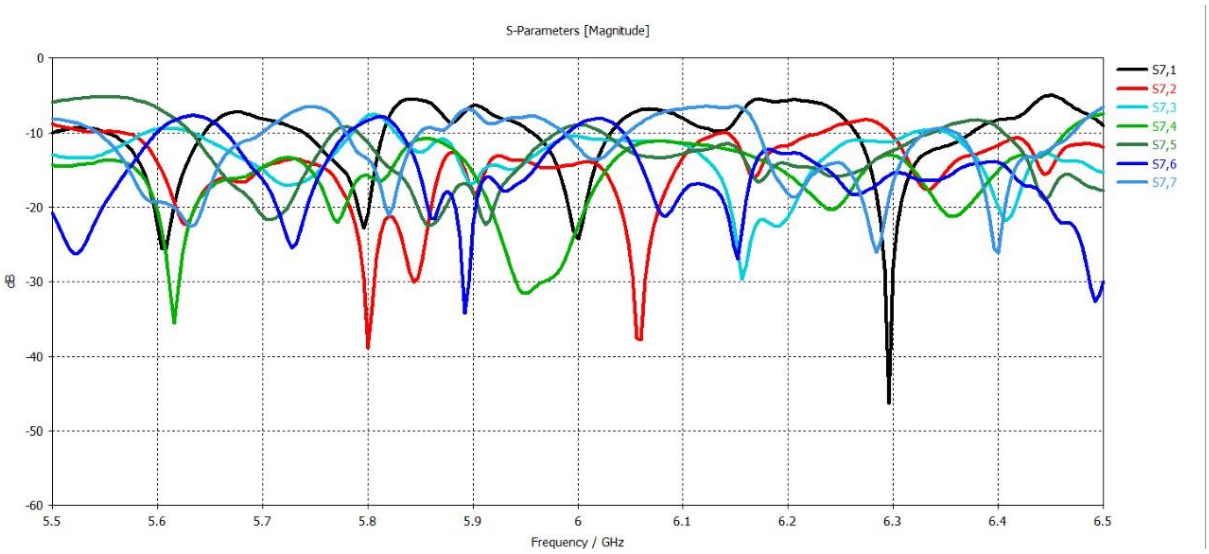


Figure 0.26: The return loss for beam port number 7 of the Rotman lens is plotted over a frequency range around 6 GHz.

Figure 0.27 displays the calculated insertion losses for each beam port operating in the 5.5–6.5 GHz range. The transmission efficiencies of beam ports 1, 2, 3, 4, 5, 6, and 7 at 6 GHz are 58%, 20%, 46%, 70%, 58%, 70%, and 63%, respectively, corresponding to their simulated insertion losses of 3.5,1.8,2.8,4.2,3.5,5.8, and 3.8 dB.

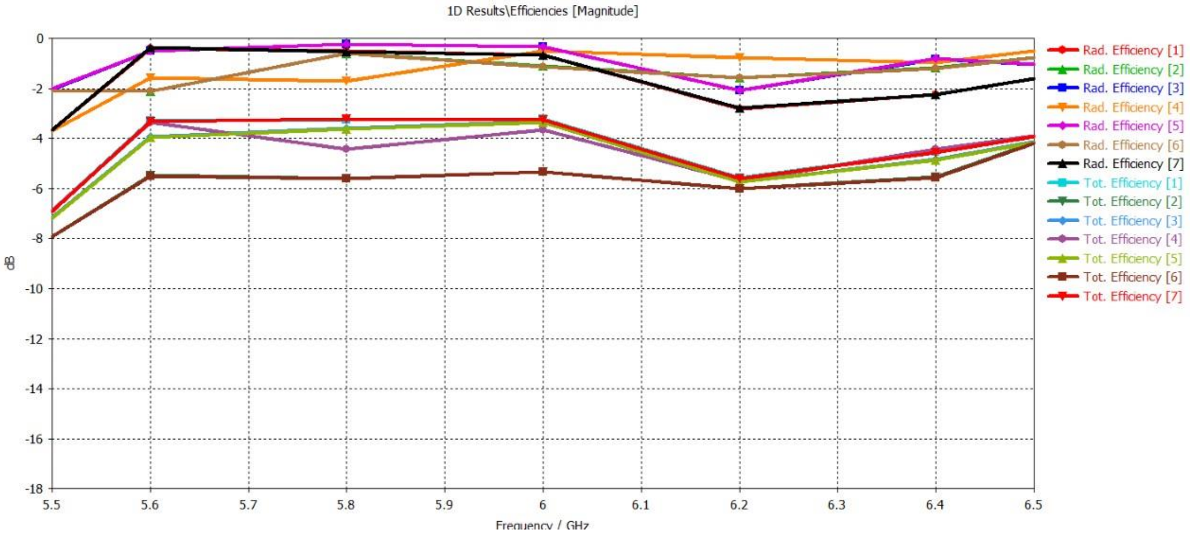
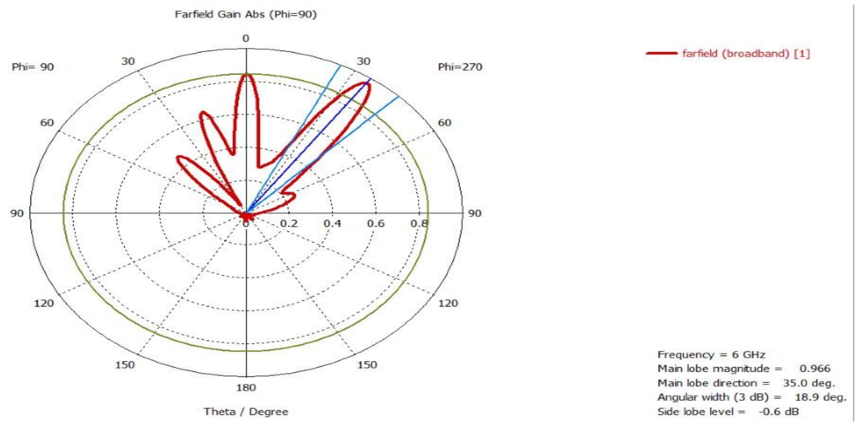
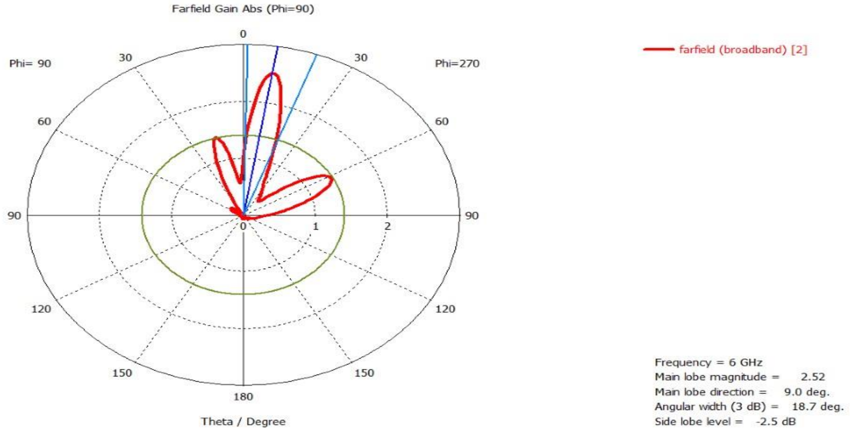
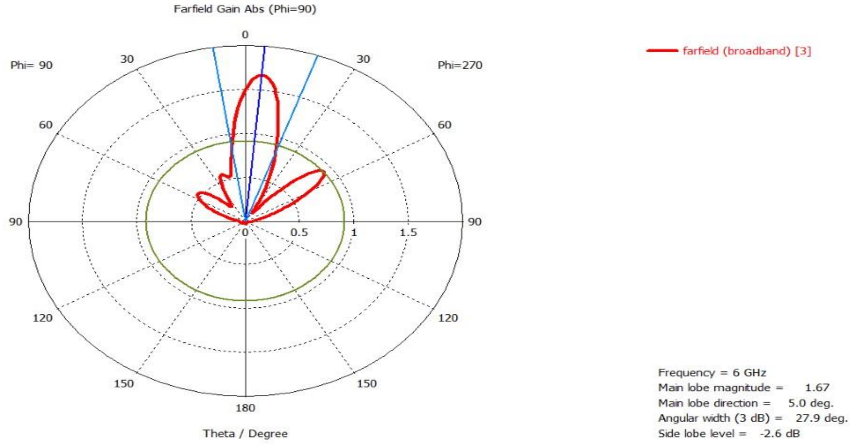


Figure 0.27 : Simulated (S) of insertion loss.

Figure 0.28 displays the radiation pattern results at 6 GHz with an antenna array. 8. The antenna array generates simulated beam pointing angles of 35°, 9°, 5°, 0°, -5°, -9°, and -35° when the beam ports 1, 2, 3, 4, 5, 6, and 7 are excited. These angles are consistent with the preset beam pointing angles of θ1 = 35°, θ2 = 9°, θ3 = 5°, and θ4 = 0°. Table III provides an overview of the simulated outcomes for the beam pointing angles at the three frequency points.







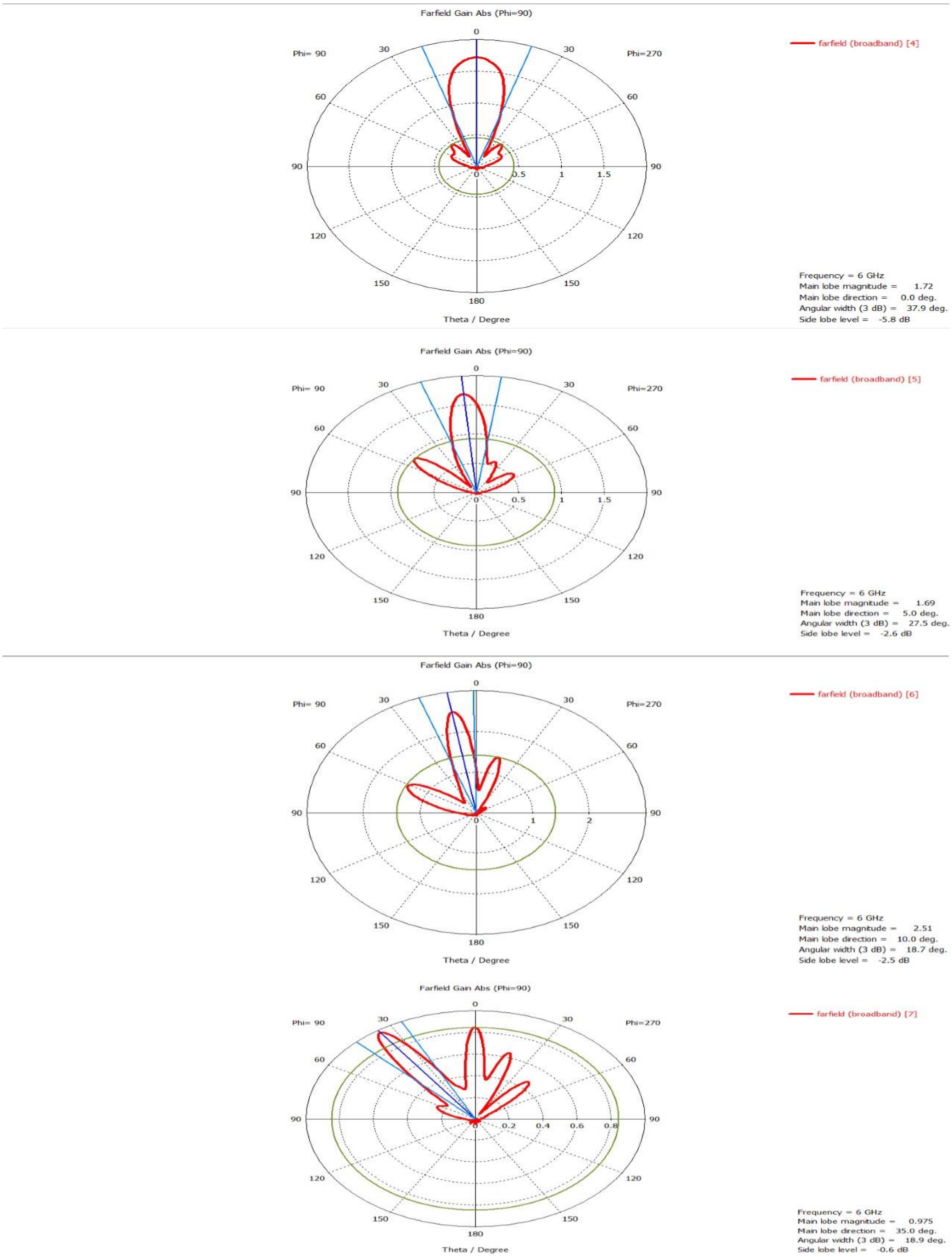


Figure 0.28 : Radiation patrens of Rotman lens with series_fed.

Frequencies GHz	**Beam Port 1**	**Beam Port 2**	**Beam Port 3**	**Beam Port 4**	**Beam Port 5**	**Beam Port 6**	**Beam Port 7**
5.4 GHz	13°	30°	4°	8°	-4°	-30°	**-13°**
5.8 GHz	2°	16°	23°	38°	-23°	-16°	**-2°**
6 GHz	35°	9°	5°	0°	-5°	-9°	**-35°**

Table 0.4:Beam pointing angles at three frequency points of final rotman lens with series _fed.

2.1.7 Comparison between the proposed and previous compact Rotman Lens:

	Port number	approach	Size/**λg**	bandwidth
[19]	4*7	Shorter lens body	33*48	27%
[20]	7*10	Folded lens body	125*60	3.5%
This work	7*10	Array port + Series_ fed rectangular microstrip patch array	181.65*317.23	>20%

Table 0.5: comparison between the proposed and previous compact Rotman lens .

1.2 *Part 02 : Leaky-Wave Antenna Array Based on Hole Array SSPPs.*

2.2.1 Structure and Parameters of LWA element:

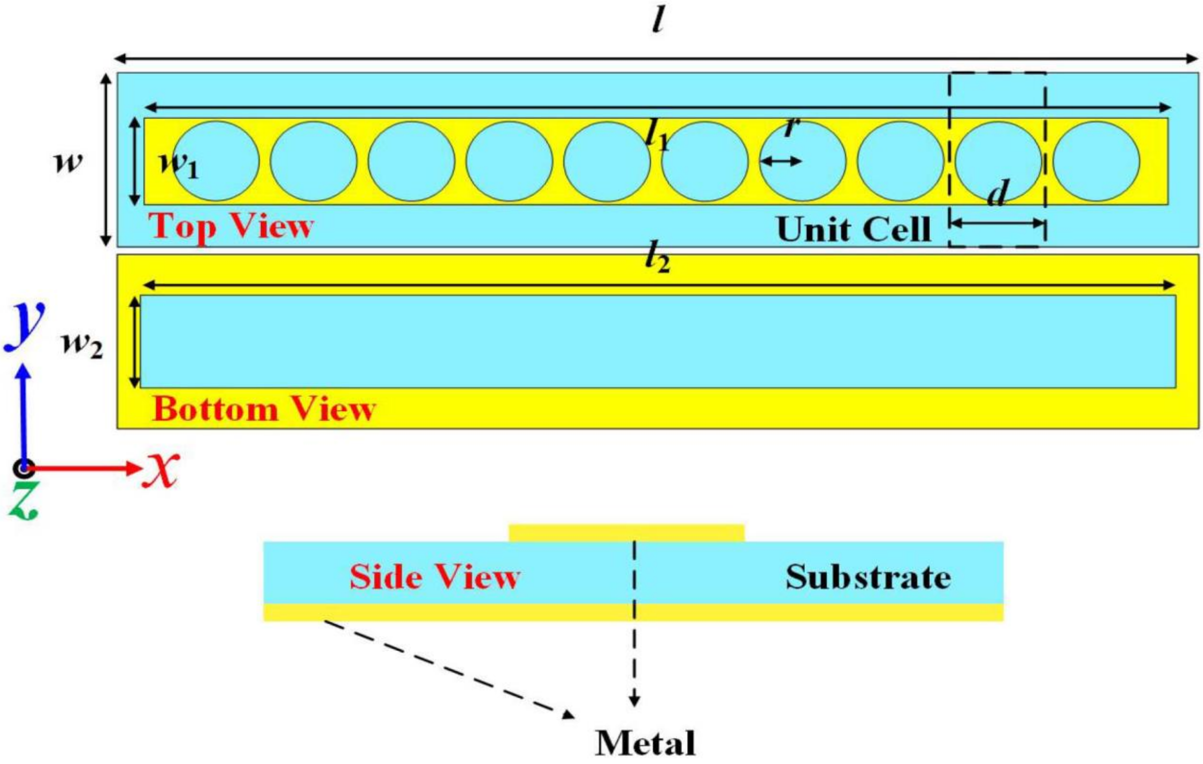


Figure 0.29: Structure of the LWA array element.

The antenna is designed on the 0.5mmF4B substrate with dielectric constant of 2.65 and loss tangent of 0.0015. The structure of antenna unit cell is shown in the dashed box.

The antenna physical parameters are as follows: w = 38 mm, $w1$ = 20 mm, $w2$ = 20, l = 240 mm, $l1$ = 231.5 mm, $l2$ = 232, r = 9.6 mm, and d = 22 mm.

The hole array and the rectangular slot are etched on the top layer and bottom layer of the LWA element, respectively, which transform the quasi-TEM mode to TM mode and support the SSPPs wave propagates on the design.

2.2.2 Design and simulation of a single LWA element (use cst software)

The simulated results show that the designed LWA array realize a good impedance matching within 2–12 GHz bandwidth with average peak gain of 16.86 dBi and the frequency beam-scanning range is 90°.

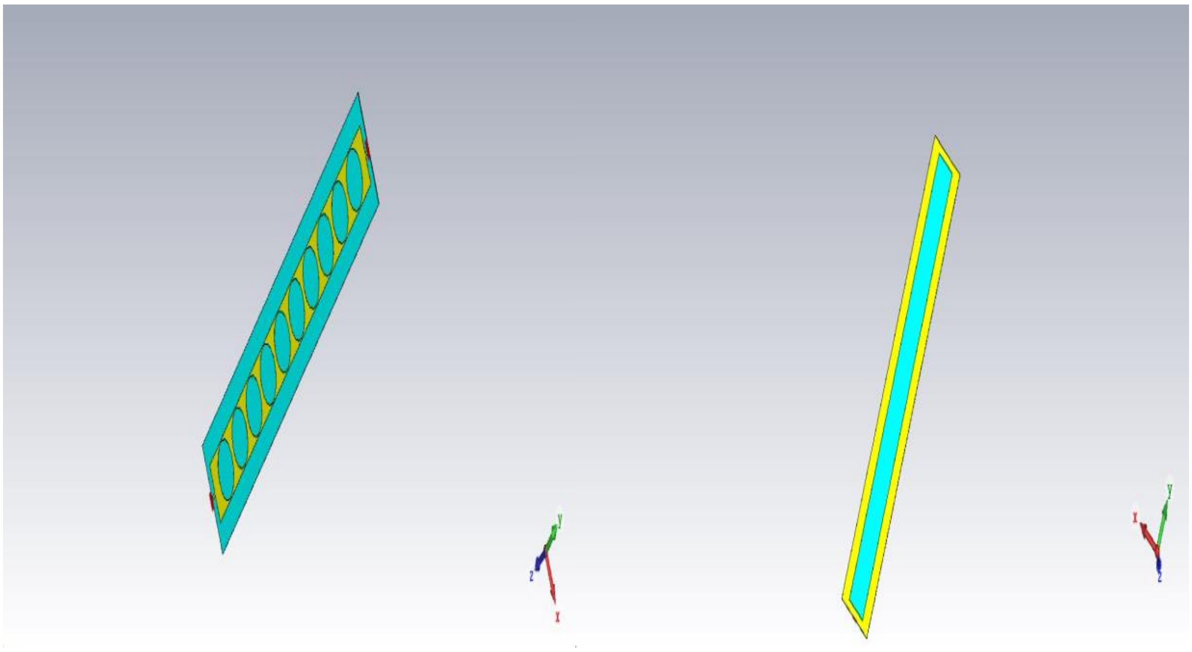


Figure 0.30: Design of the LWA array element (cst).

To present the antenna element characteristics clearly, the S_parameters and normalized radiation pattern are simulated when two ports are added in the structure. From **Figure 0.31** the structure has high transmission efficiency below 4.5 GHz and can radiate wave into free space above 4.5 GHz (|S11| and |S21| < −10 dB .

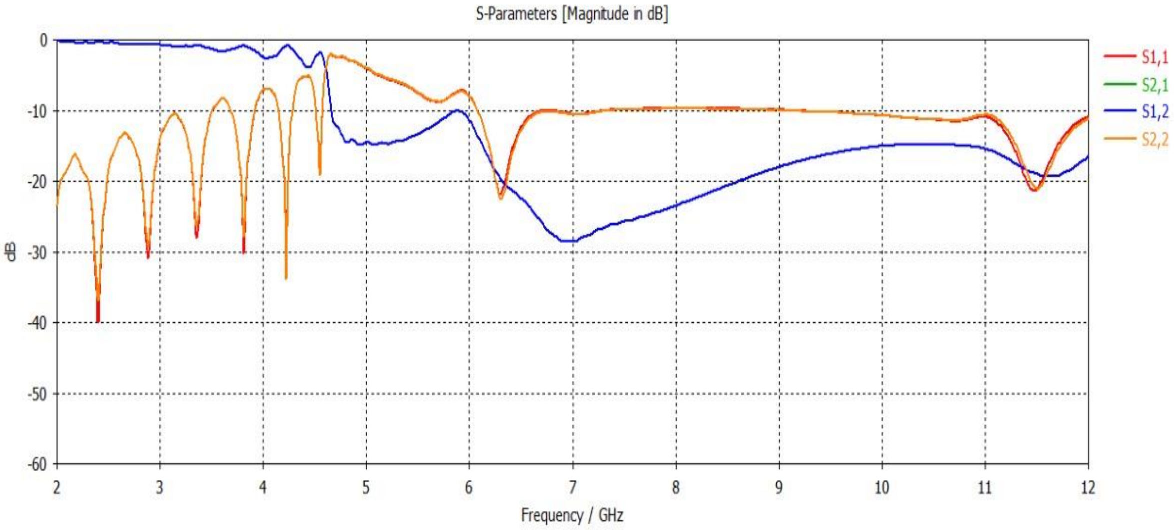


Figure 0.31 :(a) S-parameters of LWA array element.

The **Figure 0.32** and **Figure 0.32** shows that the antenna element can realize frequency beam scanning within 2–12 GHz and the scanning angle is 90°. Furthermore, the broadside radiation frequency is 12 GHz .

We observe that the beamforming takes place in the bandwidth of 2_12 GHz and that the results are symmetrical between port 1 and port 2.

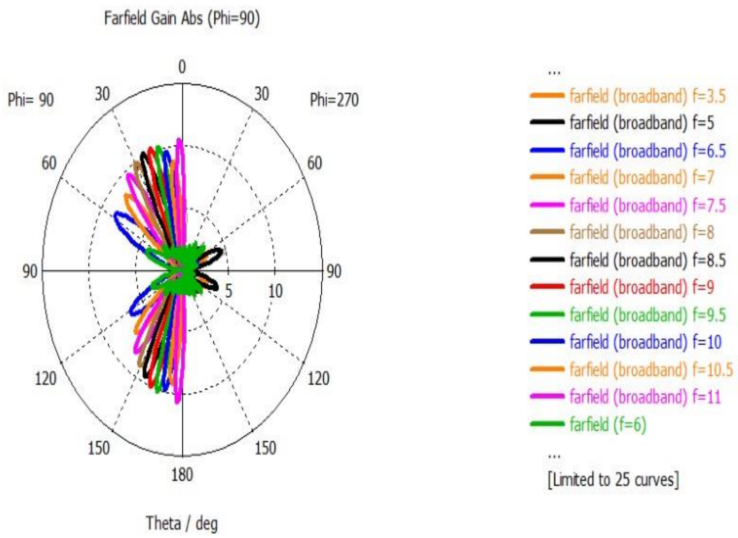


Figure 0.32: Normalized radiation pattern of LWA array element (port 1).

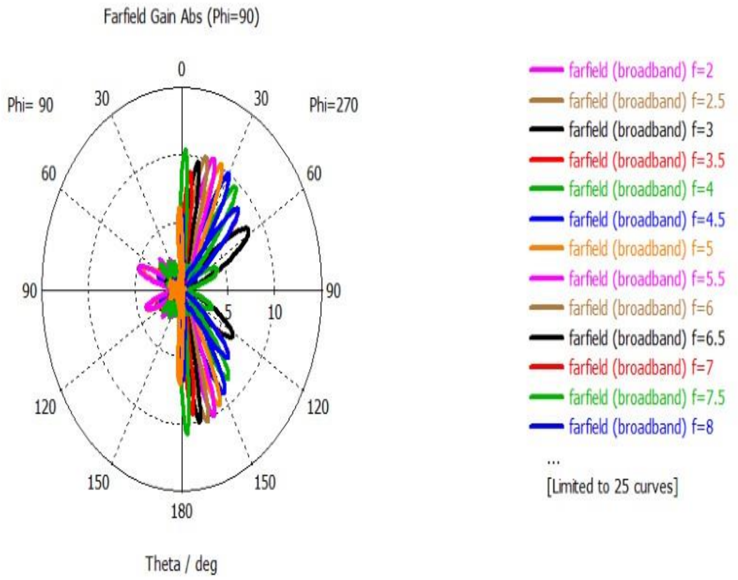


Figure 0.33: Normalized radiation pattern of LWA array element (port 2)

Figure 0.34 shows the gain value by frequency of one element of the antenna where we note that the largest gain value is 13.5dB at 11 GHz.

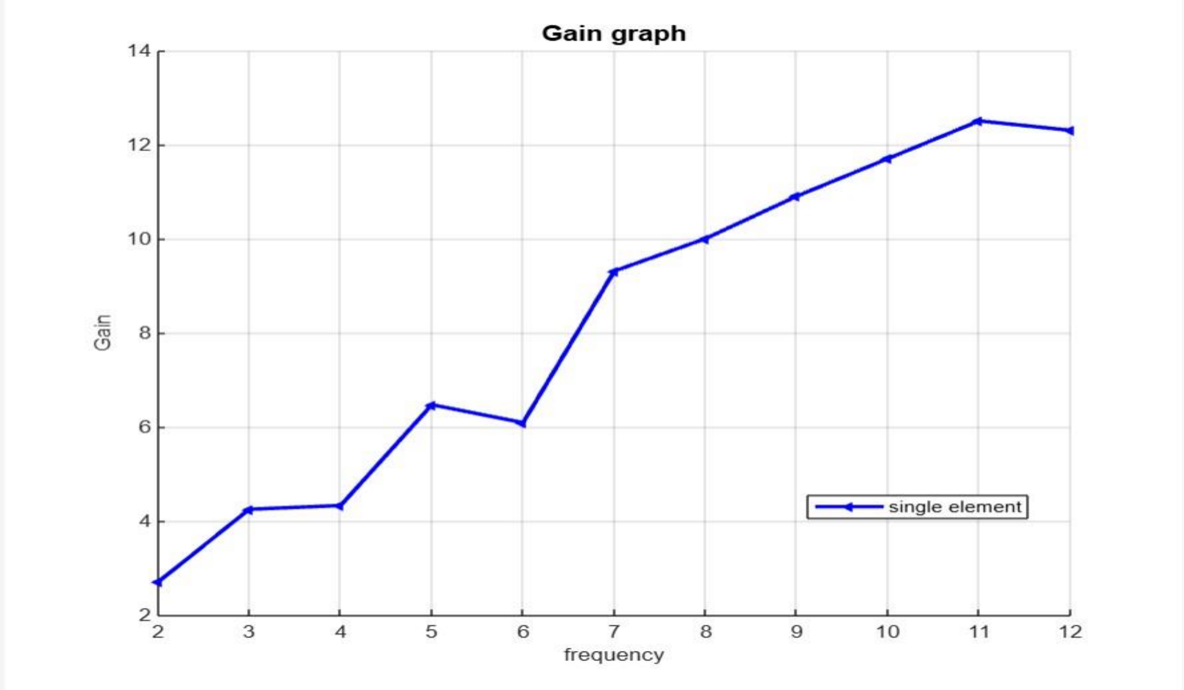


Figure 0.34: the gain value by frequency of one element of the antenna

To increase the gain, we propose to double the number of antenna elements to four (array), which we connect to a feed network via a single input in the bandwidth 2_18 GHz.

2.2.3 Feeding Network for the Proposed LWA Array:

The length (*l*4) and width of feeding line are 3.5 and 0.7 mm, respectively. The length of the multiple cascaded microstrip line is 3.7 mm and the width of the multiple cascaded microstrip line are 0.2, 0.3, 0.5, 0.6 mm, respectively. The parameters of *l*5 and *l*6 are 28.5 and 13.5 mm. the **Figure 0.35** show the structur of feeding network by cst program.

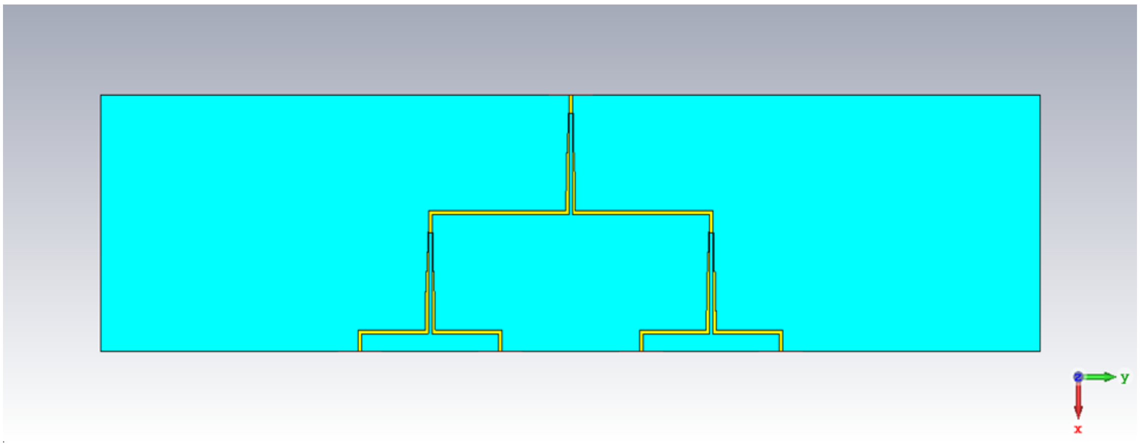


Figure 0.35:Structur of feeding network.

The performance of the design is shown in **Figure 0.36**, the feeding network has a high transmission efficiency within 6–12GHz. The |S11| is lower than−15 dB and |S21|, |S31|, |S41|, |S51| are around −6.4 dB, which indicates that the structure can be used as the feeding structure for the proposed LWA array.

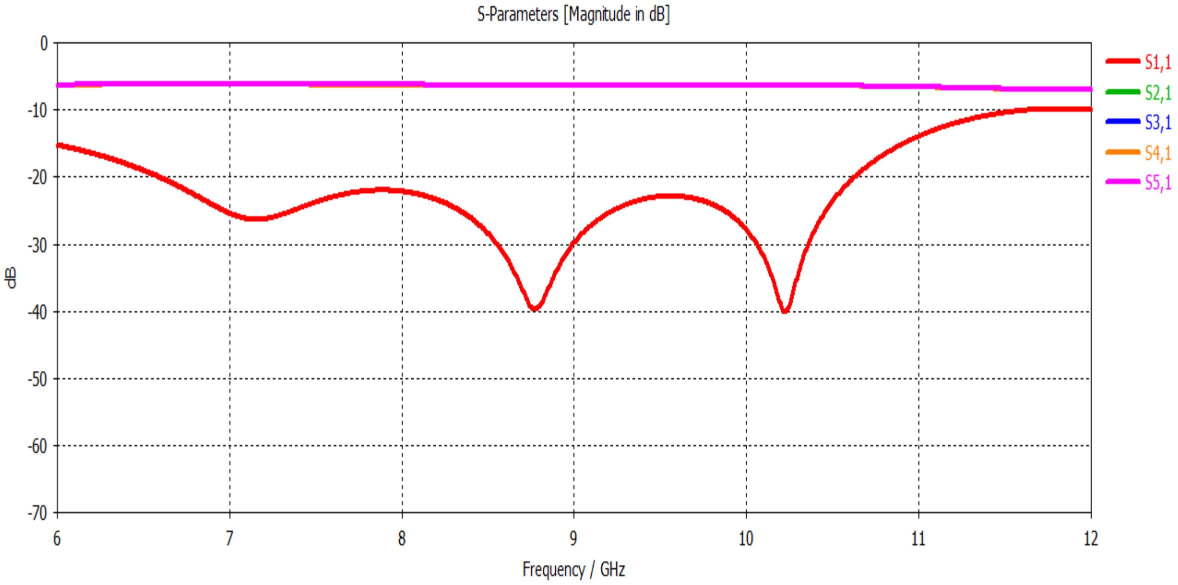


Figure 0.36: S-parameters of the ultrawideband feeding network**.**

The feeding network structure compose of three one to two power divider based on the multiple cascaded microstrip line. The schematic diagram of one to two power divider is presented in Fig.2.35. The input and output terminals of the power divider are connected with 50 Ω microstrip lines and the middle lines are cascaded λ/4 impedance transformer to enhance the impedance bandwidth. Based on the even and odd mode theory, the impedance values of Z0, Z1, Z2, Z3, Z4 can be obtained as follows: 50 Ω, 55.79 Ω, 64.79 Ω, 77.18 Ω, 89.63 Ω

2.2.4What is power divider?

Power Divider uses the quarter-wave transformers to split the input signal into two equal phase output signals. It also provides isolation between the output ports while maintaining a matched condition on all ports. It is used in the field of microwave engineering.

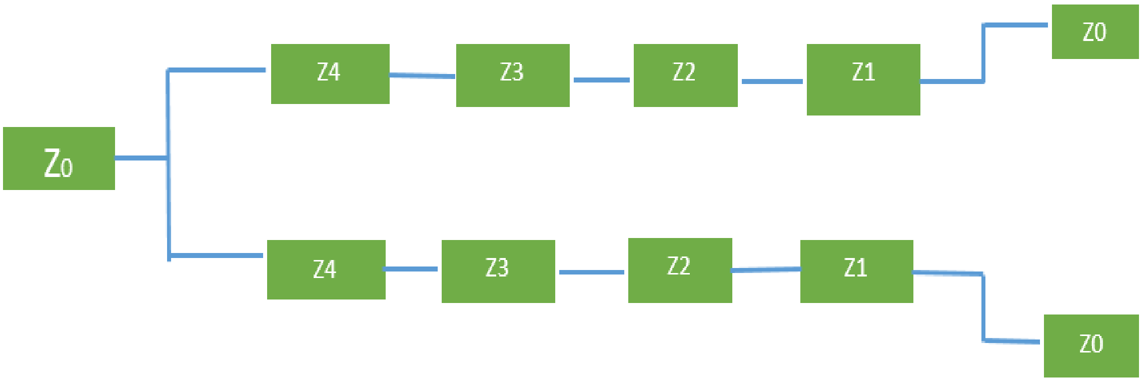


Figure 0.37: Schematic diagram of one to two power divider.

Formula :

$$\boldsymbol{Z2 = Z0 * \left(1 + \left(\frac{Pa}{Pb}\right)\right)^{0.5} * \left(\frac{Pa}{Pb}\right)^{0.5} * \left(\frac{Pa}{Pb}\right)^{0.25}} \quad \textbf{(6)}$$

$$\mathbf{Z3 = Z0} * \left(\frac{Pa}{Pb}\right)^{-0.25} \quad \textbf{(7)}$$

$$\mathbf{Z4 = Z0} * \left(\frac{Pa}{Pb}\right)^{0.25} \quad \textbf{(8)}$$

Where

Pa = Power output of Port 2.

Pb= Power output of Port 3.

Z0 = Characteristic Impedance of the overall system.

Z1, Z2, Z3, Z4 = Branch impedances.

2.2.5 Design of LWA Array:

The suggested LWA array, which consists of four antenna elements and a feeding network, is depicted in **Figure 0.38**. The metal connecting the feeding network's top layer hole array of SSPPs, and the defective ground structure is connected to the bottom layer. The LWA element is separated by 30 mm. The performance of the antenna array will be shown in the section that follows.

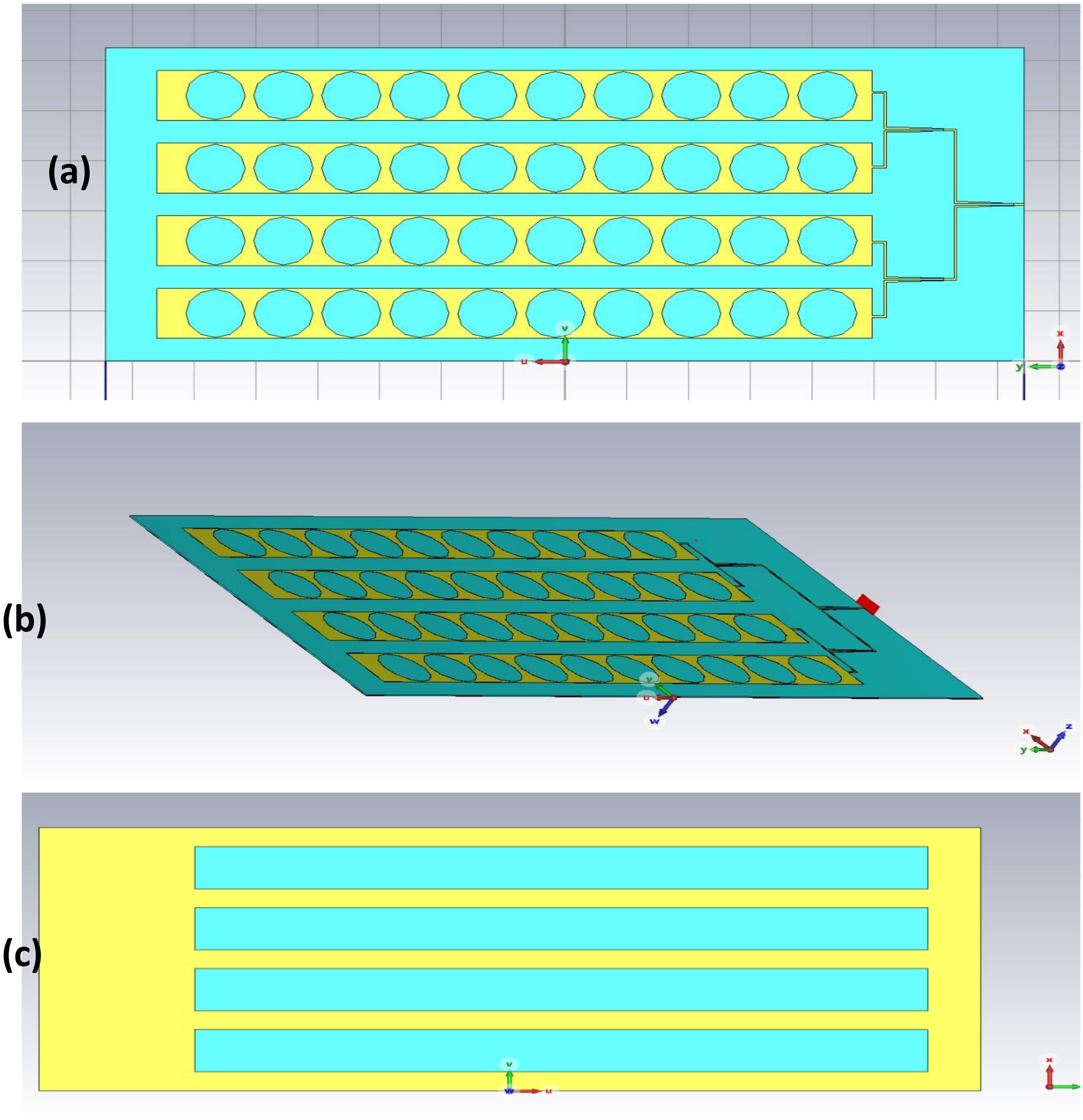


Figure 0.38: (a) (b) (c) LWA array, which consists of four antenna elements and a feeding network.

2.2.6Simulated results:

Figure 0.39 shows the simulated result |S11| of the proposed LWA array, showing that the antenna array can achieve wide impedance matching within 2–18 GHz. In addition, the simulated normalized radiation patterns of the proposed LWA array are shown in **Error! Reference source not found.** which shows that the antenna array realizes wide beam angle scans from −68° to 23° and the scanning ranges can reach 91°.

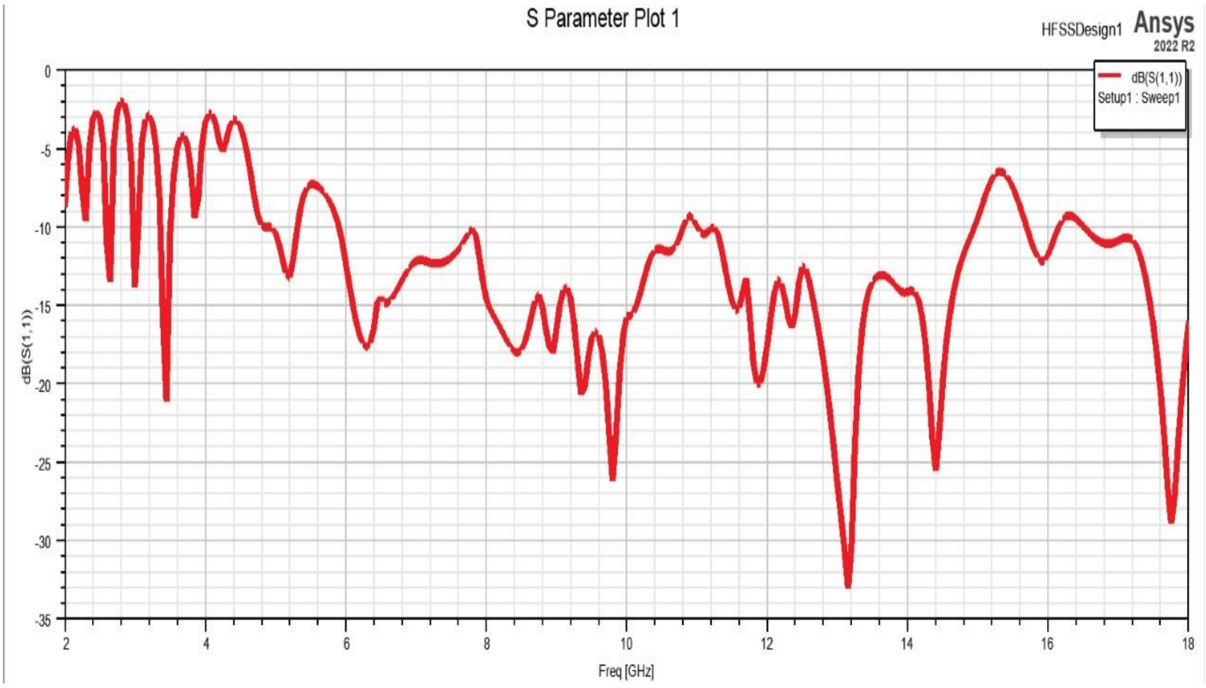


Figure 0.39 :the simulated result |S11| of the proposed LWA array.

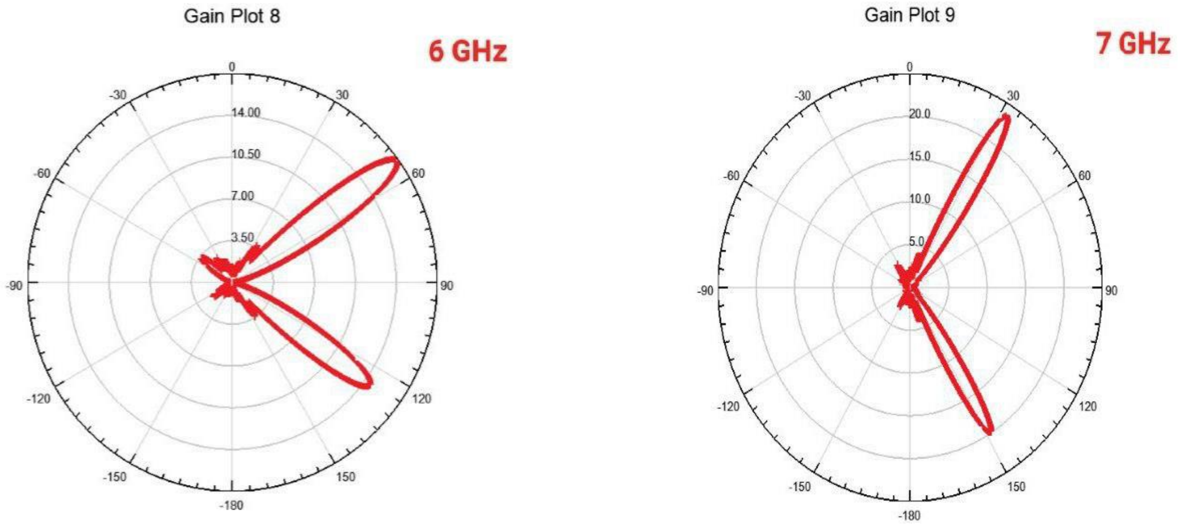
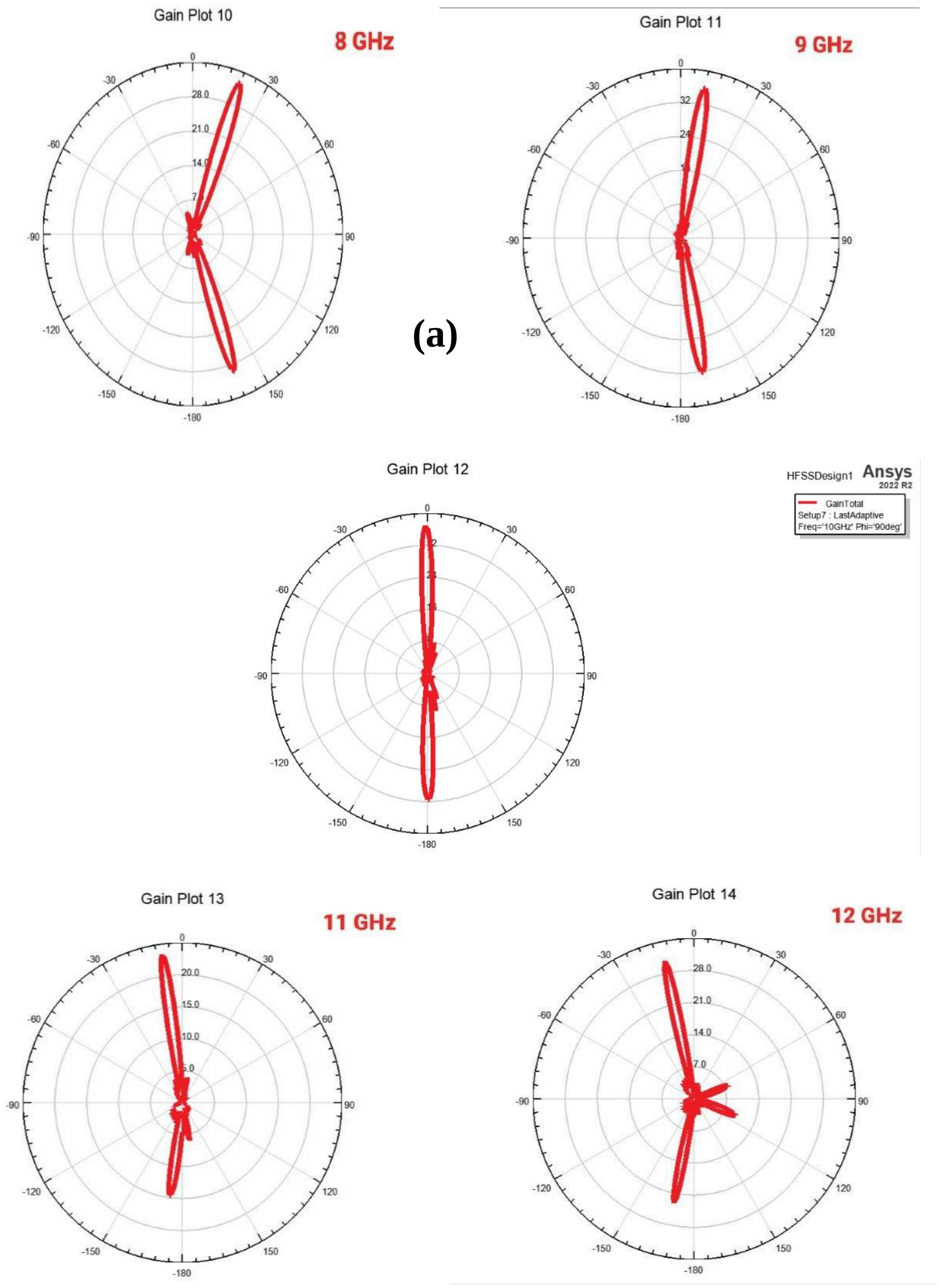


Figure 2.40:the simulated normalized radiation patterns of the proposed LWA array.


Gain Plot 10
8 GHz
28.0
21.0
14.0
Gain Plot 11
9 GHz
32
24
Gain Plot 12
HFSSDesign1
Ansys
2022 R2
GainTotal
Setup7 : LastAdaptive
Freq='10GHz' Phi='90deg'
Gain Plot 13
11 GHz
20.0
15.0
10.0
5.0
Gain Plot 14
12 GHz
28.0
21.0
14.0
7.0
0
30
60
90
120
150
-180
-150
-120
-90
-60
-30

(a)

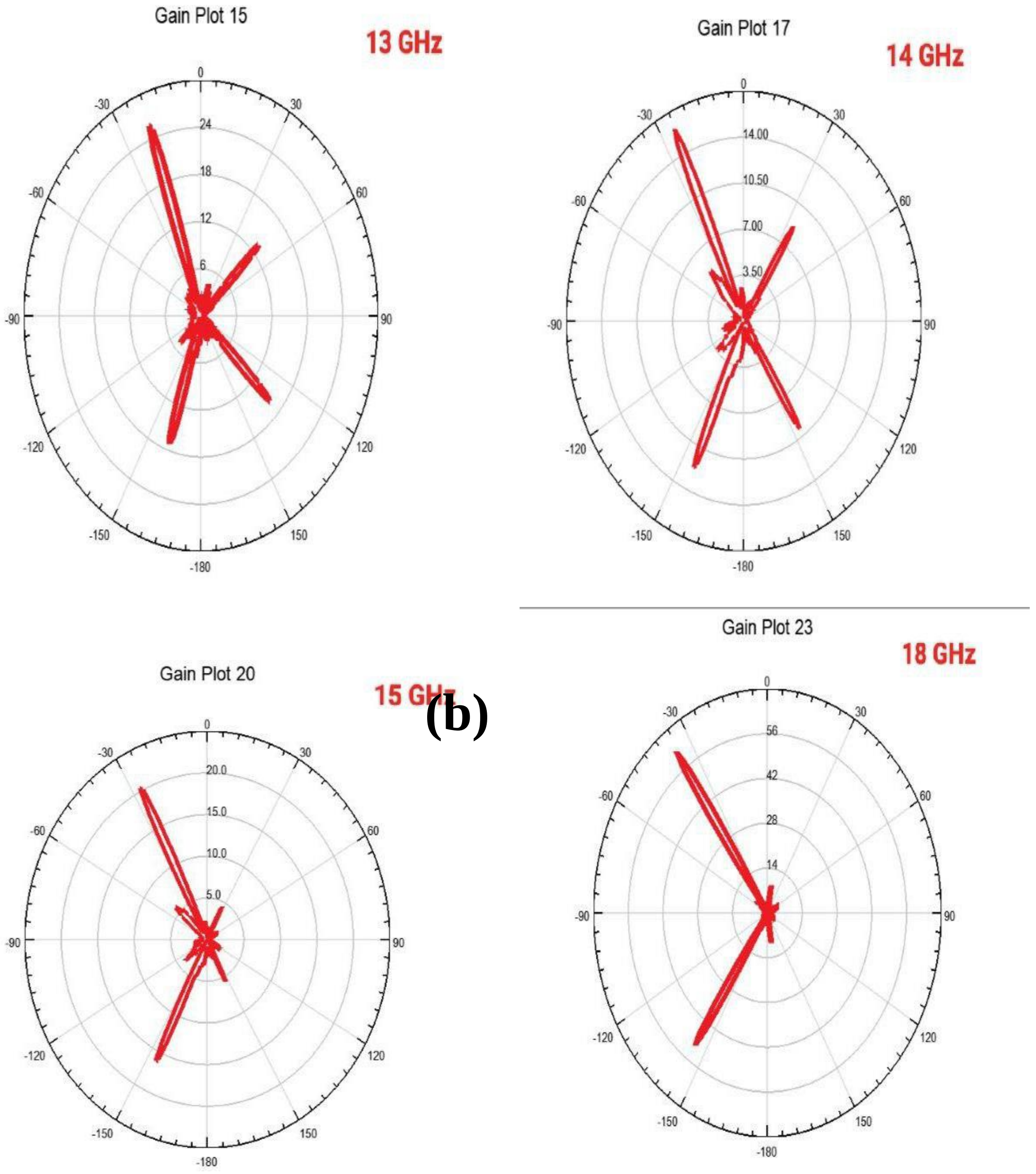


Figure 0.40: (a) Simulated and measured S-parameters of LWA array. (b) Simulated normalized radiation patterns of LWA array.

Error! Reference source not found. shows the gain value by frequency of 4 elements of the LWA antenna (array), where we find that the largest gain value is 16.37 dB at 12 GHz.

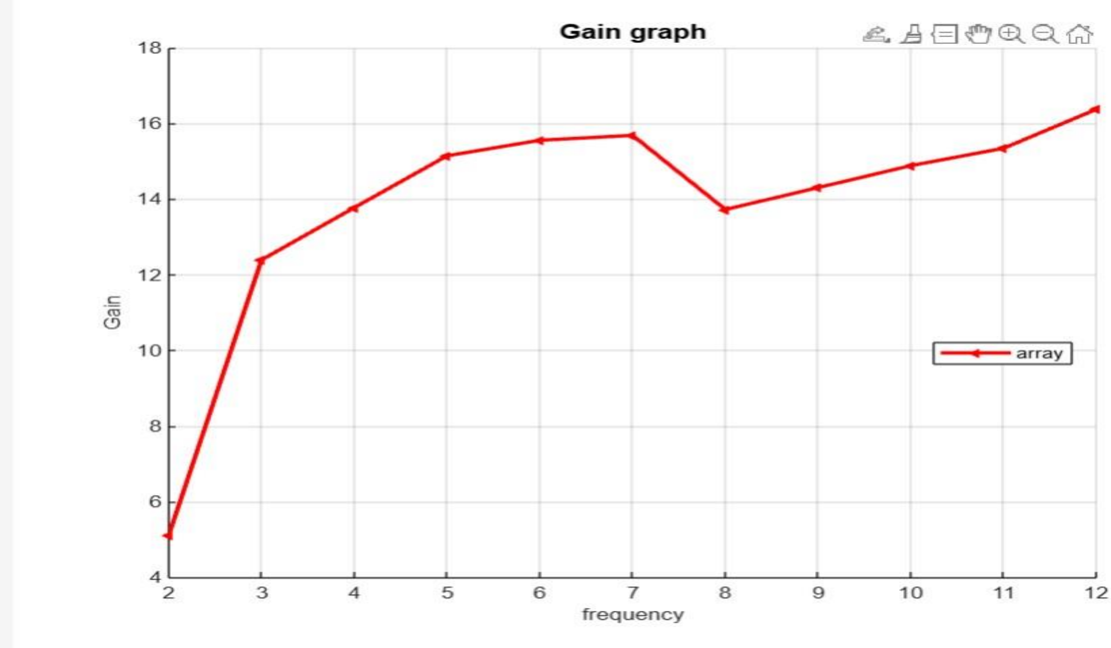


Figure 2.42:the gain value by frequency of 4 elements of the LWA antenna (array)

Figure 0.41 shows the comparison between one and four antenna elements in terms of gain value in the 2-12 GHz bandwidth, where we find that the gain value for an antenna with a 4 element LWA array compared to one element which has the highest gain, the value has increased to 12 dB in one element and to 16.37 dB in an antenna with four elements.

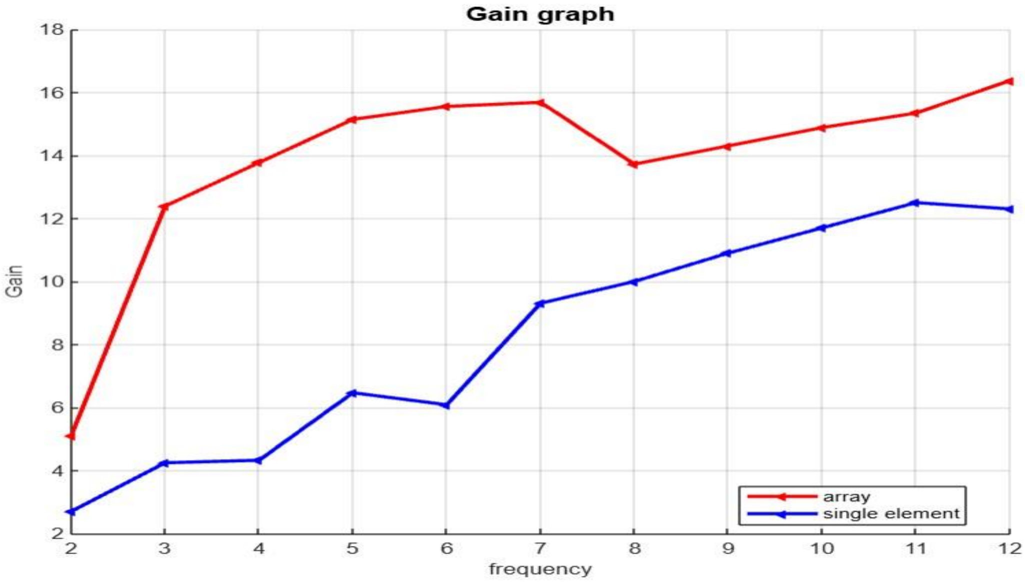


Figure 0.41 : comparison between one and four antenna elements in terms of gain value in the 2-12 GHz bandwidth.

Table 0.6 summarizes the performance comparison of existing LWA antennas. It can be seen that [21] proposed an LWA array design with a scanning angle of 81° and a maximum gain of 19.4 dBi. However, the antenna size should be further miniaturized.[22] proposed two LWAs based on specific flaring reasons. Nevertheless, these designs were of no use in the design of antenna arrays. Therefore, compared to other antennas, our work proposed a miniaturized LWA element that can be easily integrated into the feed network. In addition, it should be noted that the LWA proposed in [21] was developed based on microstrip SSPPs-TL that radiated a single beam. Therefore, this antenna has a higher maximum gain compared to other dual-beam antennas.

Ref	Antenna Size	bandwidth	Angle degree	Max gain	Array design
[21]	**9.26*1.1**	**5_7**	**81°**	**19.4 (2 array)**	**easy**
[22]	**9.72*1.8**	**9_16**	**83°**	**13.4 (element)**	**hard**
Pro Work	**4.8*0.76**	**2_12**	**91°**	**12 (element)**	**easy**
Pro work	**5.7*2.56**	**2_18**	**91°**	**16.37 (4 array)**	**easy**

Table 0.6 : the performance comparison of existing LWA antennas.

2.2.7Conclusion:

- The design of Rotman lens is proposed in this work. An initial 7 × 10 Rotman lens

Using Series_ fed rectangular microstrip patch array. The phase conditions required for the initial Rotman lens and the Series_ fed are derived, and a Series_ fed topology is designed adequately so that the beam pointing angles remain consistent before and after the extension. The measured results show that the Rotman lens exhibit good impedance matching, high beam ports isolations and high transmission efficiencies. The evaluation of radiation pattern performance shows that the Rotman lens can generate relatively stable and uniformly distributed beams within 20% bandwidth.

- an LWA array based on SSPPs is proposed to achieve wide-angle scanning performance. It uses hole arrays etched into the defective ground structure to convert the slow wave into a fast wave and generate a beam scanning wave with generated frequency by exploiting the properties of the higher order radiation mode. The antenna array is powered by a 1-to-4 power divider and achieves good impedance matching within the 6-12 GHz bandwidth, the average peak gain of the antenna array is about 64.5 dBi and the frequency beam scanning range is 91°. The antenna array features simple manufacturing, low cost and high gain performance, which can meet the high gain requirements in radar and other related fields.

General Conclusion:

In this work, we presented the design of a Rotman lens and the design of leaky wave antennas using a network Instead of an element, it is to increase the gain as well as we tried to avoid interventions and this to increase the efficiency and meet the needs of the user . Using simulators (cst studio and antennas magus). This lens is dedicated for wireless communication to achieve beamforming (the operating frequency of 5.8 GHz).

This design has made it possible to acquire the theoretical knowledge necessary for the technology of passive microwave circuits (antennas, Butler matrix, transmission line,) and similarly, to familiarize with several simulators (HFSS, antennas magus and the CST studio).

This design also accompanied by an analytical and parametric study of a Rotman lens and leaky wave antennas which allows to see the effect of different physical parameters of the lens and leaky wave antennas (focal length, focal angle, beam ports and network ports, ssps in coils …)their characteristics in terms of phase error, reflection coefficient and radiation pattern.

In Chapter 1, the theoretical study described the fundamental principles of beamforming its classifications, we also showed the advantages and disadvantages of each classification, two its techniques the Rotman lens and leaky wave antennas. Similarly, the Rotman lens has been shown to be a popular technology in multibeam formation (BFN) systems, due to its simplicity and good performance. And we also showed the concept of permeable wave antennas and their classification and antennas that depend on ssps.

In chapter 2, we did an application study where we found that LWA array based on SSPPs is proposed to achieve wide-angle scanning performance. It uses hole arrays etched into the defective ground structure to convert the slow wave into a fast wave and generate a beam scanning wave with generated frequency by exploiting the properties of the higher order radiation mode. The Rotman lens can generate relatively stable and uniformly distributed beams within 20% bandwidth , the Rotman lens exhibit good impedance matching, high beam ports isolations and high transmission efficiencies.

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