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Title

Optimizing 5G MIMO Antenna configuration for Handsets and mobile Base station

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I am deeply grateful to all those who have supported and believed in me (my sister and my friends), contributing to the successful completion of this dissertation.

Dedication

To my dear father, your presence in my life is the most precious gift in the world. I vividly recall the first day you took me to school, marking the beginning of this journey. Today, I stand here because of your unwavering support, encouragement, and belief in me. Thank you, Dad, for everything.

To the greatest woman in this life my happiness my mom. everything I do is for you. My ultimate aim has always been to bring happiness to your life, and I continuously strive to be the daughter who fills you with pride. You were always my motivation Thank you for making me live this moment with all these feelings.

To my second mom, Houria, you've consistently been my source of encouragement, showering me with immense positivity that drives me forward. Your unwavering belief in my capabilities has been a constant motivator. Thank you for everything.

To my sisters (Khadija. Halima, Anfal), you are the true treasures of my life, and I am forever grateful for your presence.

To my friend zineb the joy of my life the, you've been always more than a friend all word cannot expresses my feeling when I was with you, you’re the light in my darkness thank you for being with me to live this moment together.

Abstract

The advent of 5G technology has revolutionized wireless communication, offering unprecedented data speeds, reduced latency, and increased network capacity. At the heart of 5G technology lies Multiple Input Multiple Output (MIMO) antennas, which play a crucial role in enhancing spectral efficiency and improving overall network performance. This thesis focuses on optimizing the configuration of MIMO antennas for both handsets and mobile base stations to maximize the benefits of 5G technology.

The research begins with a comprehensive review of existing literature on MIMO antenna design principles, antennas arrays, and optimization some parameter of antennas arrays to build MIMO antenna handsets and mobile base stations.

So we designed an MIMO antenna array with 4 elements we had taken two configuration designs of handset, the results that we obtained it showed a good results (the mutual coupling between arrays is <-30 dB) which means that the distance between arrays is suitable for this designs

Résumé

L'avènement de la technologie 5G a révolutionné les communications sans fil, offrant des vitesses de données sans précédent, une latence réduite et une capacité réseau accrue. Au cœur de la technologie 5G se trouvent les antennes à entrées multiples et sorties multiples (MIMO), qui jouent un rôle crucial dans l'amélioration de l'efficacité spectrale et l'amélioration des performances globales du réseau. Cette thèse se concentre sur l'optimisation de la configuration des antennes MIMO pour les téléphones portables et les stations de base mobiles afin de maximiser les avantages de la technologie 5G.

Le travail de recherche commence par une revue complète de la littérature existante sur les principes de conception des antennes MIMO, les réseaux d'antennes, et l'optimisation de certains paramètres des réseaux d'antennes pour construire des antennes MIMO pour les téléphones portables et les stations de base mobiles.

Ainsi, nous avons conçu un réseau d'antenne MIMO avec 4 éléments nous avons eu à prendre deux conceptions de configuration de téléphone portable, les résultats que nous avons obtenus il a montré de bons résultats (le couplage mutuel entre les réseaux est <-30 dB) qui signifie que la distance entre les réseaux d’antenne adapté pour ce modèle.

ملخص

لقد قامت تقنية 5G باحدا ثورة في مجال الاتصالات اللاسلكية، وقدمت سرعات بيانات لم يسبق لها مثيل، وتقليل في التأخير، وزيادة في سعة الشبكة. في قلب تقنية 5Gتتمثل الهوائيات متعددة المداخل و متعددة المخارج (MIMO)، التي تلعب دوراً حاسماً في تعزيز الكفاءة الطيفية وتحسين أداء الشبكة بشكل عام. تركز هذه الرسالة على تحسين تكوين الهوائيات MIMO لكل من الهواتف المحمولة والمحطات الأساسية المتنقلة لتعظيم فوائد تقنية 5G . بدأ البحث بمراجعة شاملة للأدبيات الحالية حول مبادئ تصميم الهوائياتMIMO ، ومصفوفة الهوائيات الصفوف، وتحسين بعض معلمات هوائيات الصفوف لبناء هوائيات MIMO للهواتف المحمولة والمحطات الأساسية المتنقلة.

لذا قمنا بتصميم مجموعة من هوائيات MIMO مع 4 عناصر كان لدينا أخذ اثنين من تصميمات تشكيلات لليد، النتائج التي حصلنا عليها أظهرت نتائج جيدة (الارسال المتبادل بين المصفوفات هو (<-30dB) يعني أن المسافة بين المصفوفات مناسبة

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General Introduction

The rapid advancement of wireless communication technologies has ushered in the era of fifth-generation (5G) networks, promising unprecedented data speeds, reduced latency, and significantly enhanced network capacity. Central to the realization of these capabilities are Multiple Input Multiple Output (MIMO) antennas. MIMO plays a pivotal role in maximizing spectral efficiency, the ability to transmit more data within a limited spectrum. It also significantly improves overall network performance by allowing for the transmission and reception of multiple data streams simultaneously.

As the demand for high-speed mobile connectivity continues to surge, optimizing the configuration of 5G MIMO antennas for both handsets and mobile base stations becomes increasingly crucial. This dissertation delves into this critical area, focusing on optimizing antenna design for both user equipment (handsets) and base stations.

The first chapter provides a comprehensive overview of the fundamental principles of MIMO antennas. It delves into the significance of MIMO antennas in 5G networks, explaining how they enable the realization of 5G's promising capabilities. Additionally, the chapter explores the principles of antenna arrays, laying the groundwork for the design considerations in subsequent chapters.

The second chapter focuses on simulating antenna arrays to achieve specific goals. It aims to design an antenna array that offers the following key characteristics:

i)-Very high gain (> 12 dB) for enhanced signal strength and transmission range, and directive antenna behavior for focused transmission and improved signal-to-noise ratio.

ii)- Wide bandwidth (> 1 GHz) to accommodate diverse 5G frequency bands.

iii)- Operation at high frequencies (around 28 GHz) relevant to millimeter-wave (mmWave) communication, which plays a crucial role in high-capacity 5G applications.

The final chapter addresses the practical application of MIMO antenna design. It focuses on designing a 5G MIMO antenna specifically tailored for use in both handsets (user equipment) and base stations. The design is likely to utilize a four-element antenna array to achieve the desired performance characteristics.

This dissertation aims to provide a comprehensive understanding of MIMO antenna design for 5G applications. It covers the fundamental principles of MIMO antennas, their significance in 5G networks, and the design of high-gain and wideband antenna arrays for both handsets and base stations. The findings of this research are expected to contribute to the development of efficient and reliable 5G networks that can meet the ever-increasing demand for high-speed mobile connectivity.

Chapter I:

MIMO Antenna & Antenna arrays

I.1) Introduction

Single antennas typically have a broad radiation pattern, dispersing their signal in multiple directions. This results in limited directivity (gain), making them less effective for long-distance communication. To achieve the high gain required for focused signal transmission over long distances, especially crucial for 5G networks, we leverage a powerful technology: Multiple-Input Multiple-Output (MIMO) antennas combined with antenna arrays.

This chapter delves into the concept of MIMO and the principles behind antenna arrays. We'll explore their various applications and the significant advantages they offer, particularly their ability to achieve the high gain necessary for long-distance communication.

I.2) MIMO antenna

I.2.1) Introduction to MIMO antenna technology

MIMO antenna technology (Multiple Input Multiple Output), is a revolutionary approach that uses multiple antennas to improve communication performance. It has become the cornerstone of wireless communication systems, offering unprecedented data transfer rates and signal reliability.

I.2.2) definition of MIMO

MIMO technology uses multiple antennas at both the transmitter and receiver to improve communication performance. By leveraging multipath propagation, MIMO allows for increased data throughput and enhanced link reliability, leading to improved wireless communication capabilities.

MIMO technology has been widely adopted in modern wireless communication standards such as 4G LTE, 5G, and Wi-Fi, revolutionizing the way data is transmitted and received. [1]

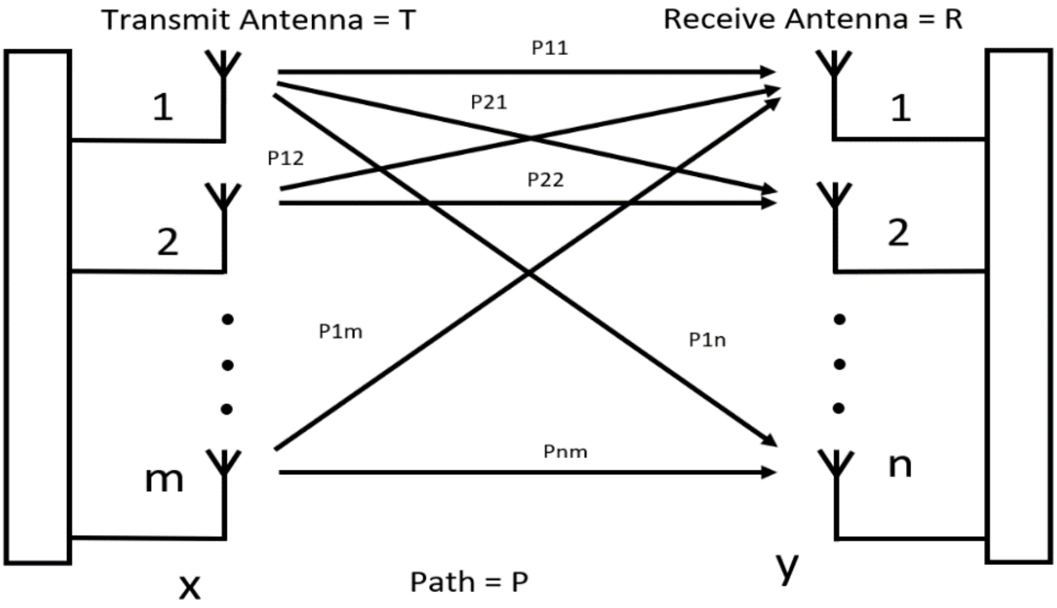


Figure I.1: MIMO architecture [2]

I.2.3) types of mimo antenna

Single-User MIMO (SU-MIMO)

Designed for single-user applications, SU-MIMO utilizes multiple antennas at the transmitter and receiver to improve data throughput and reliability for individual users.[3]

The capacity of SU-MIMO system [4] is:

$$C = \log_2(1 + SNR) \tag{1-1}$$

SNR: signal to noise ration

Multi-User MIMO (MU-MIMO)

MU-MIMO enables simultaneous transmission to multiple users, increasing network capacity and overall spectral efficiency.[3]

The capacity of MU-MIMO [4] is:

$$C = W.\log_2(1 + \frac{p}{N_0 w}) \tag{1-2}$$

W: bandwidth

N_0: spectral density

P: power received

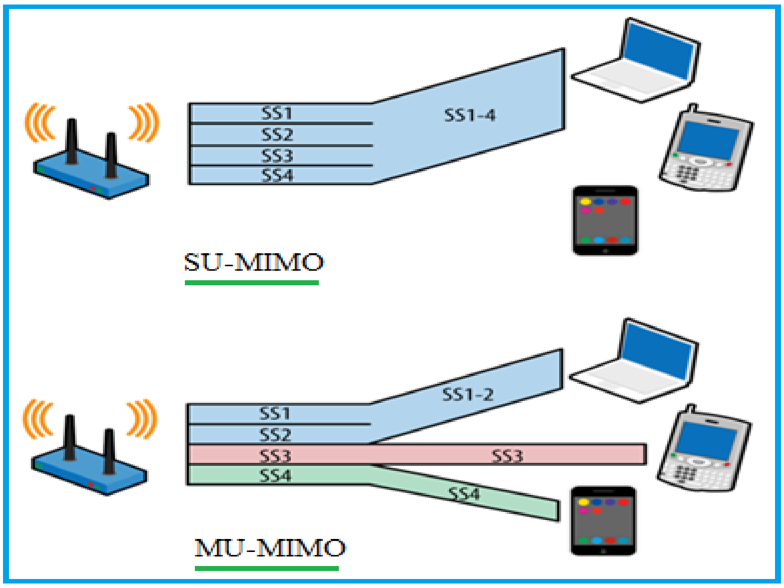


Figure I.2: the difference between SU-MIMO and MU-MIMO [5]

Massive MIMO

Massive MIMO deploys a significantly large number of antennas to serve multiple users, effectively enhancing system capacity and spectral efficiency.[6]

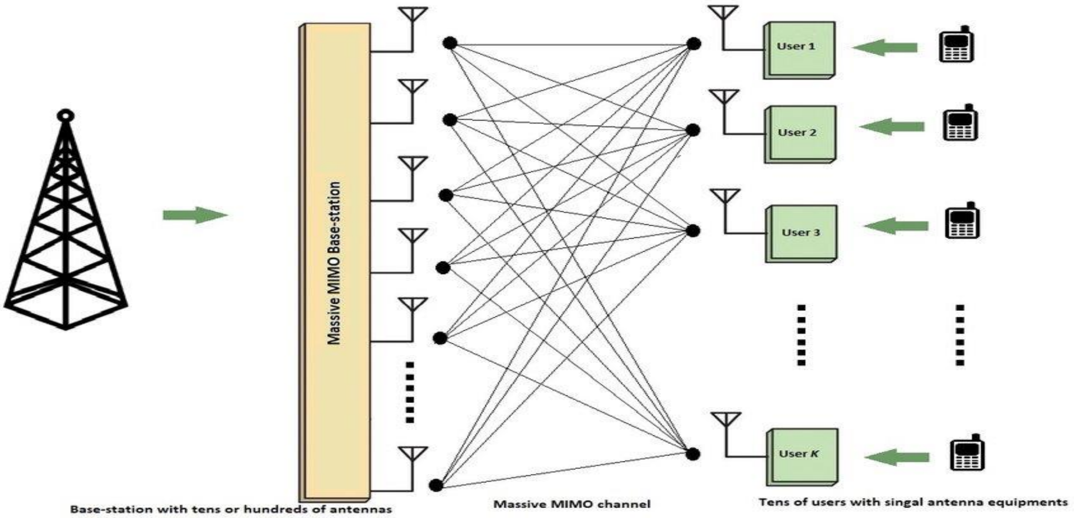


Figure I.3: Massive MIMO technology architecture [7]

I.2.4) MIMO Antenna Design Approaches

I.2.4.1) The Envelope Correlation Coefficient (ECC)

The Envelope Correlation Coefficient (ECC) is a measure used in Multiple-Input Multiple-Output (MIMO) systems to quantify the correlation between the envelopes of different antenna elements. MIMO systems use multiple antennas at both the transmitter.

In the case of lossless antennas, and assuming that the incoming waves are uniformly distributed, the ECC can be calculated from the parameters S.[8]

$$\rho ij = \frac{|\mathrm{s11} * \mathrm{s12} + \mathrm{s21} * \mathrm{s22}|^2}{(1 - |\mathrm{s11}|^2 - |\mathrm{s21}|^2)(1 - |\mathrm{s22}|^2 - |\mathrm{s12}|^2)} \qquad (1\text{-}3)$$

I.2.4.2) Diversity gain

An approximation of the diversity gain by selection in the case of a 2-port antenna i,j, at an interruption probability level of 1% can be calculated form the ECC [8]

$$\mathrm{Gij} = 10\sqrt{(1 - |\rho \mathrm{ij}|^2)} \qquad (1\text{-}4)$$

I.3) Antennas arrays

I.3.1) Definition of antennas arrays

The array antenna also called phased array consists of two antennas or more which worked simultaneously for transmitting and receiving radio waves. Individual antennas of an antenna array is termed as elements. The elements are placed so closely that each one lies in the neighboring one’s induction field. Therefore, the radiation pattern produced by them, generally used instead of single antenna for increase the performances (the gain and directivity of radiation) maximize the Signal-to-Noise Ratio SNR. [9]

Figure I.4: antennas arrays [10]

I.3.2) History of antennas arrays

Antenna arrays have been around for over a century, but early designs were limited to a few closely spaced elements. World War II further accelerated the development of antenna arrays for radar systems, where the ability to accurately detect and locate enemy aircraft was crucial. the first antenna arrays developments 1899–1937 by Brown he separated two vertical antennas by a half wavelength and feed them out of phase. He found that there was increasing in directivity, DE Forest also noted greatest in Gain due to arraying two vertical antennas. Ferdinand Braun placed three monopoles in a triangle The signal at antenna C has a 100° phase and twice the amplitude of the 0° phase signals at A and B as shown in figure I.5.

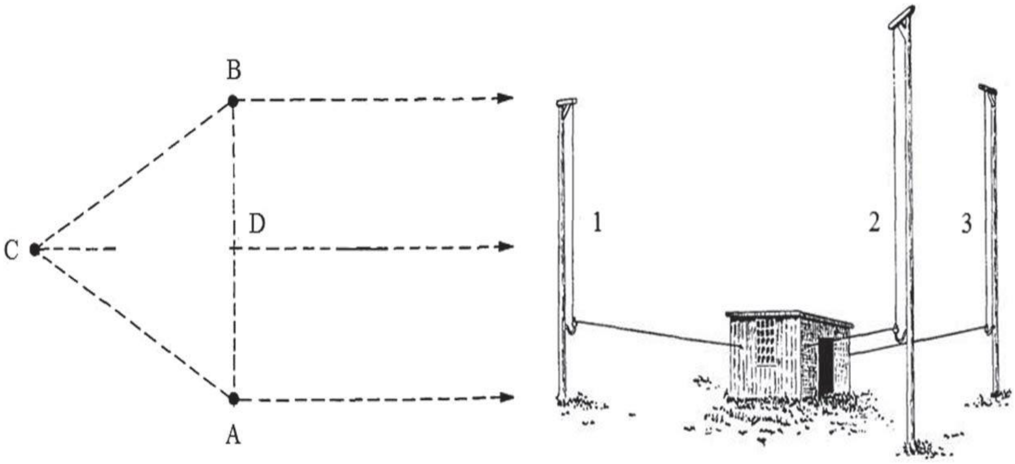


Figure I.5*:* Braun’s three-element array [11]

In 1940 World War II motivated countries to tremendously accelerate the development of radars that detect aircraft and ships at a great distance drove the extensive use of antenna arrays. Phased array antennas were employed for early radar applications, allowing for electronic beam steering and target tracking. After that in 1937-1950 antenna arrays continued to be crucial in radar systems for air traffic control, weather monitoring and air defense in the late of 1930, The 23.1-MHz transmit array had towers that were about 107 m tall and spaced about 55 m apart In April 1937, CH was able to detect aircraft at a distance of 160 km. [11], The evolution continued with the development of antennas until arrived to (smart antennas - MIMO technology - adaptive antenna - millimeter wave antennas -metamaterial antennas).

I.3.3) Types of antennas arrays

I.3.3.1) Uniform Linear array

The uniform linear array (ULA) is antenna array which consist by sum of individual elements are arranged in a straight line, and there is two types of ULA broadside antenna array and End-Fire antenna array, generally used in basic communication and radar system.[12]

A) Broadside antennas arrays

The broadside array is the array of antennas in which all the elements are placed parallel to each other with the same distance from each other and it fed with the current of same magnitude and phase.

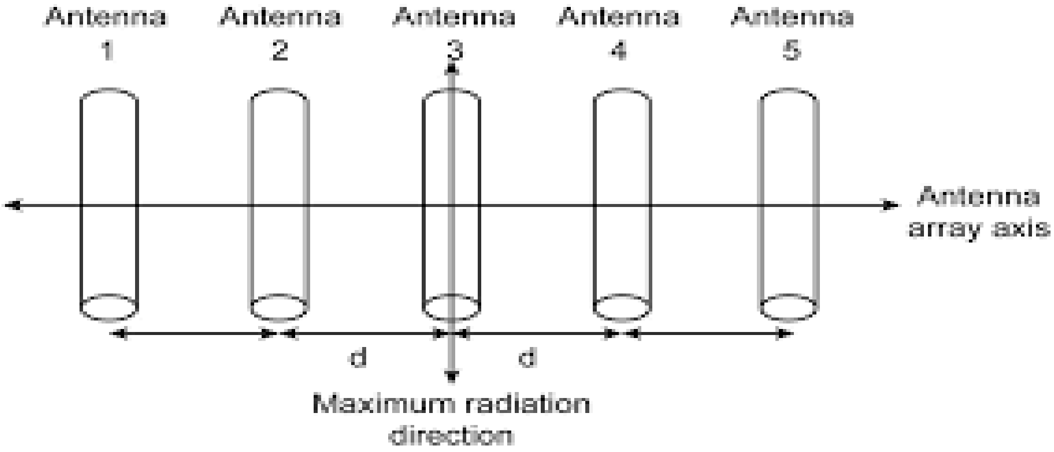


Figure I.6: broadside antenna array [13]

With frequency range between 30 MHz to 3GHz which belong to the **VHF** and **UHF** bands. The radiation pattern of the antenna is perpendicular to the array axis and it is a bidirectional. The bidirectional pattern of broadside array can be converted into unidirectional by placing an identical array behind this array at distance of λ/4 fed by current leading in phase by 90° [14].

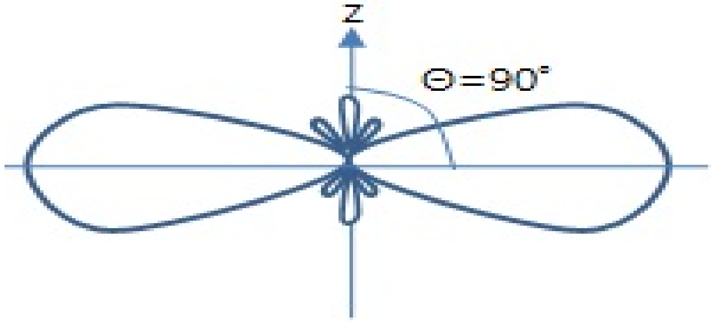


Figure I.7: broadside radiation [14]

B) End-Fire antenna array

the End-Fire array is so much similar to the broadside antenna but the main difference is in the direction of radiation array, in broadside array the direction of maximum radiation is perpendicular to the array axis while in the End-Fire array is along axis array with maximum radiation at (0°,180°) and it fed out of the phase and magnitude. The radiation pattern of EnFire array is uni-directional.[15]

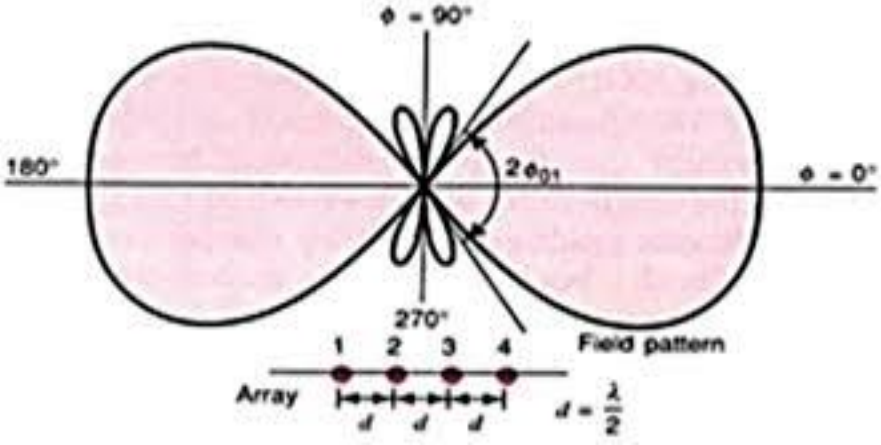


Figure I.8: Radiation pattern OF End-Fire array [16]

C) Collinear antennas arrays

The collinear array is an arrangement of antennas which placed end to end in a single line or stacked over one an another, the collinear array is the same with the broadside antenna, and the same range frequency the element ere fed equally to phase and magnitude current, the difference is the radiation pattern direction, the collinear array has circular symmetry with its main lobe everywhere normal to the principal axis. These arrays also called **broad-cast** or **omni-directional** arrays; The performance characteristic of array does not depend directly on the number of elements in the array, the maximum Gain when the elements are spaced at a distance of about **0.3 to 0.5λ. [13]**

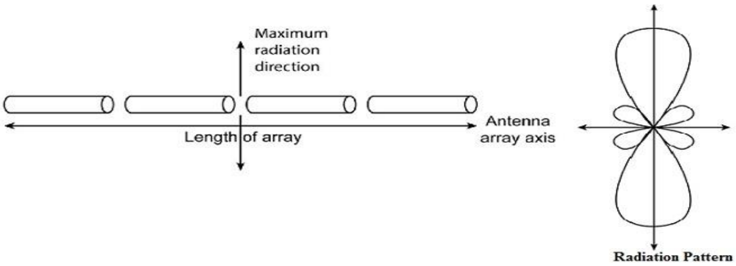


Figure I.9: collinear antenna array with radiation pattern [13]

D) Parasitic antennas arrays

The parasitic array in antenna contains multi-element to obtain high gain and high directivity by feeding one only element and the other elements will feed parasitically. It contains three principal elements, the feed element called driven element while the other elements are the parasitic elements (reflector, director), the reflector is longer by 5% than the driven element and the other parasitic element (director) is shorter by 5% than the driven element, the distance between the elements is about λ/4 and phase difference 90° provide unidirectional pattern.

The most common example of this type of parasitic array is Yagi-Uda Antenna. These antenna arrays operate in the frequency range between **100 MHz to 1000 MHz**. this antenna used to obtain high directive gain. [13] [14]

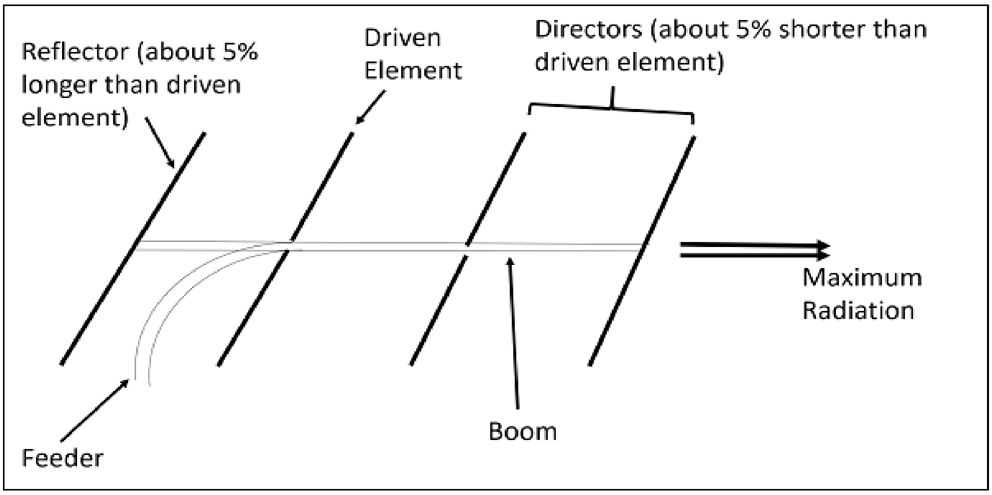


Figure I.9: parasitic antenna array [17]

I.3.3.2) non-uniform antennas arrays

Non-uniform antenna array is a type of array is which the space between the element is not uniform and feed with currents unequal magnitude, the performance of non-uniform array is the same with (ULA) but with smaller number of elements, the non-uniform array is binomial, Dolph-Tchebyscheff and Taylor arrays.

A) Binomial antennas arrays

the binomial antenna array is a type of antenna which consist of elements and each element of the array ill receive the same signal at the same phase but with different amplitudes, it is an “amplitude array “. The distance between the element smaller than λ/2 the sidelobe is not visible, however Binomial Array generates a wide mainlobe.[18]

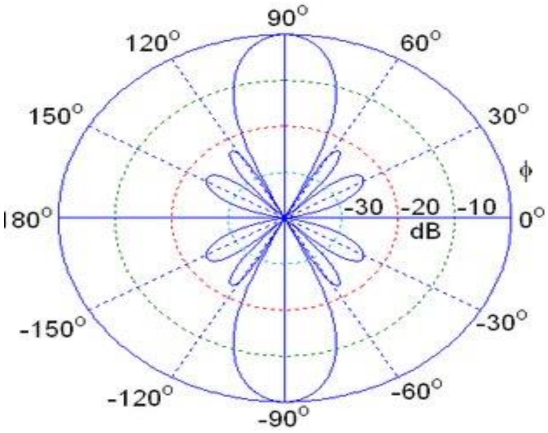


Figure I.10: radiation pattern of binomial array of 3 elements [19]

B) Dolph-Tchebyscheff antenna array

A Dolph-Chebyshev Array is a type of antenna array designed using the Chebyshev polynomial of the first kind. The design approach aims to achieve a specific trade-off between the width of the main lobe and the level of side lobes in the radiation pattern.[18]

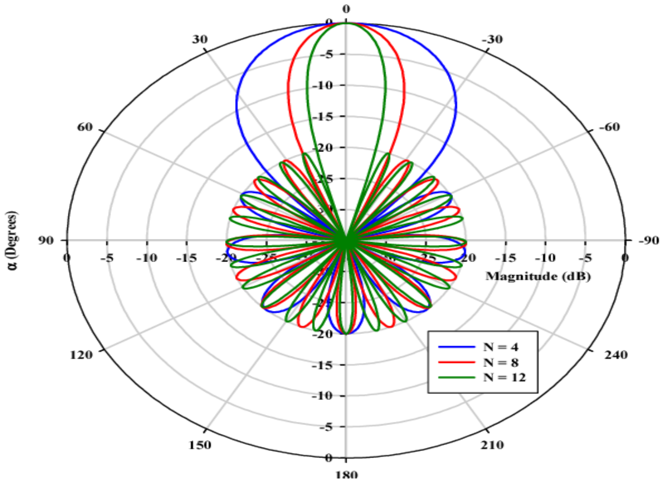


Figure I.11: radiation pattern of binomial array of 3 elements [19]

C) Taylor antenna array

A Taylor Array is an antenna array designed based on the coefficients of a Taylor series expansion. The Taylor series is utilized to determine the amplitude distribution of the array elements, allowing for customization of the radiation pattern. Taylor arrays are designed to achieve a trade-off between the width of the main lobe and the level of side lobes in the radiation pattern.[17]

I.3.4) The characteristics of antennas arrays

I.3.4.1) The array factor

A) The Array factor uniform linear array

The total resultant field at the distant point P is obtained by adding the fields due to N individual sources vectorially.

$$E_T = E_0 e^{j0} + E_0 e^{j\psi} + E_0 e^{2j\psi} + \cdots\cdots\cdots + E_0 e^{(N-1)j\psi}$$

$$E_T = E_0(1 + e^{j\psi} + e^{2j\psi} + \cdots\cdots\cdots + e^{(N-1)j\psi}$$

Noted that: $\psi=\beta d\cos(\theta)+\alpha$

Multiply by $e^{j\psi}$ on both sides:

$$E_T e^{j\psi} = E_0(e^{j\psi} + e^{2j\psi} + e^{3j\psi} + \cdots\cdots\cdots + e^{Nj\psi}$$

$$(E_t/E_0) = AF = [\frac{\sin(\frac{N}{2}\psi)}{\sin(\frac{1}{2}\psi)}]$$

A.1) The array factor of broadside array

$$AF(\theta) = \frac{\sin(\frac{N\beta d}{2}\cos(\theta))}{\sin(\frac{\beta d}{2}\cos(\theta))}$$

which for a small spacing between the elements (d << λ) can be approximated by: π

$$AF(\theta) = \frac{\sin(\frac{N\beta d}{2}\cos(\theta))}{\frac{\beta d}{2}\cos(\theta)}$$

N number of element

$\beta = \frac{2\pi}{\lambda}$ the phase constant related to the wavelength of the signal

d is the spacing between adjacent elements

θ is the angle of radiation

α is the progressive phase shift between two adjacent point sources.

I.4) The application of antennas arrays

Antenna arrays find application in various fields due to their ability to enhance specific characteristics of electromagnetic wave transmission and reception. Some common applications of antenna arrays include:

1) Radar Systems

2) Communication Systems

3) Satellite Communication

4) Wireless LANs and Wi-Fi

5) Astronomy

6) Direction Finding and Localization

I.5) conclusion

This chapter provided an in-depth examination of MIMO antennas, including their types, architecture, and design approaches. We also explored antenna arrays, discussing their types, characteristics, and applications. The next chapter delves into the practical aspects of designing 5G patch antenna arrays.

Chapter II:

Designing of 5G patch Antennas Array

II.1) Introduction

The most important parameters of antenna is Gain (directivity), radiation Pattern and the Bandwidth, so the single element patch antenna provided a wide radiation pattern witch means small value of Gain and directivity and for increasing this parameters for 5G system we should to design a model of antenna contain multiple elements of patch antenna (antennas arrays) , and this what we will do it in this chapter by using the software (Ansys Electronics, HFSS).

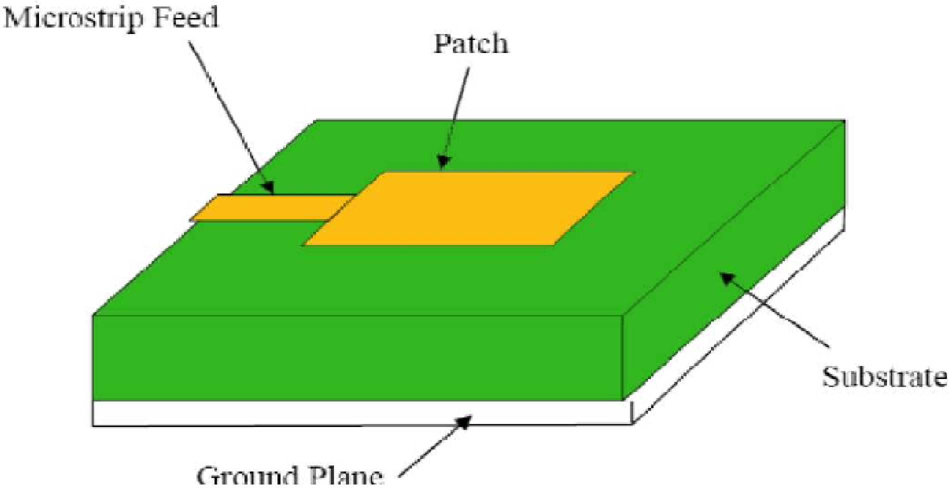


Figure II. 1: Microstrip Patch Antenna [22]

The patch is generally made of conducting materials such as copper or gold and it could take any possible shape.

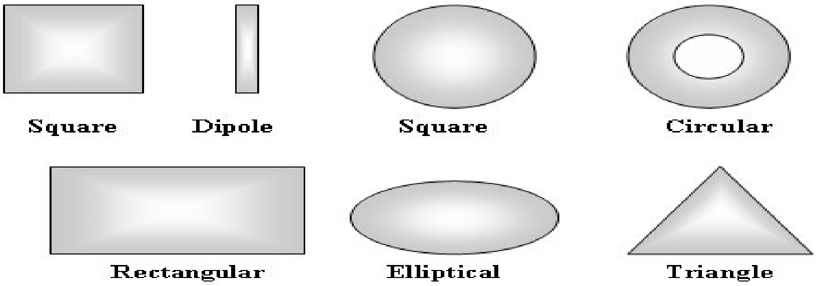


Figure II.2 : Shapes of patch antenna

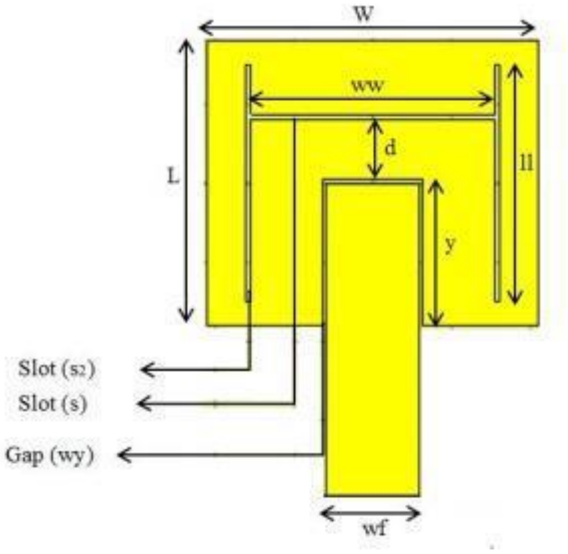


Figure II. 3: Slotted single element (28GHz) antenna.

II.4) Design of Two element antenna array

Based on the slotted single-element design illustrated in Figure (II.3), a two-element antenna array is devised to enhance the directivity and gain of the slotted antenna. To achieve impedance matching, we implemented a quarter-wavelength transformer in the feeding network, along with the parallel feeding method depicted in Figure (II.4). The dimensions of the transmission lines in the feeding network are detailed in Table 1.

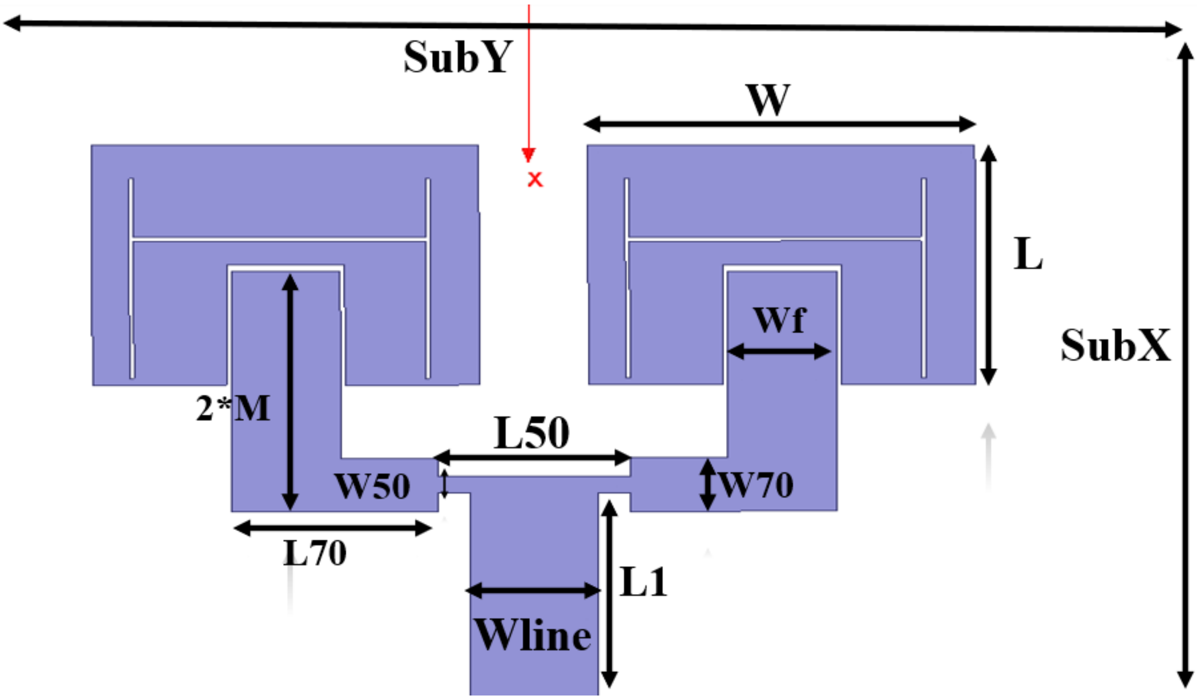


Figure II. 4:design of two elements array

Table 1: parameter of antenna array 2 elements

length of patch	L	3.6
width of patch	W	4.8
length of substrate	Suby	22
width of substrate	Subx	22
high of substrate	Subh	1.575
length of ground	Suby	22
width of ground	Subx	22
length of feedline1	L1	3.575
length of feedline2	w50	0.1
Length of feedline 3,4	w70	0.8
length of feedline 5 ,6	2*M	2*1.8
width of feedline 1	Wline	1.179
width of feedline 2	L50	2.08
width of feedline 3, 4	L70	2.229
width of feedline 5,6	Wf	1.179

II.4.1) Optimization parameter

A) Case 1 (Wline)

From Table 2 and Figure II.6, it's evident that the Gain values exhibit a consistent range of approximately 10.3 to 10.55 dB. However, a significant disparity in bandwidth is observed, particularly notable in Figure II.5. Specifically, for the values of Wline=0.779 mm and Wline=1.579 mm, there appears to be a lack of adaptation. Conversely, among other cases, the optimal parameter emerges as Wline=1.379 mm, delivering the widest bandwidth at 5.6 GHz.

Table 2: optimization of Wline

Wline (mm)	**0.779**	**0.997**	**1.179**	**1.379**	**1.579**
Gain (dB)	10.54	10.53	10.54	10.39	6.3
Fr (GHZ)	34.4	34.1	33.8	34	35
BW (GHZ)		1.3	2.6	5.6	

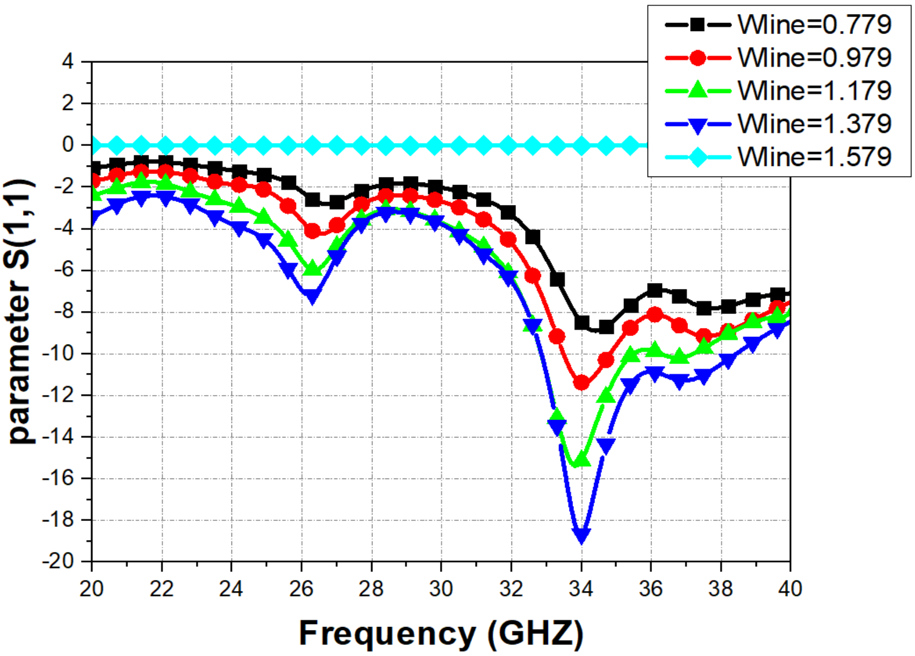


Figure II.5: Calculated S11 versus the frequency for each value of wline

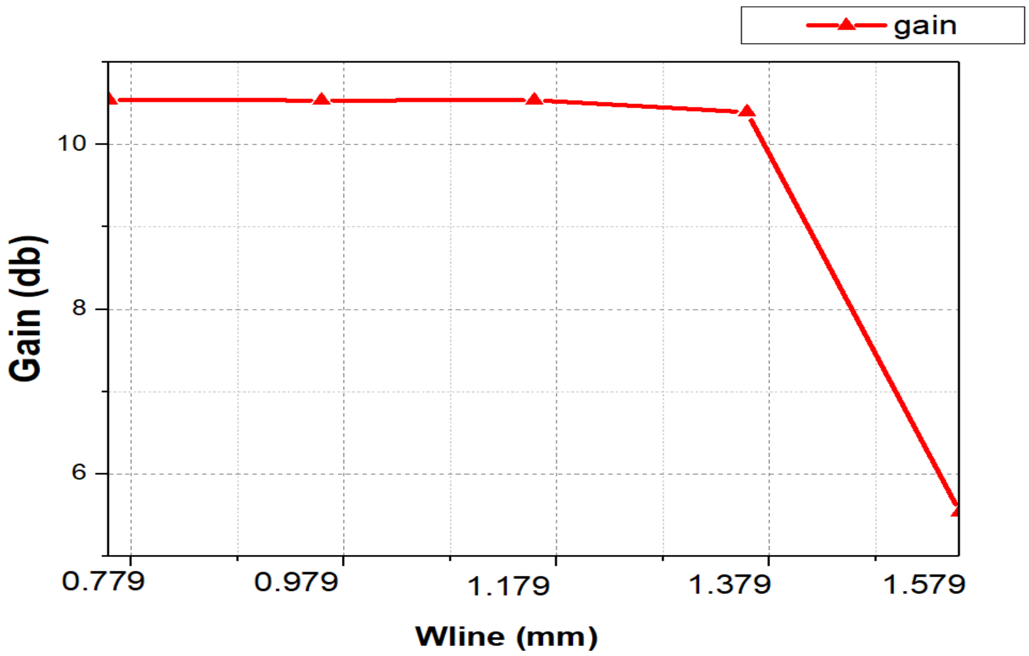


Figure II. 6: Calculated gain versus wline

B) Case 2 (W50)

Now that we have established the optimal value of Wline, our focus shifts to optimizing W50 to enhance antenna gain and bandwidth. Analysis of Table 3 and Figures II.7 and II.8 reveals that the Gain ranges from 10.1 to 10.5 dB. To determine the optimal value, we compare the bandwidth. Notably, the largest bandwidth is achieved when W50=0.1 mm, indicating its superiority as the optimal value

Table 3: optimization of W50

W50 (mm)	**0.05**	**0.1**	**0.15**	**0.2**	**0.25**
Gain (dB)	10.5	10.39	10.31	10.31	10.10
Fr (GHZ)	33.9	34	34	34	34
BW (GHZ)	2.8	5.6	5.1	3.2	4.7

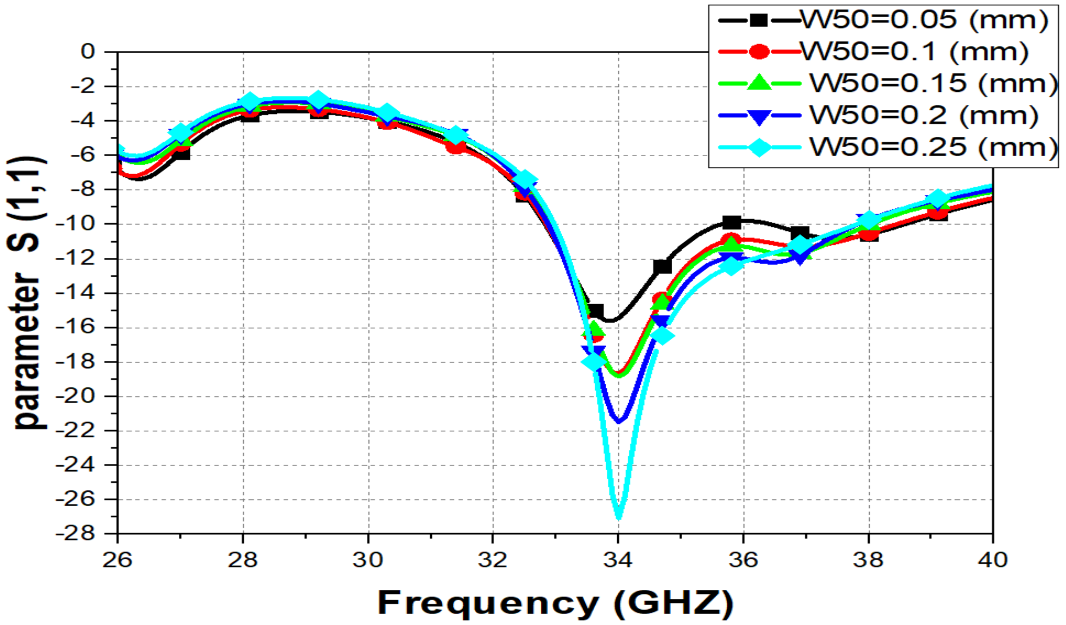


Figure II. 7: Calculated S11 versus the frequency for each value of w50

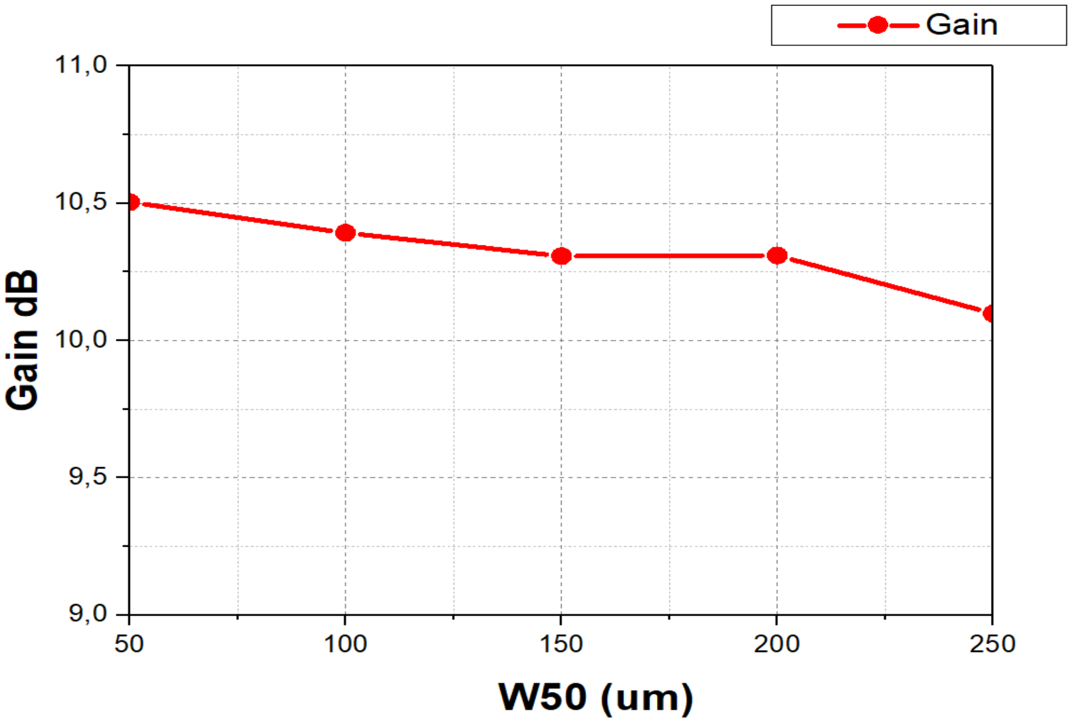


Figure II. 8: Calculated gain versus w50

C) Case 3 L50

In this section, we focus on optimizing L50 while keeping other parameters fixed. Analysis of Table 4 and Figures II.9 and II.10 reveals that the gain remains relatively consistent at around 11 dB for each value of L50. However, the primary difference lies in the

S (1,1) parameter, where two optimal cases emerge. Firstly, when L50 = 1.68 mm, a notable observation is a Dual Band occurrence at 32 GHz and 24.9 GHz. Conversely, the second optimal case occurs when L50 = 2.08 mm, exhibiting the largest bandwidth of 4.6 GHz and the highest gain at 10.39 dB

Table 4: optimization of L50 the width of feedline

L50 (mm)	**1.68**	**1.88**	**2.08**	**2.28**	**2.48**
Gain (dB)	9.92	10.28	10.39	10.49	10.64
Fr (GHz)	32.2	34	34	33.9	33.7
BW (GHz)	3	5.6	5.6	5.4	5.1

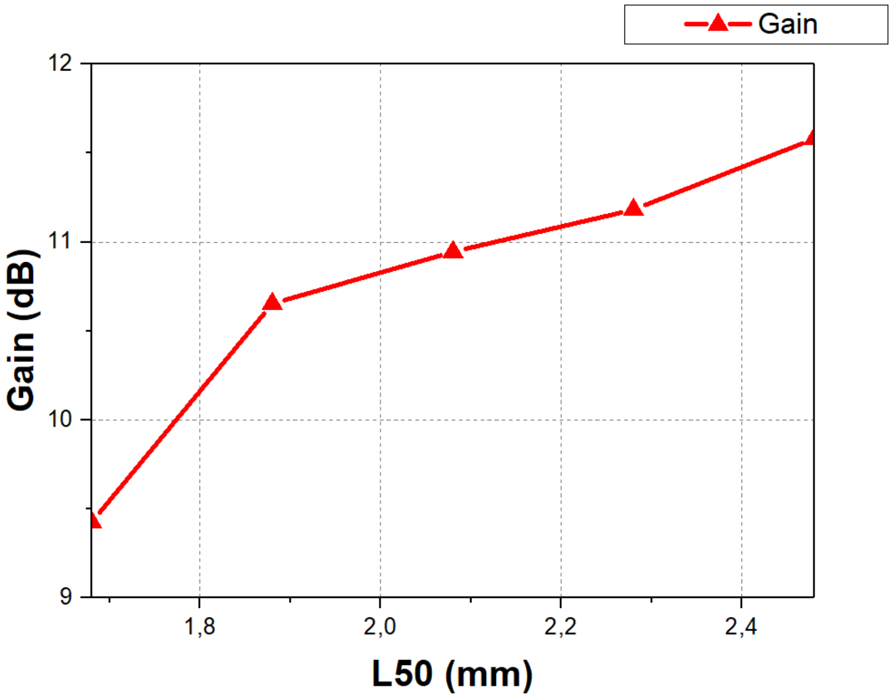


Figure II.9: Calculated gain versus L50

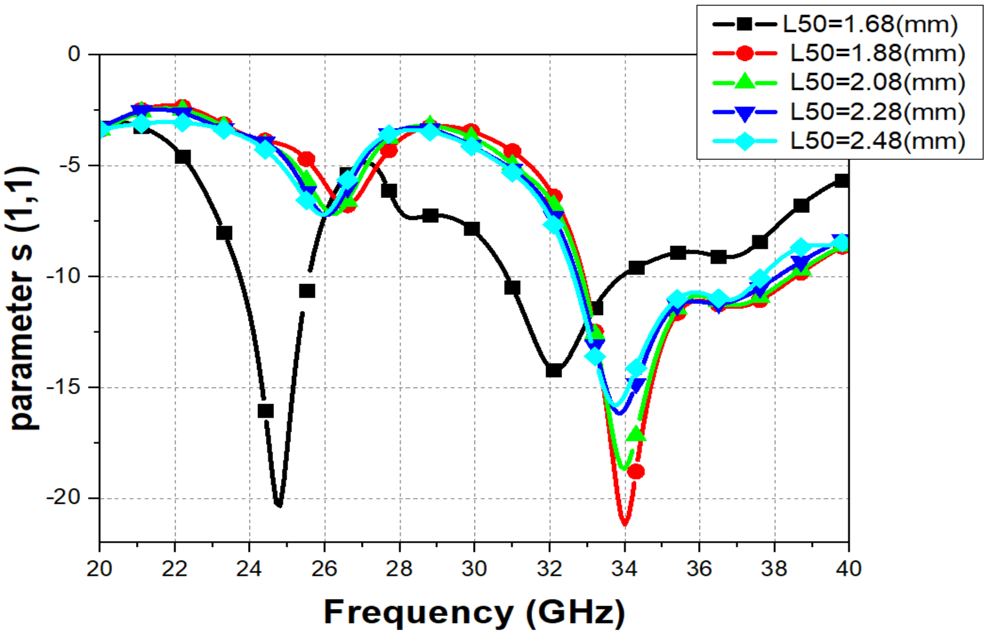


Figure II.10: Calculated S11 versus the frequency for each value of L50

The optimal values are as follows: Wline=1.379 mm, W50=0.1 mm, and L50=2.08 mm. These parameters yield a gain of 10.39 dB, a bandwidth of 5.6 GHz, and a resonant frequency of 34 GHz.

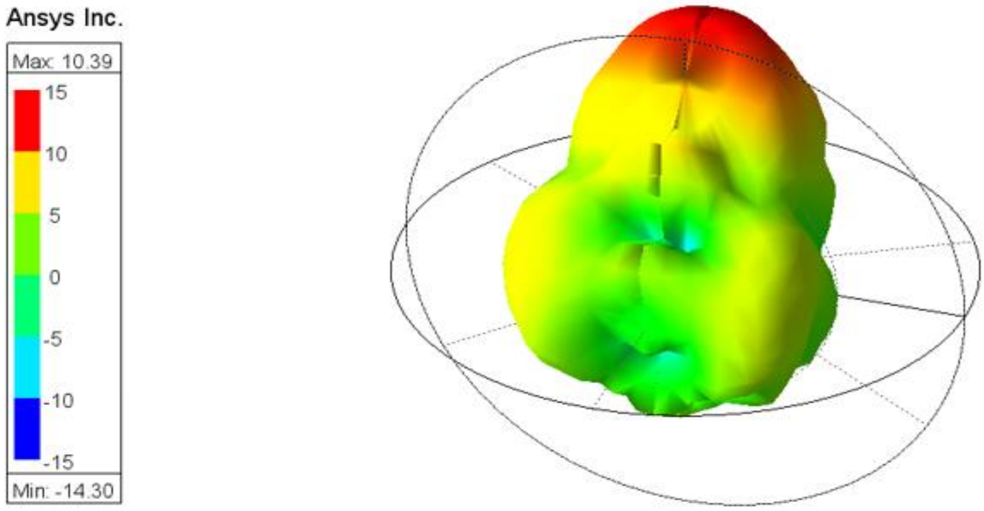


Figure II. 11: 3D gain of of the optimal value

II.4.3) the design of four elements antennas array (first configuration)

In this section we design four element array antennas to enhance the array antenna gain and bandwidth (figure II.12) show the antenna array first configuration

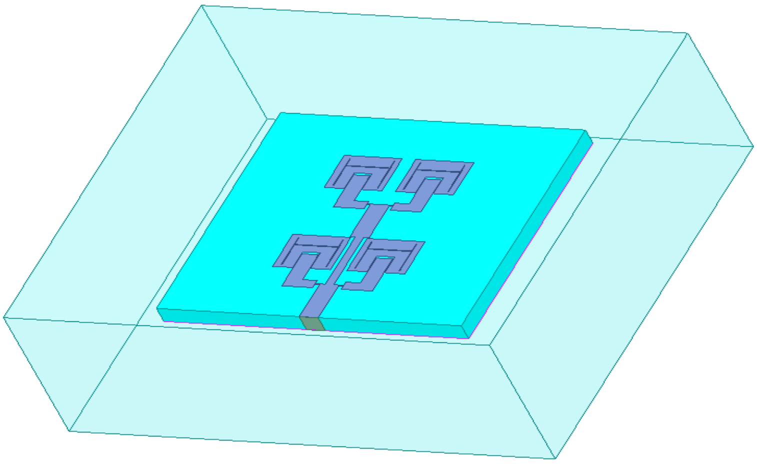
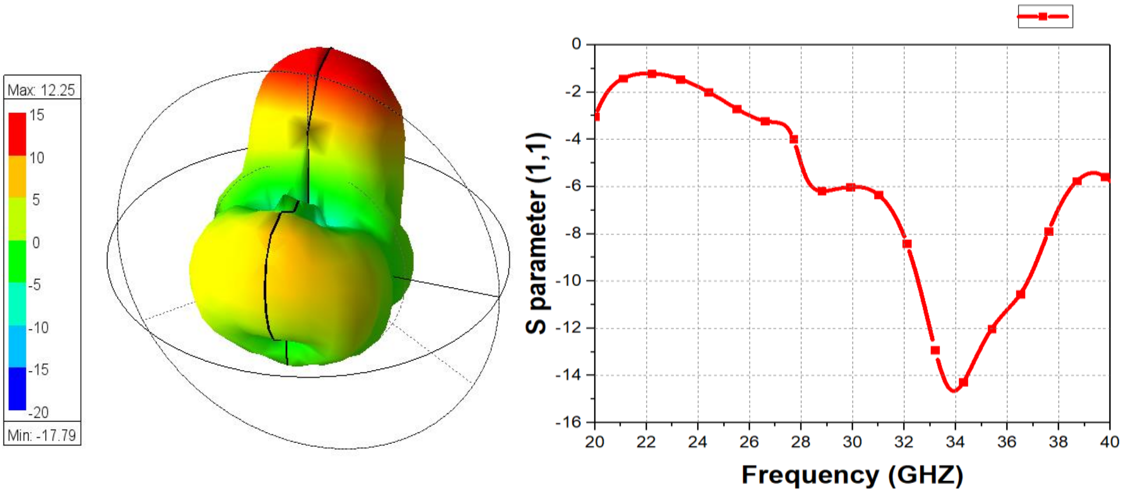


Figure II. 12:antennas array first configuration



(A) **(B)**

Figure II. 13: (A) the three dimensional Gain and (B) the s11 parameter of first configuration of four elements antenna arrays

II.4.4) optimization parameters

We will optimize several parameters of the array antenna, including w40, as well as the distances L2 and L5 as depicted in Figure (II.13). Our goal is to achieve higher gain and a larger bandwidth through these optimizations.

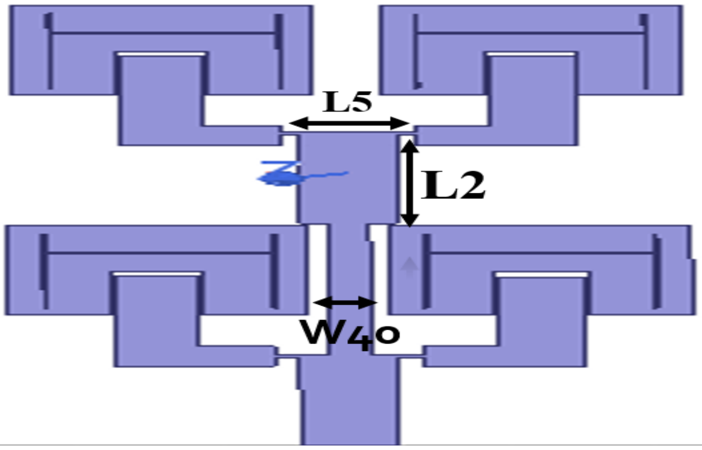


Figure II.14: antennas arrays dimensions

A) Optimization of W40

From Figure II.14 and Table 5, it's apparent that all values of W40 yield similar gains, averaging around 12 dB. However, the notable discrepancy lies in the width of the bandwidth. Consequently, we opt to fix W40 at 0.2 mm, which yields a gain of 12.01 dB and a bandwidth of 4.6 GHz .

Table 5 : optimization of W40

W40 (mm)	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**
Gain (dB)	12.01	12.25	12.27	12.25	12.31
Fr (GHZ)	33.5	33.7	34	34	34
BW (GHZ)	4.6 (14%)	4.4 (13%)	4.3 (12%)	4.4 (13%)	4.3 (12%)

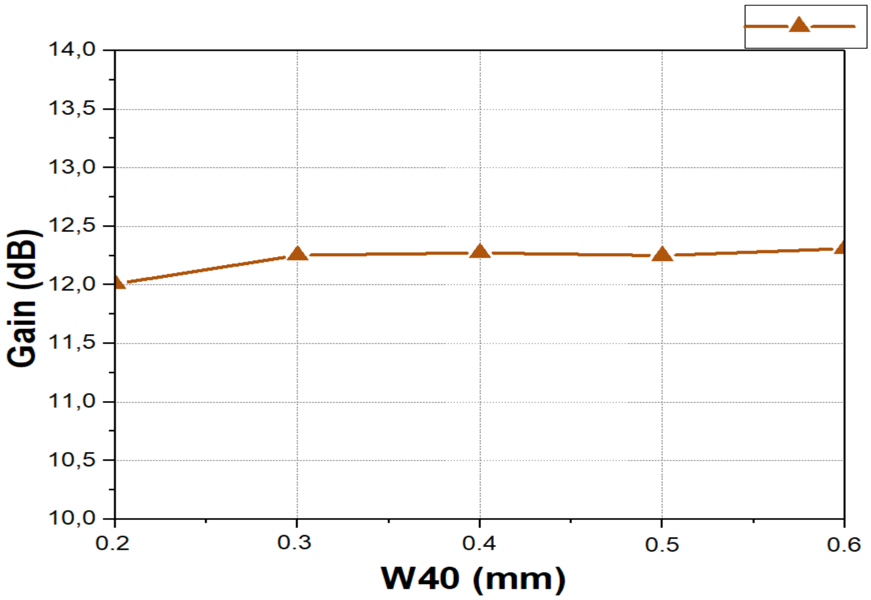


Figure II. 15: gain of each case W40

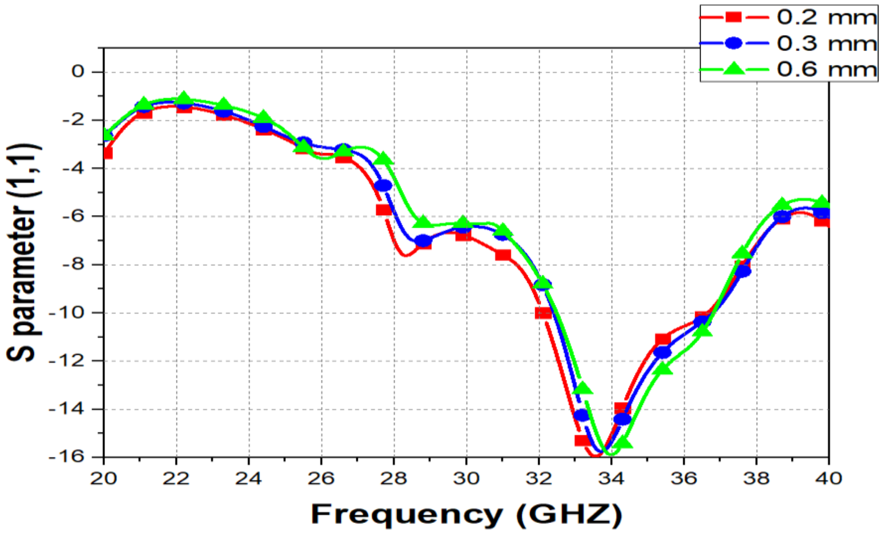


Figure II. 16: S (1,1) parameter of each case of W40

B) Optimization of L2

In this section, we have fixed the previous parameters and concentrated on optimizing the distance L2. We analyze the impact of this optimization on the performance of the antenna array

Table 6: optimization of L2

L2(mm)	**2.975**	**3.175**	**3.375**	**3.575**	**3.757**	**3.975**	**4**
Gain (dB)	12.25	12.35	12.38	12.01	11.95	11.52	11.50

Fr (GHZ)	33.4	33.7	33.7	33.5	34.1	34.2	33.9
BW (GHZ)	2.9	2.6	3.3	4.6	3.8	3.6	3.9

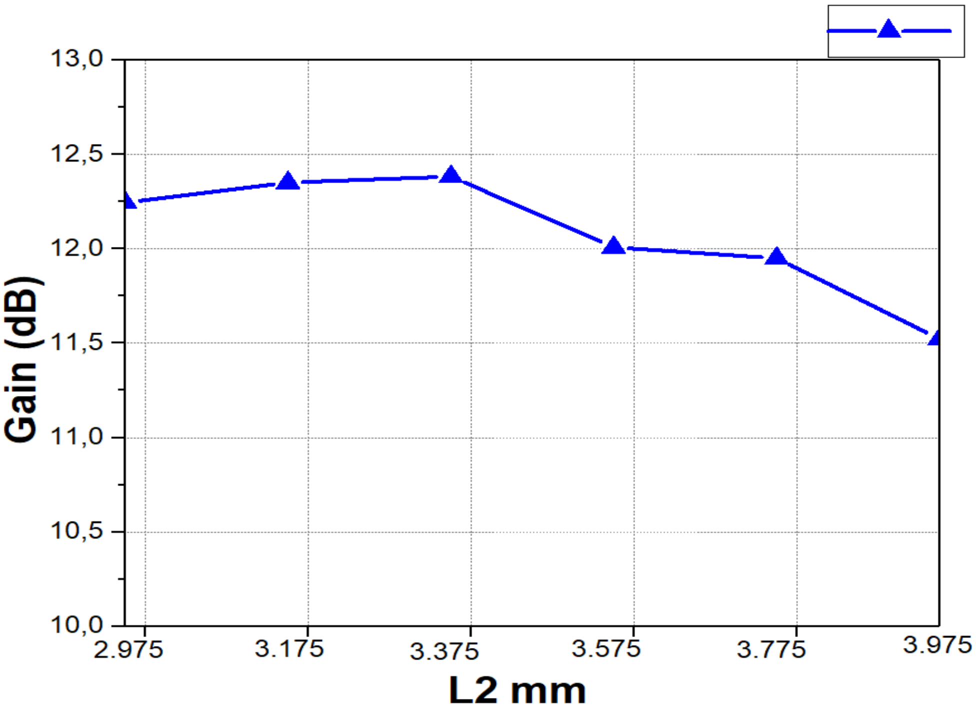


Figure II. 17: Calculated gain versus L2

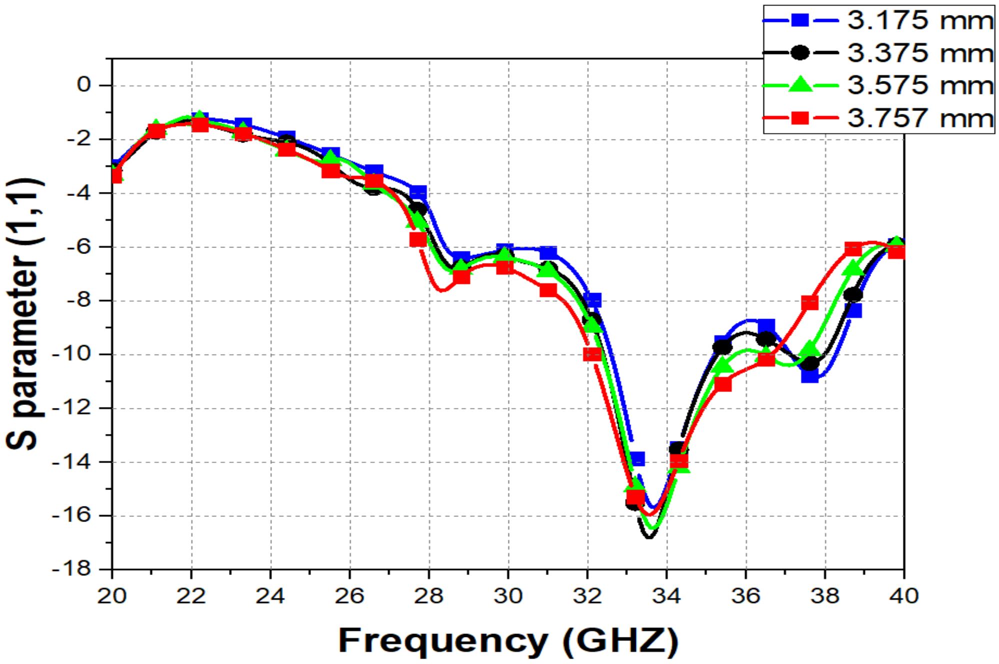


Figure II. 18: Calculated S11 versus the frequency for each values of L2

C) Optimization of L5

In this section, we have fixed the previous parameters and focused on optimizing the distance L5. Despite the gain remaining consistent across these cases, our comparison is based on bandwidth. The optimal scenario arises when L5=1.88 mm, resulting in a gain of 12.35 dB and a bandwidth of 4.6 GHz. Analysis from Table 7 and Figure II.18 illustrates

Table 7: optimization of L5

L5 (mm)	**1.68**	**1,88**	**2.08**	**2.28**	**2.48**
Gain (dB)	12.29	12.35	12.01	11.76	12.04
Fr (GHZ)	33.7	33.6	33.7	33.6	33.7
BW (GHZ)	4.3	4.6	4.6	4.3	4.3

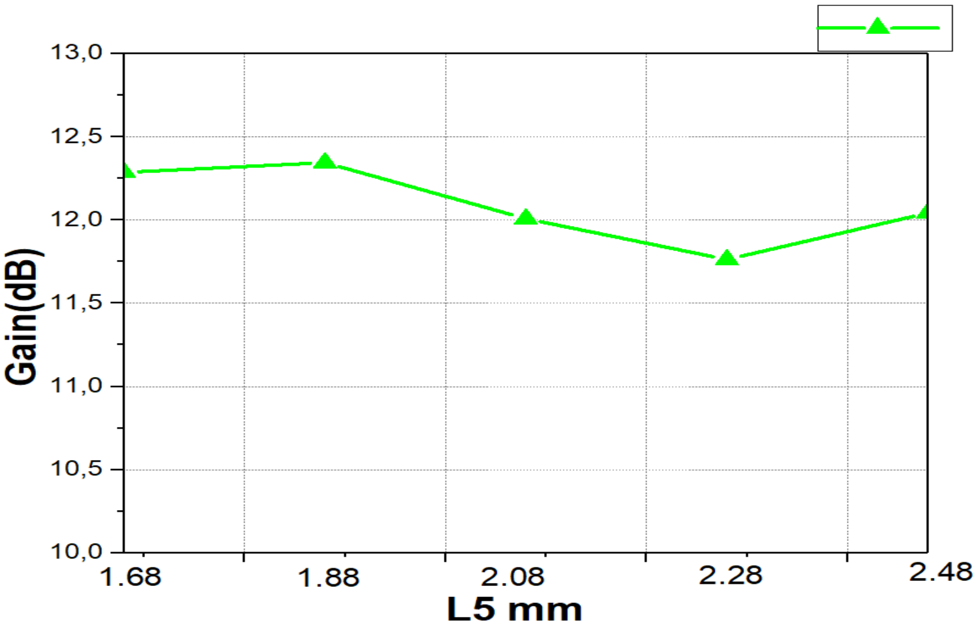


Figure II. 19: Calculated gain versus L5

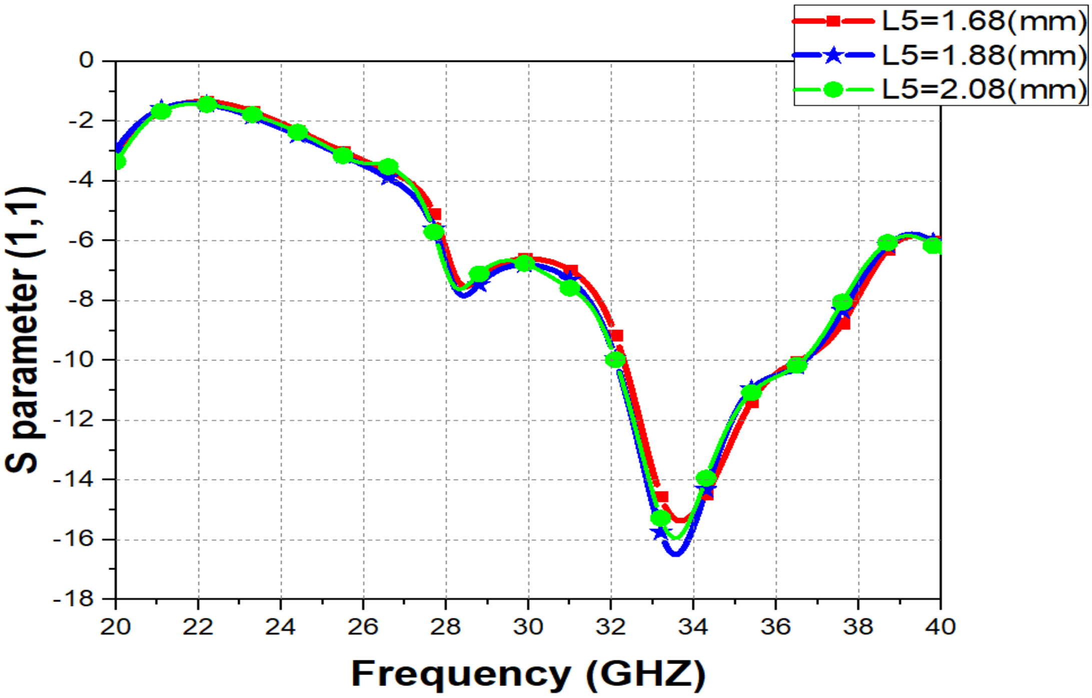
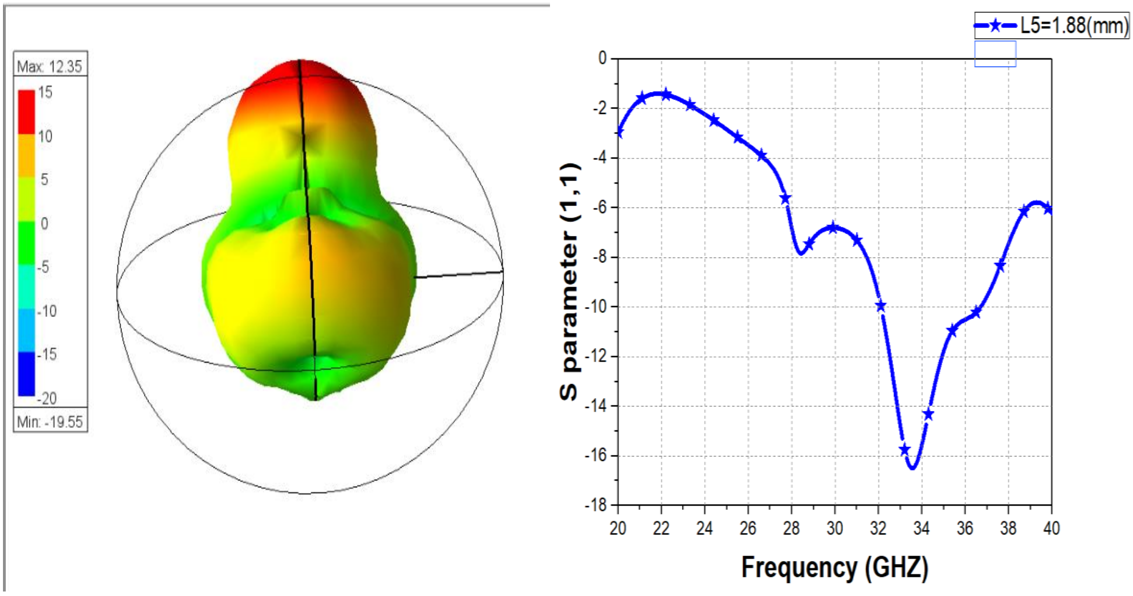


Figure II. 20: Calculated S11 versus the frequency for each value of L5

(Figure II.20) illustrates the gain and bandwidth of the optimal values for these antenna arrays, which are determined to be W40=0.2 mm, L2=3.575 mm, and L5=1.88 mm. These parameters result in a gain of 12.35 dB, a bandwidth of 4.6 GHz, and a resonant frequency of 33.6 GHz.



(b) **(b)**

Figure II. 21: (a) ***3D*** gain and **(b)** return loss S11 versus frequency for the optimal value of L5

II.4.6) Second configuration of antenna array

The second configuration of the four-element array antenna is depicted in Figure (II.21), with its corresponding dimensions outlined in Table 8.

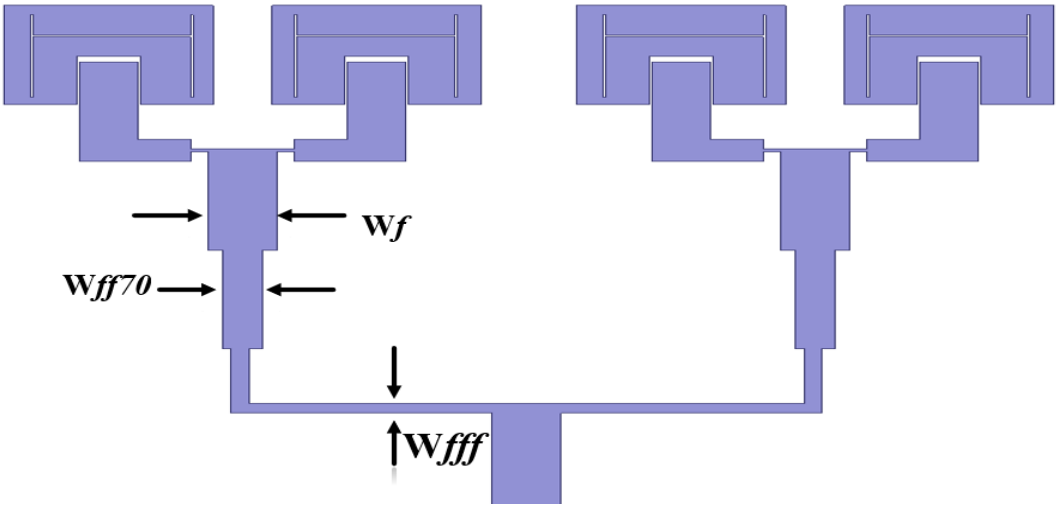


Figure II. 22: Second configuration of antenna arrays

Table 1: array antenna dimensions

#	Parameter	Dimensions (mm)
1	*wf70*	0.8
2	*wff70*	0.8
3	*wfff*	0.35

The simulated S11 results demonstrate favorable matching at a frequency of 26.2 GHz, corresponding to -14.9 dB (Figure II.22). Additionally, the three-dimensional simulated radiation patterns at 28 GHz exhibit a commendable realized gain of 11.19 dB, as illustrated in Figure II.23

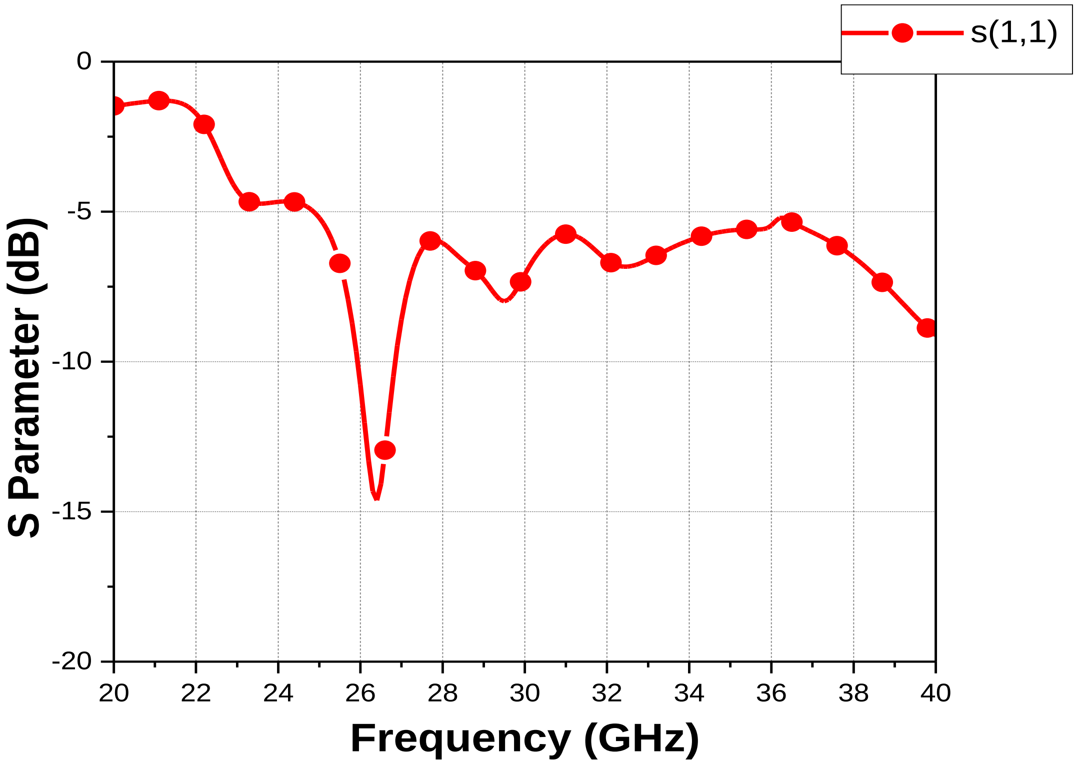


Figure II. 23 : S (1,1) parameter of second configuration antennas array

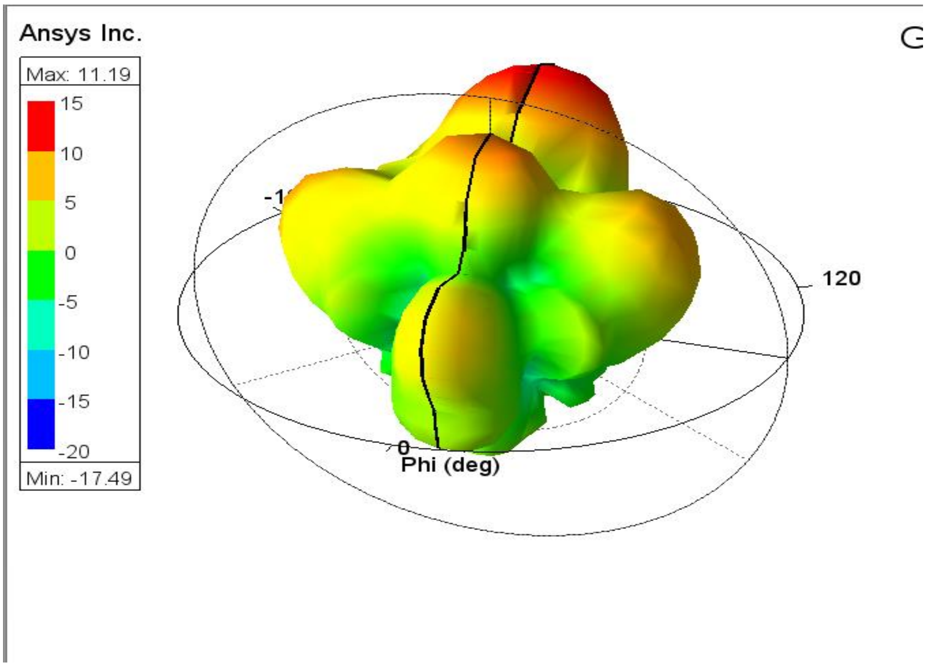


Figure II. 24 : Gain of the second configuration antenna arrays

II.4.7) antenna array with fixed beam steering

The direction of the antenna radiation pattern is also very important in the antenna design, where the 5G systems require antennas with a beam steering capability. Higher directivity means narrower radiation beams so we have to be able to control the main beam direction.

Beam steering feature of the antennas for 5G systems can be achieved by many methods that depend on changing the phase or the magnitude of the input signal to the antenna.

This will change the direction of the main beam to a desired direction according to the phase difference between the signals feeding the antennas. Figures II.24 and II.25 present the structure of phase shifted four-element antenna array where the phase shifter was added once on the right side and another on the left side. Those two structures can achieve fixed beam steering capability where one can direct main beam to θ direction and the other structure directs the beam to -θ direction.

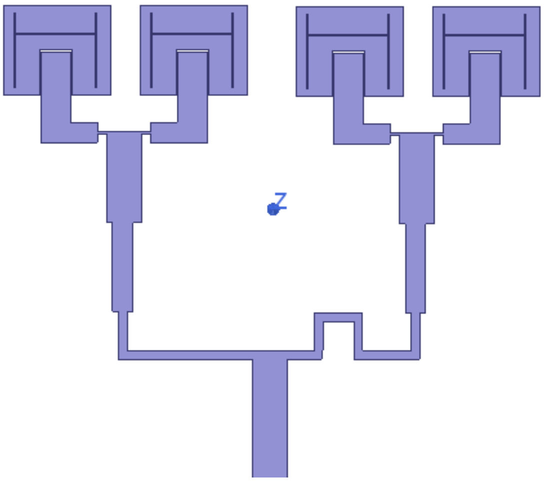


Figure II. 25: right phase shifter arrays

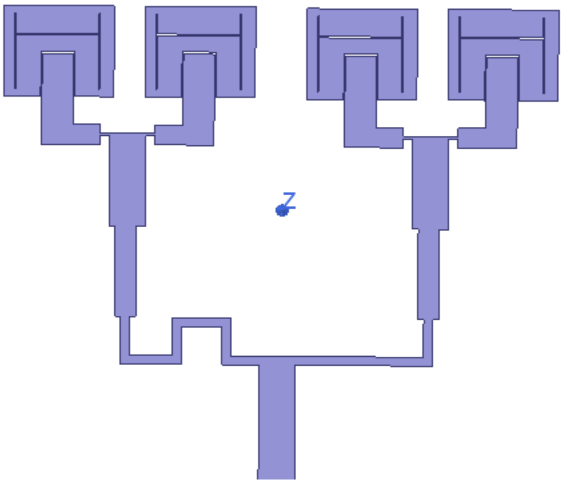


Figure II. 26 : Left phase shifter arrays

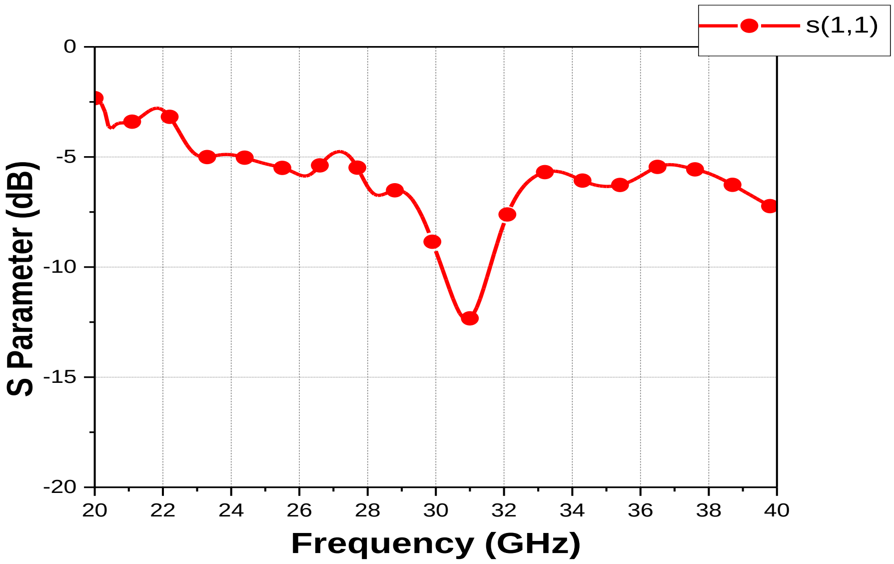


Figure II. 27 : S (1,1) Parameter of right shift antennas arrays

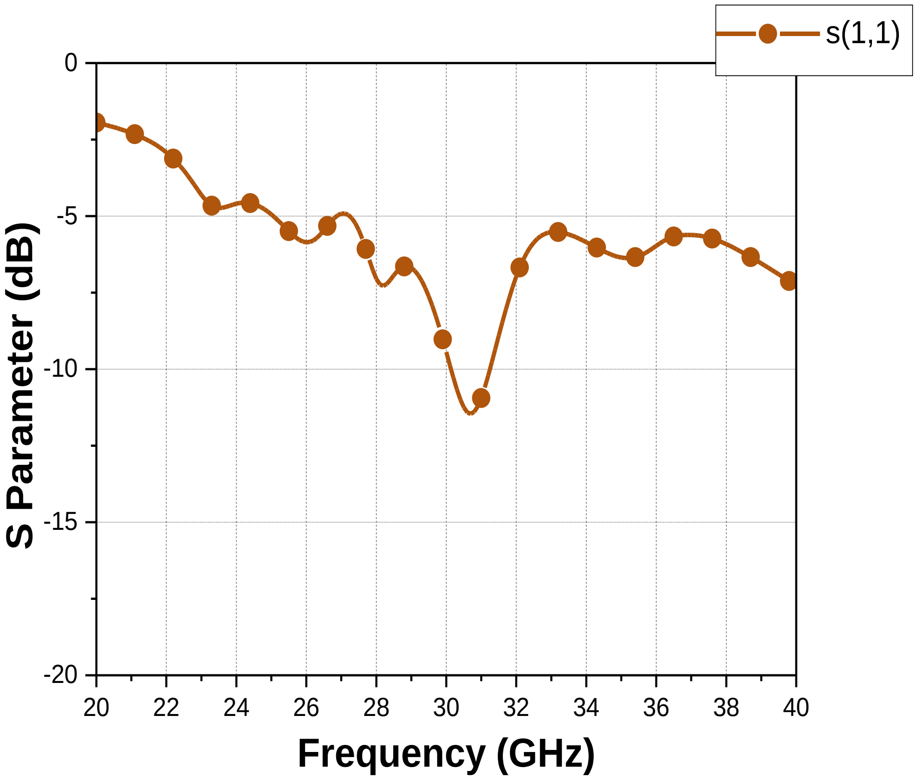
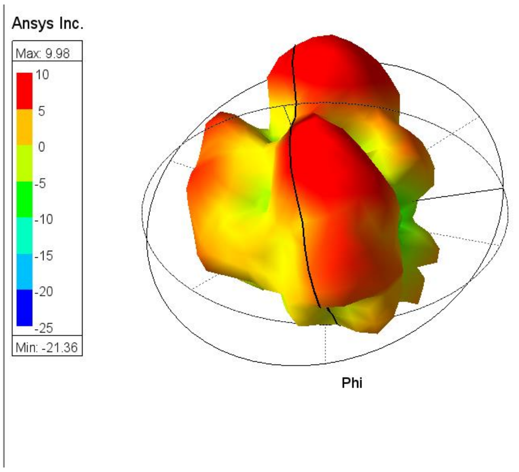


Figure II. 28 :S (1,1) parameter of left shift antennas arrays

(Figure II.28) depicts the antenna gain for both the left and right phase shifts, averaging around 10 dB. The radiation patterns in the E and H planes are illustrated in Figures II.30 and II.31, respectively. It's evident that the beam steering is controlled within a range of 15 degrees to -15 degrees in the E plane.



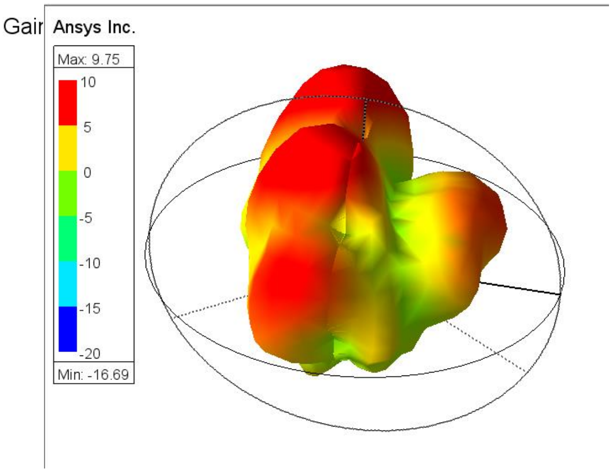


Figure II. 29: the gain of right phase shifter **Figure II. 30:** the gain of Left phase shifter

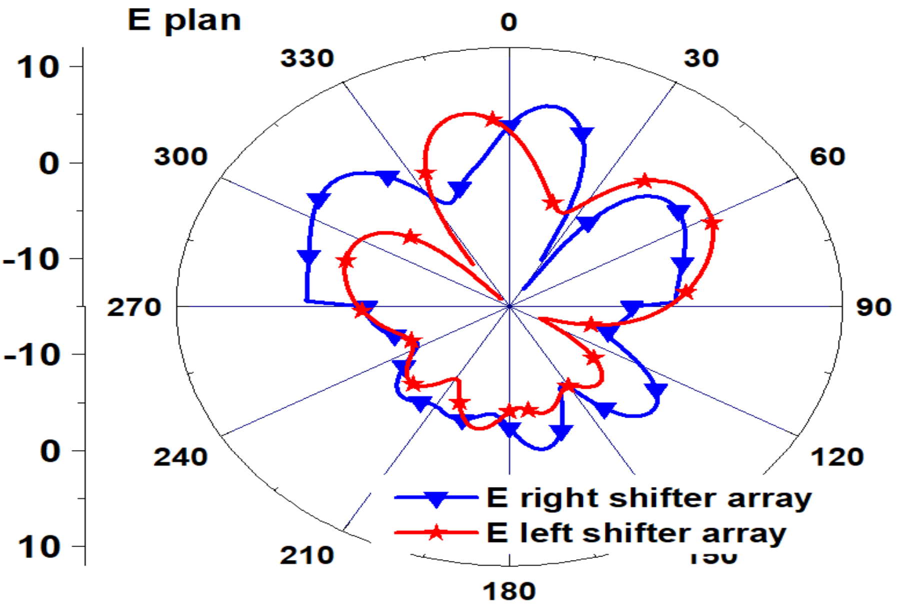


Figure II. 31: E plan for right and left shifter arrays

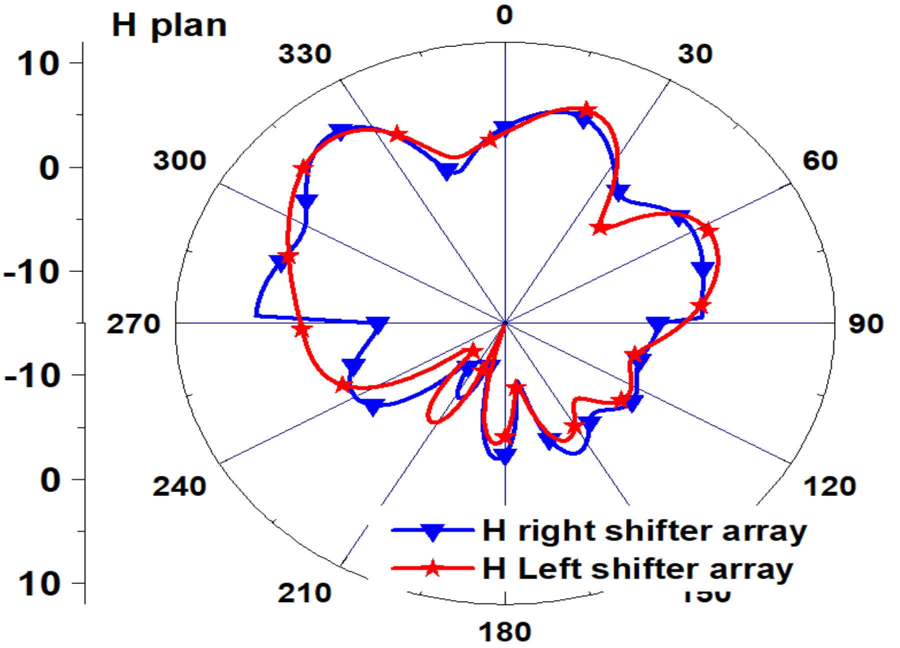


Figure II. 32: H plan for right and left shifter array

After adding the phase shifter to the four-element design, the simulated result of S11 shows

good matching at the two resonant frequencies which is -11 dB at 28 GHz as shown in Figures (II.27-II.28). Also, the three-dimensional simulated radiation pattern at 28 GHz shows a good realized gain of 9.98 dB where the beam is steered to θ = +10 degree in the structure with right phase shifter and 9.75 dB in θ = -10 degree in the structure with left phase.

II.5) conclusion

Using ANSYS Electronics HFSS simulation program, a new design of dual band dual polarization micro-strip antenna array has been designed for serving 5G wireless communication systems. The antenna operates at the frequencies between 28 GHz and 38 GHz and its size is less than 2.4 cm.

An H-shaped slot has been used in the single patch antenna for achieving the dual band feature, where the proposed design achieved good gain at the resonant frequency.

The array configuration is used for enhancing the gain and the directivity of the antenna because for the 5G communication systems the gain of the antenna has to be more than 12dBi. This gain has been achieved in the four-element antenna array design were the gain is more than 12 dB at the two resonant frequencies.

After that we look for achieving more features for the 5G communication system, so we add a phase shifter to the four-element design to achieve the beam steering feature. We designed two phased four-element configurations where the right phase shifter in first configuration causes shifting for the main beam with angle +10 toward x-axis and the left phase shifter in the second configuration causes shifting for the main beam with angle -10 toward the x-axis.

Chapter III:

Design of 5G MIMO antenna for handset and Mobile base station

III.1) Introduction

In this chapter, we will use the antenna from the previous chapter to design MIMO (Multiple Input Multiple Output) technology, which is employed to increase the data rate and system capacity for 5G applications. These antennas are designed to support various MIMO configurations, such as 2x2, 4x4, or even higher, depending on the device capabilities. MIMO technology in handsets enables improved data speeds, better coverage, and enhanced reliability, especially in challenging signal environments

III.2) Design of 5G MIMO FOR handset and base station

Handset design case 1

In this section, we utilized 4-element antenna arrays in the handset design, as illustrated in Figure III.1, with dimensions of 55*55 (mm). The design comprises four arrays: two positioned on the upper and lower horizontal edges of the handset, and the other two on the right and left vertical edges, with appropriate spacing between the patches

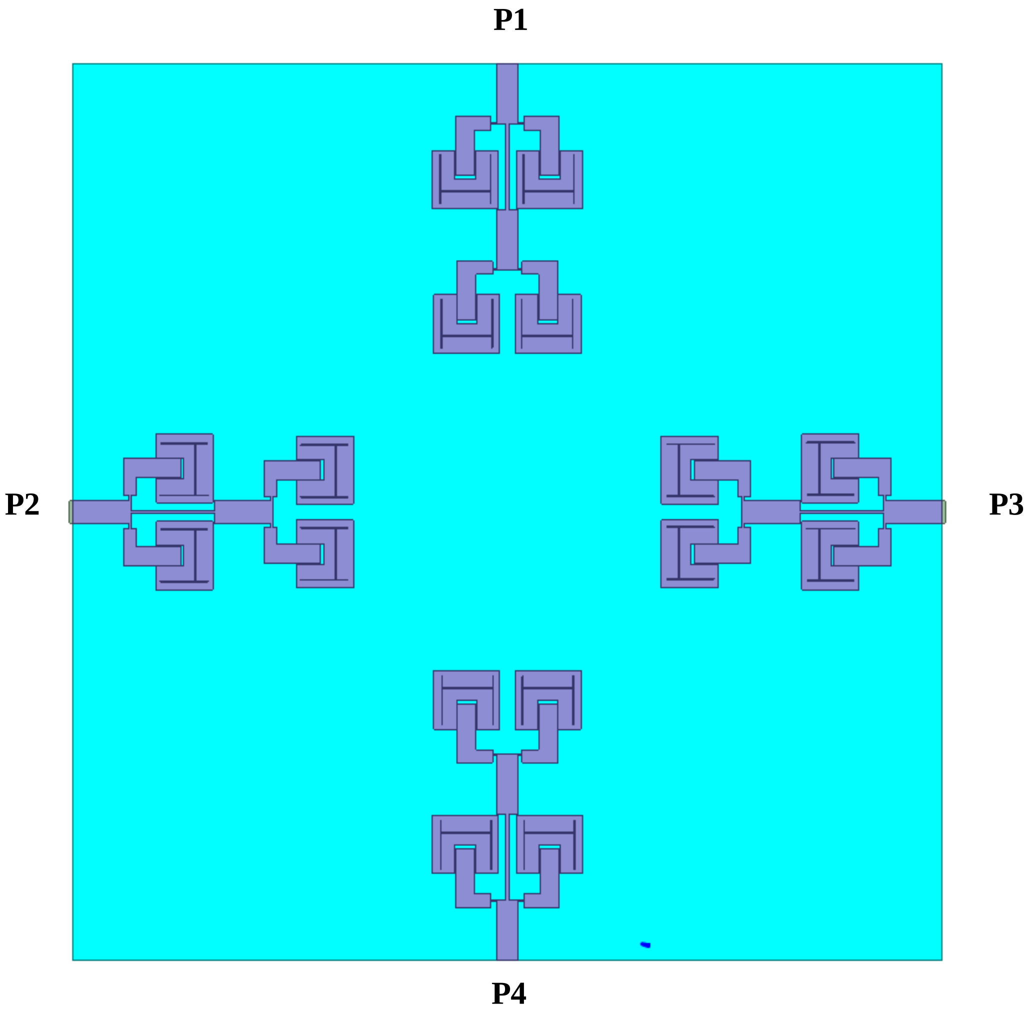


Figure III.1 : Handset design case 1

Figures (III.2) to (III.5) show the simulation of mutual coupling results between the ports of the antennas. the mutual coupling simulated result between the ports (1,2,3,4) is better than -30 dB. So, in this design, the distances between the arrays in the MIMO configuration are suitable and all the simulated mutual coupling results are acceptable as noticed from the graphs.

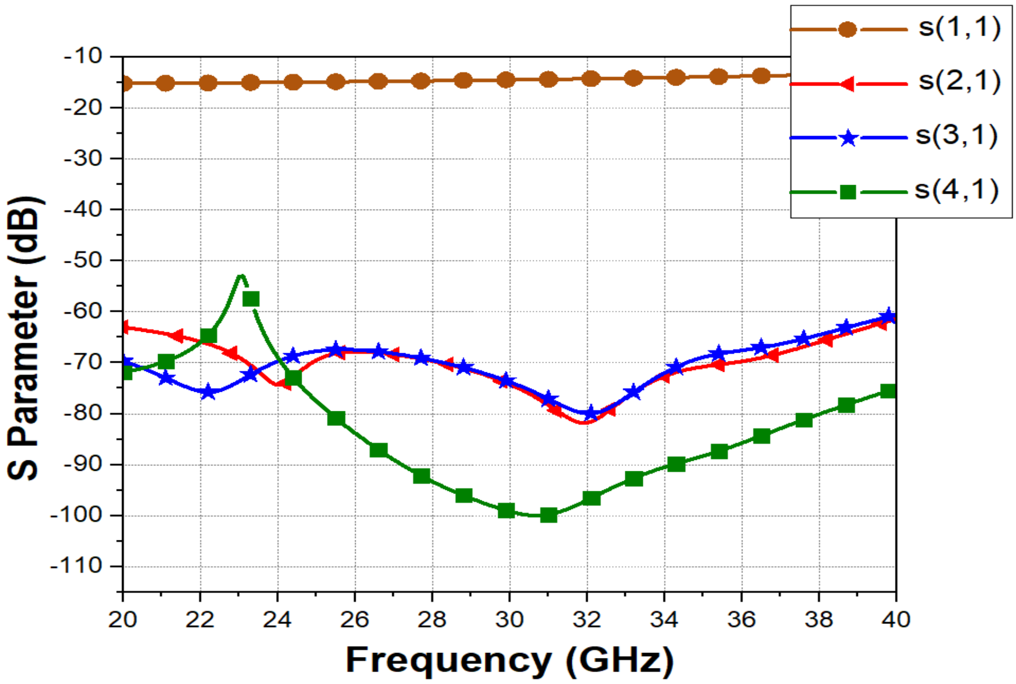


Figure III. 2: Mutual coupling between arrays (Port 1excited)

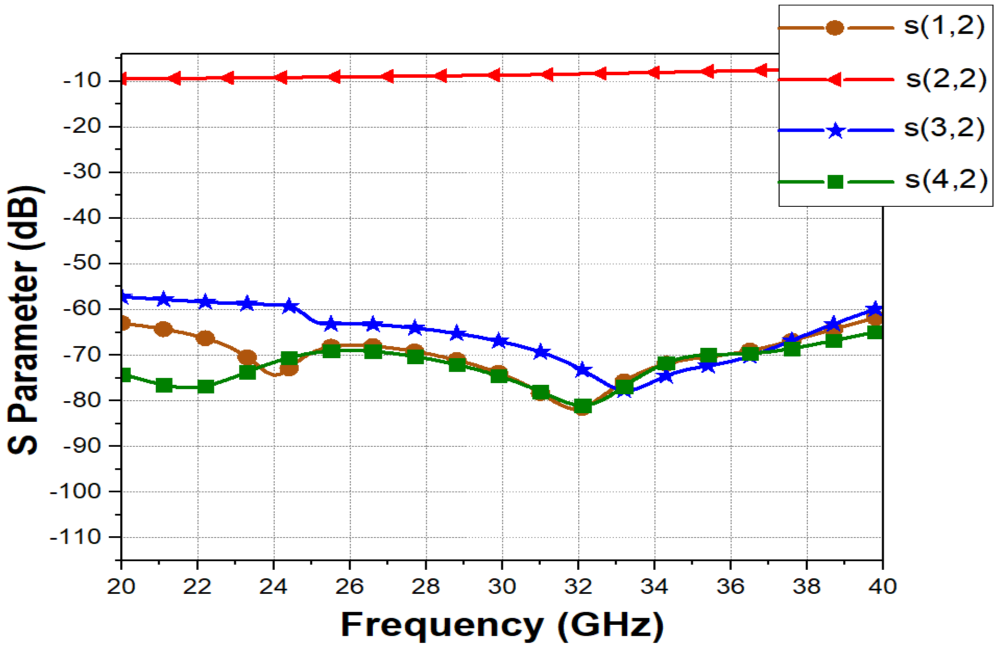


Figure III. 3: Mutual coupling between arrays (Port 2 excited)

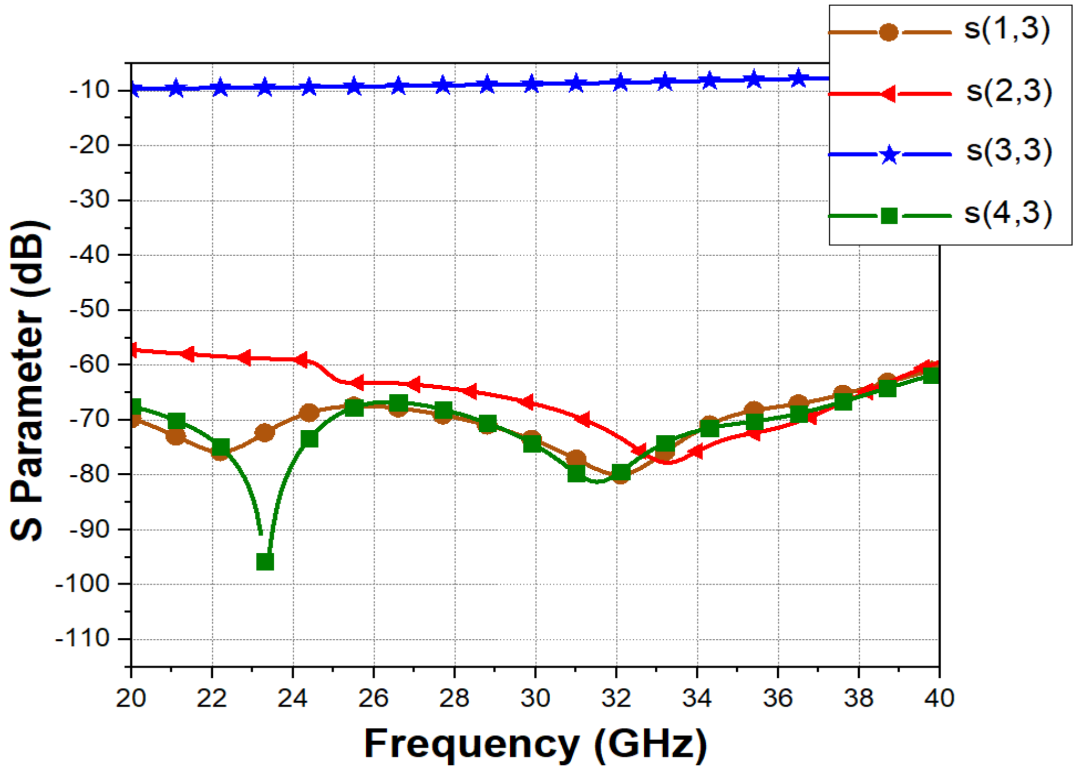


Figure III. 4 : Mutual coupling between arrays (Port 3 excited)

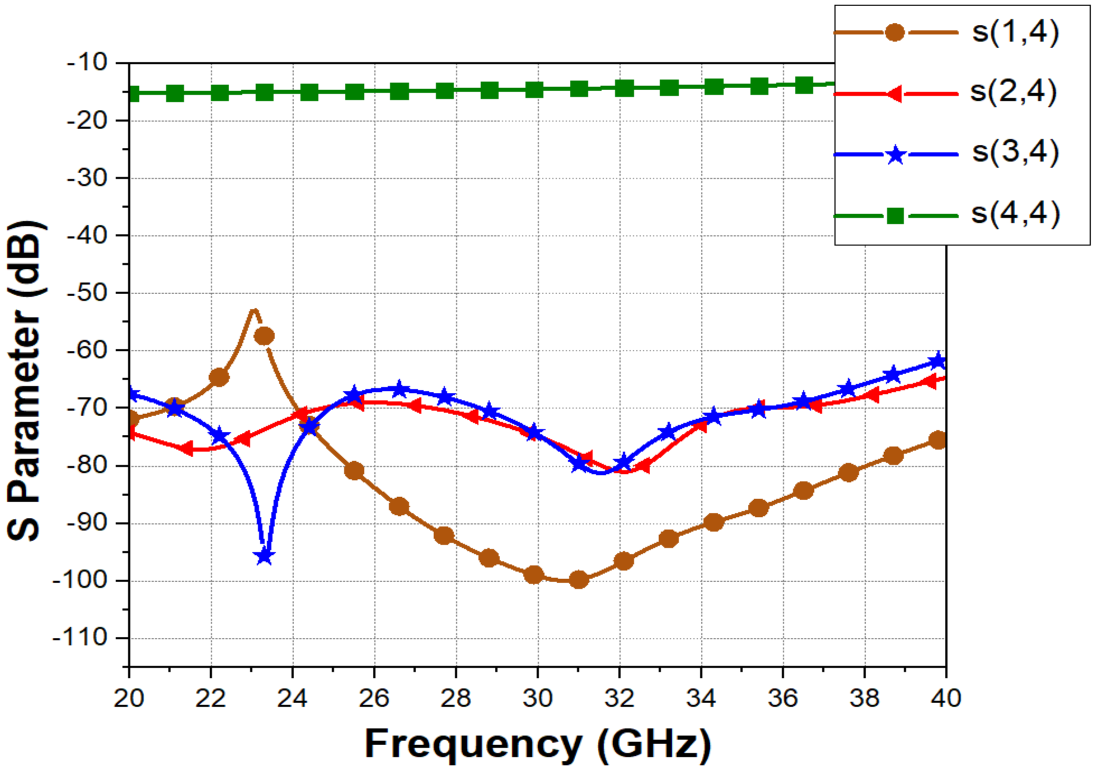


Figure III. 5: Mutual coupling between arrays (Port 4 excited)

Handset Design case 2

Here, we have used 4-element antenna arrays in the handset design as depicted in Figure III.6 The design has four arrays, two of them are put on the upper horizontal edge of the handset and the other two arrays are put on the right vertical edge of the handset with suitable distances between the patches.

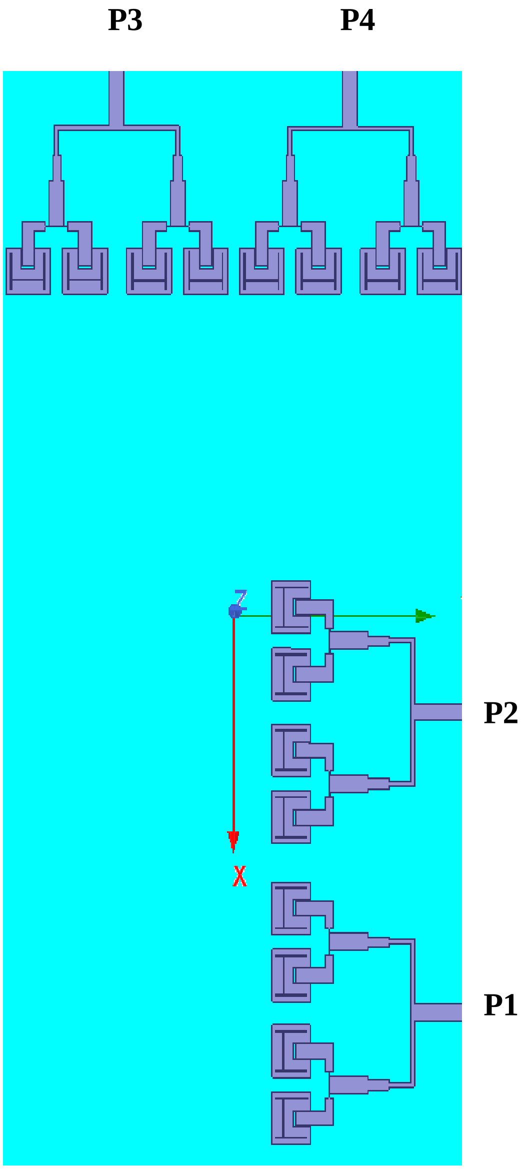


Figure III. 6: Handset design case 2

The distribution of the antenna gave the dual polarization feature to the design were the patches on the horizontal size served the vertical polarization and the side patches served the horizontal polarization. Also, the proposed structure supports MIMO technology, and also achieves dual-band operation, sufficient gain (>10 dB) and sufficient bandwidth (>1GHz). Hence, the proposed antenna design is a good candidate for handsets for 5G Communication system.

Figures (III.6) to (III.7) show the simulation of mutual coupling results between the ports of the antennas. The nearest ports to each other are port 1 and port 2 and the mutual coupling simulated result between them is better than -30 dB. Generally, in this design, the distances between the arrays in the MIMO configuration are suitable and all the simulated mutual coupling results are acceptable and better than -30 dB as noticed from the graphs.

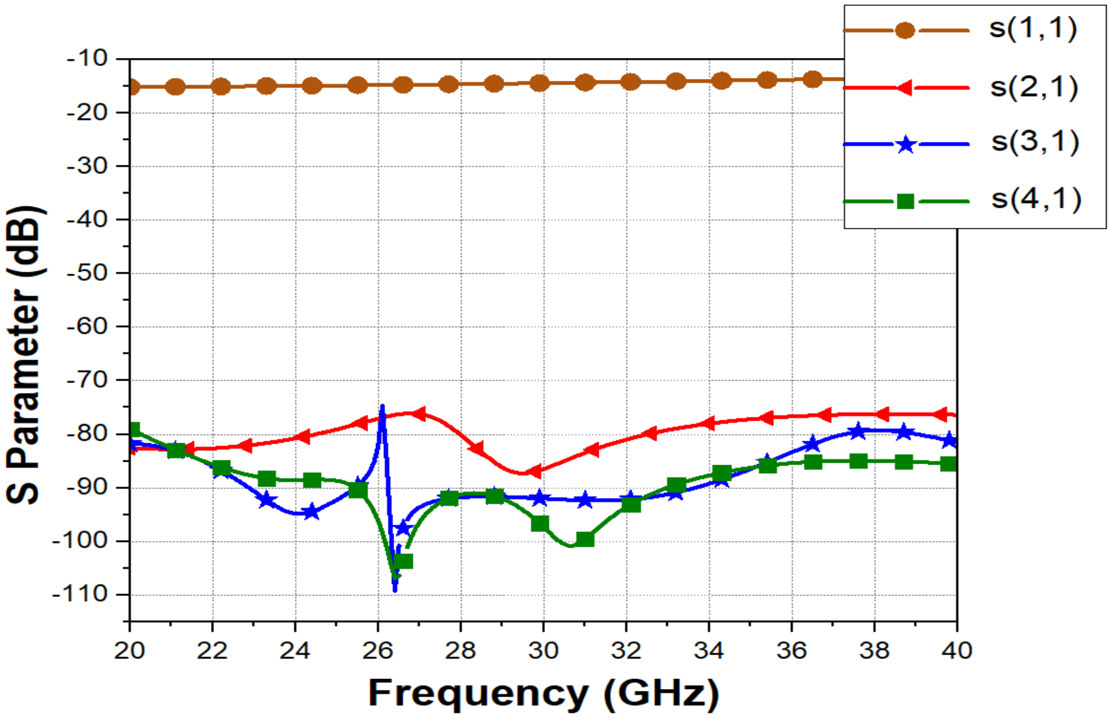


Figure III. 7: (case 2) Mutual coupling between arrays (Port 1 excited)

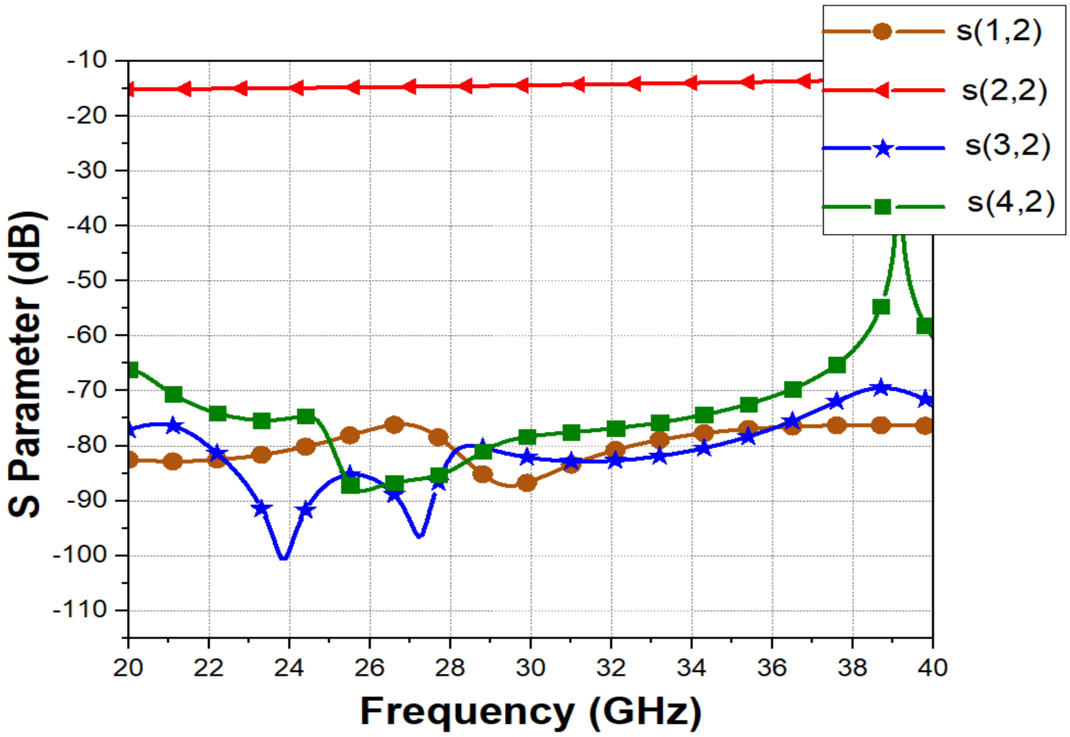


Figure III. 8: (case 2) Mutual coupling between arrays (Port 2 excited)

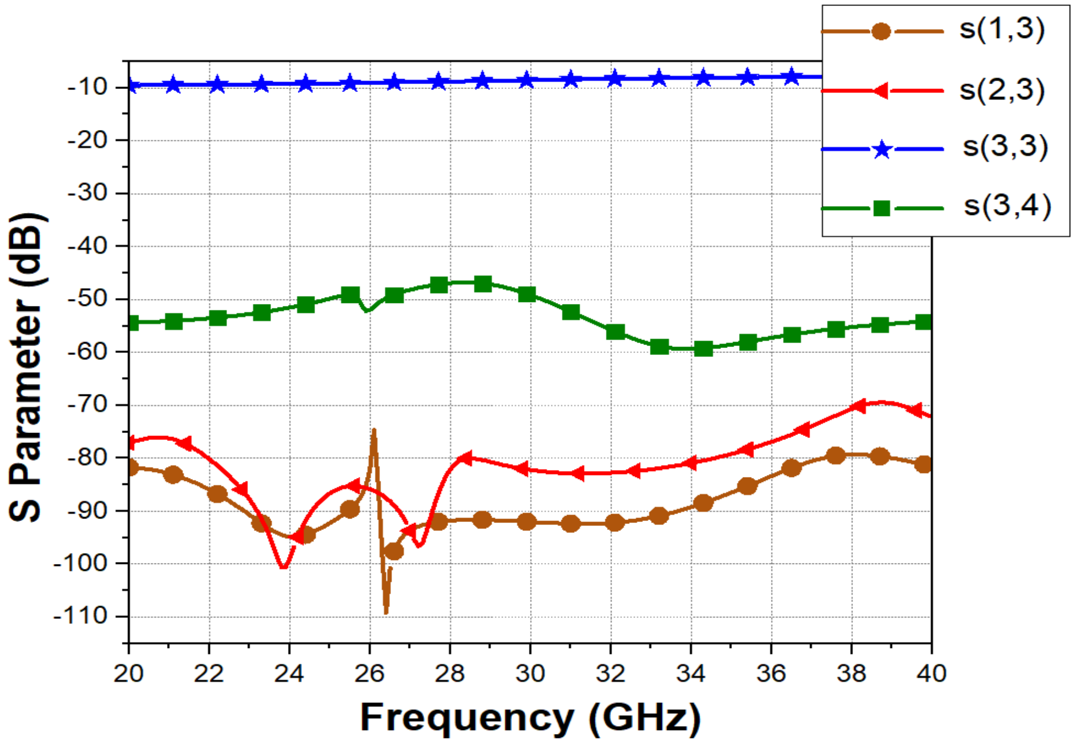


Figure III. 9: (case 2) Mutual coupling between arrays (Port 3 excited)

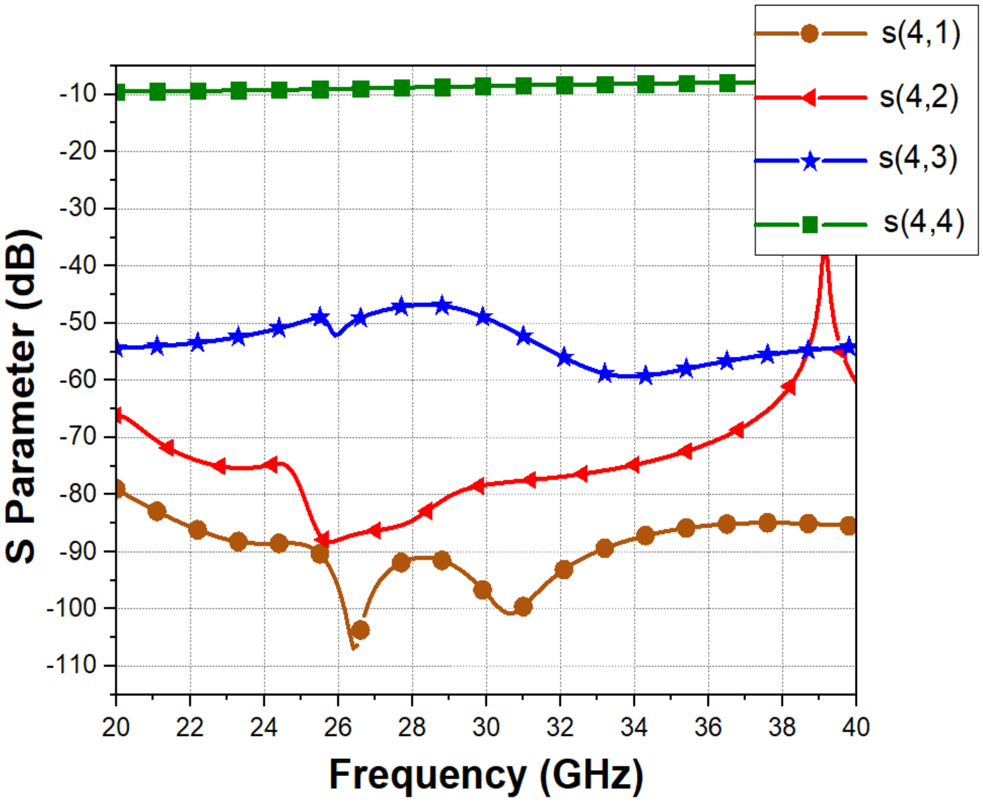


Figure III. 10: (case 2) Mutual coupling between arrays (Port 4 excited)

III.3) Conclusion

In this chapter, a proposed antenna two designs of modern handset have been presented. The MIMO concept is taken into consideration also other features of the 5G communications system, the design have we presented gives a good results witch the mutuel coupling between the arrays less than -30 dB which means low interference and good cover.

Conclusion

In conclusion, the development of a dual-band, dual-polarization microstrip antenna array represents a significant advancement in meeting the demanding requirements of 5G wireless communication systems. By operating at frequencies between (28 GHz,38 GHz) within a compact size of less than 2.4 cm, the antenna demonstrates exceptional performance characteristics essential for 5G applications.

The integration of an H-shaped slot in the single patch antenna enables dual-band functionality, while the array configuration enhances gain and directivity, surpassing the requisite 12 dB gain threshold for 5G communication systems. Furthermore, the addition of a phase shifter allows for beam steering capabilities, enhancing the adaptability and versatility of the antenna array.

With a bandwidth exceeding 1.5 GHz at both resonant frequencies and mutual coupling below -20 dB, the antenna array design exhibits robust performance metrics. Moreover, the adaptation of the four-element design to create a dual-band, dual-polarization antenna for smartphone devices underscores the versatility and applicability of the proposed design approach.

Overall, the successful development and optimization of the dual-band, dual-polarization microstrip antenna array represent a significant contribution to the advancement of 5G wireless communication technology. With its compact size, robust performance, and adaptability to diverse applications, the antenna array holds promise for enabling enhanced connectivity and communication capabilities in the era of 5G and beyond.

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