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THEME

Design of metamaterial-based MIMO antenna for 5G application

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Abstract

Metamaterial-based MIMO (Multiple-Input Multiple-Output) antennas have gained significant attention in recent years due to their ability to enhance the performance of wireless communication systems. Metamaterials are artificial materials that possess unique electromagnetic properties, which can be tailored to improve the antenna's characteristics. This paper presents an abstract on metamaterial-based MIMO antennas and their potential applications in wireless communication systems. The proposed design utilizes a combination of metamaterial structures, such as split-ring resonators (SRR), to achieve improved antenna performance. The MIMO configuration provides multiple signal paths, which can increase the data transmission rate and reduce interference. The proposed design has been simulated using logical of simulation, and the results show that the metamaterial-based MIMO antenna offers enhanced performance compared to traditional MIMO antennas. The proposed design is suitable for various wireless communication applications, including 5G networks.

Keywords: Metamaterial, MIMO Antenna, 5G, SRR.

Résumé :

Les antennes MIMO à base de métamatériaux (Multiple-Input Multiple-Output) ont suscité une attention considérable ces dernières années en raison de leur capacité à améliorer les performances des systèmes de communication sans fil. Les métamatériaux sont des matériaux artificiels qui possèdent des propriétés électromagnétiques uniques, qui peuvent être adaptées pour améliorer les caractéristiques de l'antenne. Cet article présente un résumé sur les antennes MIMO à base de métamatériaux et leurs applications potentielles dans les systèmes de communication sans fil. La conception proposée utilise une combinaison de structures de métamatériaux, telles que des résonateurs à anneau fendu (SRR), pour obtenir des performances d'antenne améliorées. La configuration MIMO fournit plusieurs chemins de signal, ce qui peut augmenter le taux de transmission des données et réduire les interférences. La conception proposée a été simulée à l'aide de la simulation logiciel de simulation, et les résultats montrent que l'antenne MIMO à base de métamatériaux offre des performances améliorées par rapport aux antennes MIMO traditionnelles. La conception proposée convient à diverses applications de communication sans fil, y compris les réseaux 5G.

Mots-clés : Métamatériel, Antenne MIMO, 5G, SRR.

ملخص :

اكتسبت هوائيات MIMO (متعددة المدخلات والمخرجات) القائمة على المواد الفوقية اهتمامًا كبيرًا في السنوات الأخيرة نظرًا لقدرتها على تحسين أداء أنظمة الاتصالات اللاسلكية. المواد الفوقية هي مواد اصطناعية تمتلك خصائص كهرومغناطيسية فريدة يمكن تكييفها لتحسين خصائص الهوائي. تقدم هذه الورقة ملخصًا عن هوائيات MIMO القائمة على المواد الفوقية وتطبيقاتها المحتملة في أنظمة الاتصالات اللاسلكية. يستخدم التصميم المقترح مجموعة من الهياكل الخارقة ، مثل الرنانات ذات الحلقة المشقوقة (SRR)، لتحقيق أداء هوائي محسن. يوفر تكوين MIMO مسارات إشارات متعددة ، والتي يمكن أن تزيد من معدل نقل البيانات وتقليل التداخل. تمت محاكاة التصميم المقترح باستخدام محاكاة HFSS ، وأظهرت النتائج أن هوائي MIMO القائم على المواد الفوقية يوفر أداءً محسنًا مقارنة بهوائيات MIMO التقليدية. التصميم المقترح مناسب لمختلف تطبيقات الاتصالات اللاسلكية ، بما في ذلك شبكات 5G.

الكلمات المفتاحية: المواد الخارقة , الهوائي , الرنانات ذات الحلقة المشقوقة

Dedications

To my parents, for your love, your patience and generosity, I dedicate this work to you in testimony of my great gratitude and my eternal love.

To my dear sisters Imane and Nada, I wish them success in their lives, I love you very much.

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KhaliDa

Dedications

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List of Abbreviations

1G: First Generation Wireless Systems

2G: Second Generation Wireless Systems

3G: Third Generation Wireless Systems

4G: Forth Generation Wireless Systems

5G: Fifth Generation Wireless Systems

B.W: Bande With

CSRR: Complementary Split-Ring Resonator

DNG: Double Negative Materials

EBG: Electromagnetic Band Gap

ENG: Epsilon Negative Media

MIMO: Multiple Input Multiple Output

MISO: Multiple Input Single Output

mMTC: Machine-Type Communication

MNG: Mu- Negative Media

PIFA: Printed Inverted F-Antenna

RF: Radio Frequency

S11: Reflection Coefficient

SIMO: Single Input Multiple Output

SNG: Single Negative Materials

SRR: Split-Ring Resonator

URLLC: Ultra-Reliable Low-Latency Communication

Wi-Fi: Wireless Fidelity

ϵ_r :Relative Permittivity

ϵ_{eff} :Effective Dielectric Constant.

Introduction

Wireless communication systems are rapid growing systems in industry specially the cellular systems. In **2020**, the number of mobile phone users in the world is 6.95 billion and it is expected to reach 7.49 billion at the end of **2025**.

The term wireless communication literally consists of two words: the first is communication, which means sending and receiving different messages between two points. The second word is "wireless", meaning there is no physical connection between the two connection points and there is no cable between them. Based on the above, we can define wireless communication as a communication process between two different points without a tangible connection between them.

In the pre-industrial era, wireless communication was used by the means available in it. Smoke signals, light signals, reflective lenses, audio signals, and various other methods of communication were used, but all these old systems were suffering from the lack of distance between the different communication points, and there must be a clear line of sight between the transmitter and the receiver.

In **1895**, radio communication was born, where Marconi transmitted the first radio signal (electromagnetic signal) for about 18 Km, so all the early wireless communication methods were replaced by radio communication systems. The early radio communication systems used analog signals in transmitting, but nowadays most of the wireless communication systems use digital signals which are composed of binary bits (**Andrea Goldsmith, 2005**). [1].

Due to this thesis we aimed to achieve all the important features of the recent wireless communication systems by designing a dual band, multiple-input multiple-output MIMO micro-strip antenna for serving the 5G communication systems. The proposed antenna will design to operate at high frequency (mm-waves) which is 28GHz. The 5G main features must be satisfied in the proposed design like, dual polarization, high bandwidth (>1 GHz) and high realized gain (>12 dB) [2]

Antenna array structures are also proposed in this thesis for enhancing the directivity and achieving the required realized gain of the antenna for the 5G communication systems. Beam steering capability will also be achieved by inserting a phase shifter (transmission line) into the final design. This proposed modification aims to add the ability for tilting the main radiation pattern to particular direction at the both resonant frequencies.

Metamaterial has received great interest during the last ten years in distinct field, owing of its key characteristics such as enhancement in bandwidth, radiated power, directivity and controls the direction of electromagnetic radiation. It is a smart or a new class of manmade invented materials that can achieve electromagnetic properties that do not occur naturally, such as electromagnetic cloaking or negative index of refraction.

The metamaterials have enabled the development of new devices and concepts and possible utilization in diverse novel applications (medical sector, automotive, aerospace...), and many other devices (biosensor, crowd control, absorbers, antennas, optical filters, infrastructure monitoring, smart solar power management, energy harvesters and even shielding structure from earthquakes..., etc.).

Finally, will be design of metamaterial-based MIMO antenna for 5G application.

Chapter I:

MIMO Antenna

I.1 Introduction

In recent years, wireless communication has become an essential part of our daily lives. With the increasing demand for high-speed data transmission, multiple-input multiple-output (MIMO) technology has emerged as a promising solution to improve the capacity and reliability of wireless communication systems [1]. MIMO antennas are a key component of MIMO systems, providing multiple antenna elements to transmit and receive data over the same frequency band. This memoire aims to provide a comprehensive understanding of MIMO antennas, including their working principle, configurations, and optimization techniques. [3]

In this chapter, we will clarify what MIMO antennal is and his types. We also summarize how to work in 5G.

I.2 MIMO Systems

The need to transmit information in complex environments while increasing throughput has given rise to an original solution that uses not only several antennas in reception but also in transmission.

This technique known as MIMO allows using the same spectral band to transmit more throughput or improve the quality of the link. Several techniques are proposed in the literature. There are several antennas here in transmission and in reception; the MIMO (Multiple Input Multiple Output) configuration is the most general, it includes MISO (Multiple Input Single Output) and SIMO (Single-Input Multiple-Output) systems as special cases [4].

The MIMO system is the place for communication engineers to open after a third connection « spatial dimension »

I .2.1 Spatial Multiplexing

- The possibility of sending packets of different information on each communication channel separately.
- Double the amount of information sent [5].

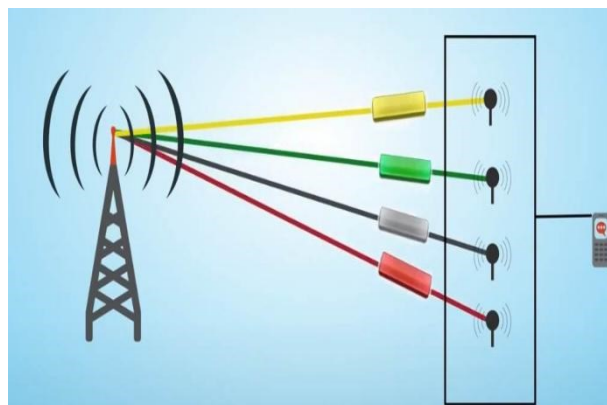


Figure (I.1): Spatial Multiplexing.

I.2.2. Diversity

-During the transmission process, data may be subject to distortions.

- The principle of **diversity** is to send copies of data on more than one communication channel, then the receiver comparison between copies in order to extract the original data.

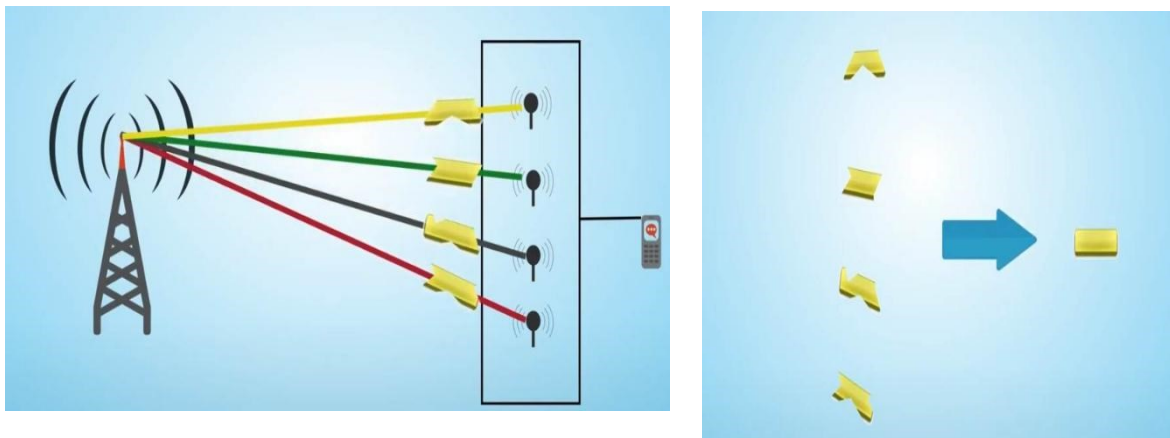


Figure (I.2): Diversity.

I.2.3. Beamforming

“Transmission wave interference “ [6]

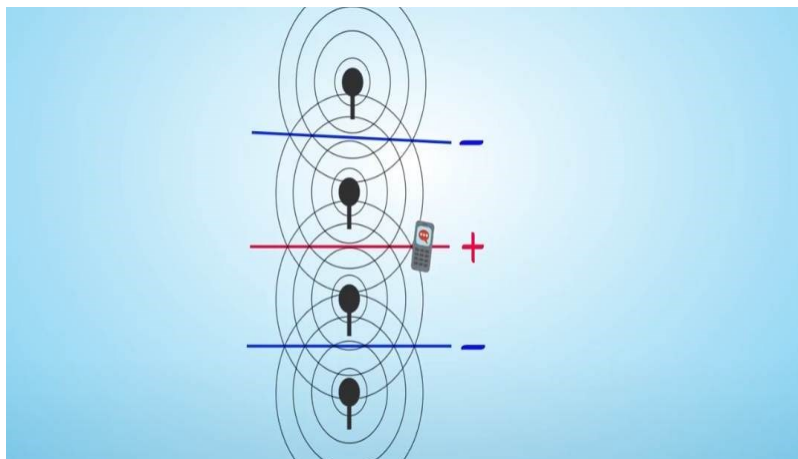


Figure (I.3): Beamforming.

I.3 MIMO antenna

I.3.1 Definition

A MIMO antenna is a type of antenna that uses multiple antennas to transmit and receive signals simultaneously. This helps to improve the performance and speed of wireless communication systems, such as Wi-Fi, cellular networks, and satellite communication systems. MIMO antennas are commonly used in routers, modems, and other wireless devices to provide faster and more reliable wireless connectivity. They are also used in vehicles, aircraft, and ships to improve the quality of wireless communication in these environments [7].

I.3.2 Types of Antennas

MIMO antennas are a type of directional antenna, which means they focus their signal in a specific direction. They can be designed depending on the application and frequency range:

2-2-1) patch antenna:

Patch antennas come in various shapes and sizes and consist of a patch of metal directly above a ground plane. Figure 0. shows an example of a patch antenna. For example, some patch antennas are approximately half a wavelength on each side. The polarization can be either circular or linear depending on the design of the patch. In a patch antenna, most of the propagation is above the ground plane and can have high directional gain [8].

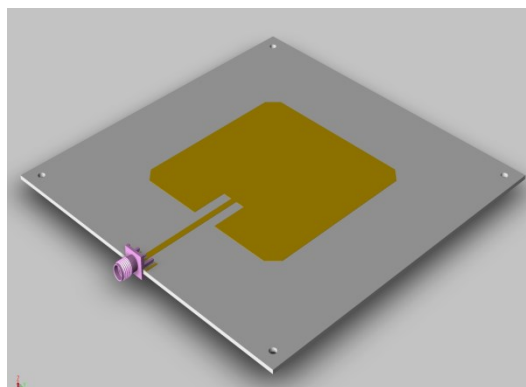


Figure (I.4): Patch Antenna.

2-2-2) dipole antenna:

A dipole antenna is defined as a type of RF (Radio Frequency) antenna, consisting of two conductive elements such as rods or wires. The dipole is any one of the varieties of antenna that produce a radiation pattern approximating that of an elementary electric dipole [9].

Dipole antennas are the simplest and most widely used type of antenna.

MIMO antennas can have multiple elements, such as two, three, or four antennas, which are arranged in a specific pattern to optimize the signal transmission and reception.



Figure (I.4): Dipole Antenna.

I.3.3 Working Principle of MIMO antenna

MIMO antennas work by exploiting the spatial diversity of the wireless channel. Instead of relying on a single antenna to transmit and receive data, MIMO systems use multiple antenna elements to create multiple spatial streams. Each antenna element is connected to a separate radio frequency (RF) chain, which is controlled by a signal processing algorithm that optimizes the transmission and reception of data.

At the transmitter side, the signal processing algorithm divides the data into multiple streams and maps each stream to a separate antenna element. The signals from each antenna element are combined at the receiver side using signal processing algorithms that take into account the channel characteristics and interference. This results in improved signal quality and higher data rates.

I.3.4 MIMO Antenna Configuration

MIMO antennas can operate in different configurations, depending on the number of antenna elements used. The most common configurations are 2x2, 4x4, and 8x8, which refer to the number of transmit and receive antenna elements. For example, a 2x2 MIMO system uses two transmit and two receive antenna elements, while an 8x8 MIMO system uses eight transmit and eight receive antenna elements.

The choice of MIMO antenna configuration depends on various factors such as the available bandwidth, the distance between the transmitter and receiver, and the desired data rate. Higher-order MIMO configurations offer higher capacity and data rates but require more complex signal processing algorithms and hardware.

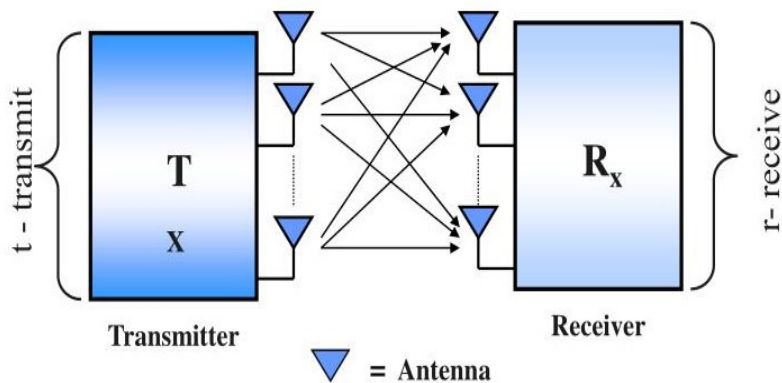


Figure (I.5): Configuration MIMO Antenna axa.

I.4 Literature Review

I.4.1 5G MIMO Antenna

A compact wide-band MIMO antenna has been presented in (Wang, Duan, Li, Wei, and Gong, 2017) [10]. Its operation band covers from 3 GHz to 30 GHz. In this paper, there are two designs. The first one is without slots and its S11 shows -20 dB and less at the range from 5 GHz to 10 GHz, and the most deep value is -45 dB at 8 GHz. The second one is

with slots and its S11 shows A -20 dB and less at the range from 3 GHz to 18 GHz, and the deepest value is -55 dB at 5.5 GHz. In the paper, a single element antenna had been designed. Multiple-element antenna is not addressed.

A dual band MIMO antenna for 5G handsets has been presented in (Dioum, Diop, Sane, Khouma and Diallo, 2017). The operation frequencies are 2.6 GHz and 3.6 GHz. The single element antenna has a suitable size for handsets and its S11 shows about -15 dB at 2.65 GHz and 3.75 GHz. The MIMO antenna has 4 elements and its S11 shows a deep value equal to -80 dB at 2.8 GHz. In this paper only a single element antenna had been designed [11].

A dual polarized cavity-backed aperture antenna for 5G MIMO applications has been presented in (Liu, Hsu, and Lin, 2015). The operation band is around 30 GHz. The structure of antenna is a combination of rectangular antenna and tapered slot antenna. The S11 shows -25 dB on the range from 25 GHz to 36 GHz. However, in this paper the designed antenna has a complex structure and it is not easy to fabricate. The proposed designs in this thesis are microstrip-based and they are easy to fabricate [12].

A compact tapered slot antenna array for 5G millimeter wave massive MIMO system has been presented in (Yang, Yu, Dong, Zhou, and Hong, 2016). The system has a good beam-forming performance because the space between array elements meets the requirement of half wavelength. The operation band of antenna array is from 22.5 GHz to 32 GHz. The S11 is -10 dB along the operation band and the deep value of it is about -35 dB which is from 25 GHz to 30 GHz. In this paper, the antenna size is about 6 cm and it cannot be used for mobile handset [13].

I.4.2 5G Antenna for Handsets

An end-fire phased array antenna has been presented in (Parchin, Shen and Pedersen, 2016). The single element antenna has leaf bow-tie shape and it served the (28 GHz, 38 GHz) bands. Its S11 is -20 dB at 28 GHz and -30 dB at 38 GHz. The MIMO antenna has eight elements of leaf shaped bow-tie antenna which form a linear phased array. In this paper, 9-11 dB gain was achieved [14].

A compact MIMO antenna system has been presented in (Thomas, Veeraswamy and Charishma, 2015). There are two antenna elements employed in the system. The first one

has rectangular shape and the second has circular shape. The 8 combinations of these two antennas serves a group of frequencies (1.50 GHz, 2.2 GHz, and 28 GHz). A single band PIFA antenna has been presented in (Haraz, Ashraf and Alshebeili, 2015). It has three rectangular shape elements located at the same line and separated by an equal distance between their centers. The antenna serves 28 GHz frequency and its S11 is -25 dB at this frequency. The peak gain of it is 6.06 dB. This designed is served single band only and array structure has not been used. The proposed antenna design in this thesis uses the array structure and serves dual bands [15].

A dual band MIMO antenna with folded structure for 5G mobile handsets has been presented in (Shi, Zhang, Xu, Liu, Wen, and Wang, 2017). The antenna consists of 8 elements located on the orthogonal frame corner of substrate. The operation bands are (3.4 GHz – 3.6 GHz) and (4.55 GHz – 4.75 GHz) and its S11 is -35dB at the first range and -25dB at the second one. In this design, they used short neutral line to reduce the mutual coupling at both bands. In this paper, the array structure is not used and also their design does not support higher 5G frequencies (28 GHz).

An eight-port dual polarized MIMO antenna for 5G smartphone applications has been presented in (Li, Xu, Ban, Yang and Zhou, 2016). The operation band is (2.55 GHz-2.65 GHz). The antenna has a simple structure where the single elements of it has a square shape hollow from inside and the boarder width equal to 2mm. Its S11 is -35 dB at 2.6 GHz. In this paper, only a single element antenna has been designed and it also does not support higher 5G frequencies (28 GHz) [16].

A dual band antenna array with a circular polarization and beam steering capability features has been presented in (Mahmoud and Montaser, 2018). Its operation bands are 28 GHz and 38 GHz. The single element consists from three copper layers where the middle layer has T-shape feeding line every substrate layer has a hole for aperture feeding. This single element used in a 12-element array for a mobile handset where they were divided equally on top, right and left sides of the mobile. However, the fabrication of this design in not easy compared with the proposed antenna design in this thesis.

I.4.3 5G Antenna For base station

A compact millimeter wave massive MIMO has been presented in (Ali and Sebak, 2016). Its S11 is -17 dB at 28 GHz and -28 dB at 38 GHz. At 28/38 GHz the gain value is more than 12 dB at each band. Antenna elements are distributed in space for massive MIMO base station architecture with a radius of 25 mm. Total beams scanning of 360° is achieved by 12 switched elements [17].

A massive MIMO 5G small cell antenna with high isolation has been presented in (Liao, Chen and Sim, 2017). The operation band is (3.4 GHz – 3.6 GHz) and the cell has 8-ports. The single element has T-shaped bars which result to good isolation between the closed ports. However, the does not support operation at higher 5G frequencies such as 28 GHz [18].

A 5G phased patch antenna array for mobile base station has been presented in (Ishfaq, Abd Rahman, Yamada and Sakakibara, 2017). Its operation frequency is 28 GHz. The array consists from 8-elements connected by series fed technique. The base station also consists from 8 arrays, so the total number of elements is 64. The proposed antenna in this thesis serves dual band operation and used corporate feed technique which gives the ability to control the beam direction [19].

A conical frustum array antenna of multi polarization has been presented in (Mahmoud and Montaser, 2018). 5G dual bands had been served by the base station (28,38 GHz). Its 32-element array antenna had been distributed in conical frustum configuration and it achieved 8.17 dB gain. However, the base station design does not support MIMO technology.

A triple band indoor base station with dual polarization has been presented in (Alieldin, Huang, Boyes, Stanley, Joseph, Hua, and Lei, 2018). This base station is proposed for the 1G, 2G, 3G, 4G and 5G (sub-6 GHz) applications. The proposed antenna used in this base station consists from three types of dipoles where each type served one band. The fabrication of the antenna structure is not easy also the shortage of the bandwidth at sub-6 GHz causes reduction of the data rate of the system [20].

A 5G massive MIMO antenna system for a triangular 72- port base station with switched beam steering feature has been presented in (Al-Tarifi, Sharawi and Shamim,

2018). The base station dimensions are 120x60 cm. Every single port consists from 2x2 patch antenna array. The antenna consists from three metallic layers, the top one has the patches, the middle one is the ground layer and the bottom one has the feeding networks. The probe feed techniques used in the design [21].

I.5 The role of MIMO antenna in 5G

Antenna MIMO (Multiple Input Multiple Output) technology is an essential component of 5G networks. It enables multiple antennas to transmit and receive data simultaneously, thereby increasing the capacity and speed of the network, MIMO technology uses spatial diversity to improve the signal quality, by transmitting multiple signals through different paths.

In 5G networks, MIMO technology is used to support higher data rates, lower latency, and improved network reliability. It is also essential for supporting massive machine-type communication (mMTC) and ultra-reliable low-latency communication (URLLC) applications.

The antennas used in 5G MIMO systems are typically small and compact, designed to operate at high frequencies. They are often integrated into the device itself, such as a smartphone or tablet, or mounted on a base station.

* There are several types of MIMO antennas used in 5G networks, including:

1. Single-user MIMO (SU-MIMO): This technology uses multiple antennas at the transmitter and receiver to improve the signal quality for a single user [22].

2. Multi-user MIMO (MU-MIMO): This technology enables multiple users to transmit and receive data simultaneously using the same frequency band [22].

3. Massive MIMO: This technology uses a large number of antennas at the base station to support many users simultaneously [23].

Overall, antenna MIMO technology is a critical component of 5G networks, enabling higher data rates, improved network reliability, and support for new applications.

I.6 The Advantages of MIMO antenna

1. Increased data rate: MIMO antennas can increase the data rate by transmitting multiple streams of data simultaneously over the same frequency band.
2. Improved signal quality: MIMO antennas can reduce the effects of fading and interference, resulting in improved signal quality and reliability.
3. Better coverage: MIMO antennas can provide better coverage and range than single-antenna systems.
4. Enhanced capacity: MIMO antennas can support more users or devices at the same time, increasing the network capacity.

I.7 The disadvantages of MIMO antenna

1. Complexity: MIMO antennas are more complex than single-antenna systems, requiring additional hardware and software to manage the multiple antenna elements.
2. Cost: MIMO antennas are more expensive than single-antenna systems due to the additional hardware and complexity.
3. Power consumption: MIMO antennas require more power than single-antenna systems, which can be a concern for battery-powered devices.
4. Interference: MIMO antennas can experience interference from other nearby wireless devices or objects, which can degrade the signal quality.

I.8 Conclusion

MIMO antennas are a key component of MIMO systems, providing multiple antenna elements to transmit and receive data over the same frequency band. MIMO technology has revolutionized wireless communication by improving capacity and reliability. To achieve optimal performance, MIMO antennas must be properly configured and calibrated using specialized hardware and software. The optimization techniques discussed in this memoire can help improve the performance of MIMO systems, enabling high-speed data transmission and reliable wireless communication.

Chapter II:

The Metamaterial

II.1 Introduction

Metamaterial is a new and exciting technology that has the potential to revolutionize the field of wireless communication. It is an artificially engineered material that has unique electromagnetic properties, allowing it to manipulate electromagnetic waves in ways that are not possible with conventional materials. By incorporating metamaterials into MIMO antenna designs, it is possible to achieve higher gain, wider bandwidth, and better radiation efficiency, which can significantly improve the performance of wireless communication systems. This technology has the potential to transform the way we communicate wirelessly, enabling faster data transfer rates and more reliable connections in a variety of applications.

In this chapter, we will clarify what metamaterial is and report the recent progress on metamaterials. We also summarize the potential applications in areas such as antenna design.

II .2 Definition

The Metamaterial is a material engineered by man. Consisting of unit cells with an artificially designed structure of conventional materials, the latter consisting of atoms and molecules, see Figure 1, are the microscopic sources of the phenomena of polarization and magnetization [24].

Polarization microscopy consists of three mechanisms. The first is electronic polarization. It relates to the modification of the internal charge repartition of each atom or ion. It is constantly present, whatever the state of matter under study. The second is atomic or ionic polarization. It is about the displacement of atoms or ions relative to their equilibrium positions in the crystal edifice to which they belong. The third is the direction of polarization. It arises when an atomic or molecular dipole moment is directed under the influence of an electric field.

The origin of microscopic magnetization is the magnetic moments of microscopic electric currents caused by the movement and rotation of charged particles contained in atoms.

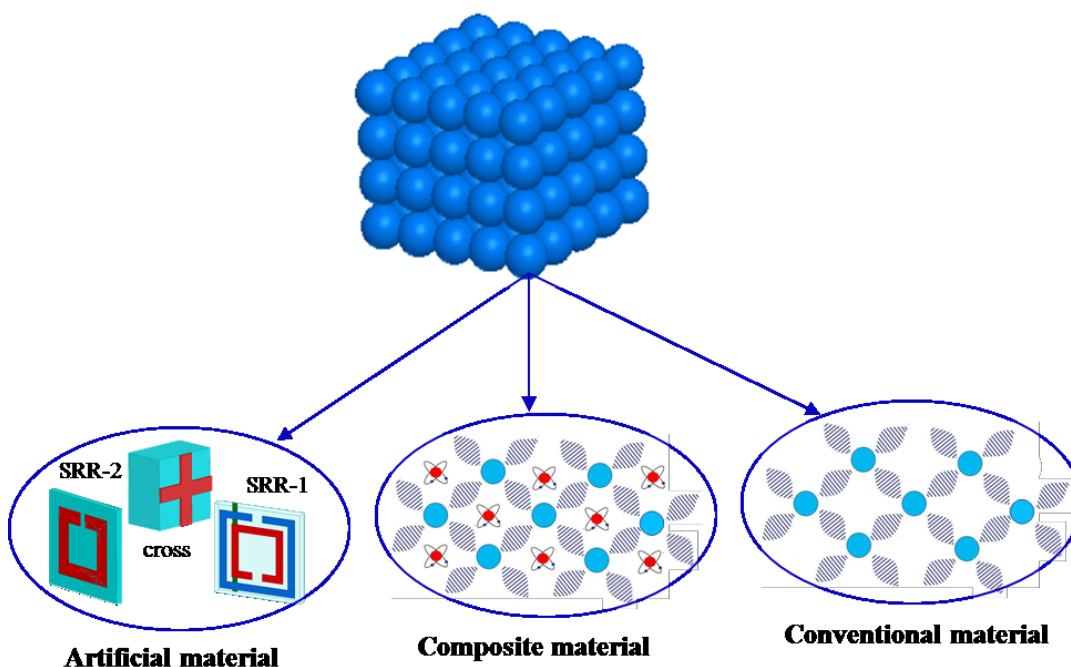


Figure (II-1): Unit cell types arranged in space compared to atomic scale in conventional materials.

II .3 Historical points for metamaterials

The concept of metamaterials was first proposed by the Soviet physicist Victor Veselago in 1968. He theorized that it was possible to create materials with negative refractive index, which would allow them to bend light in ways that were not possible with conventional materials [25].

However, it wasn't until the early 2000s that the first practical metamaterials were developed. In 2000, researchers at the University of California, San Diego created a material that could bend microwaves in the opposite direction to what was expected, demonstrating the negative refractive index predicted by Veselago.

Since then, researchers around the world have been working to develop metamaterials with a wide range of electromagnetic properties. These materials have been used in a variety of applications, including invisibility cloaks, superlenses, and high-performance antennas.

In recent years, advances in nanotechnology have enabled the development of metamaterials with even more complex and precise electromagnetic properties. As a result, the potential applications for these materials continue to expand, from improving wireless communication to developing new types of sensors and medical devices.

II .4 Characteristic of Metamaterial

Metamaterials have unique electromagnetic properties that are not found in natural materials. These properties are created by the arrangement of the material's structure on a microscopic scale, rather than by the chemical composition of the material itself.

Some of the key characteristics of metamaterials include:

1. Negative refractive index: Metamaterials can bend light in ways that are not possible with conventional materials. This is due to their negative refractive index, which allows them to refract light in the opposite direction to what is expected.

2. Tailored electromagnetic response: Metamaterials can be designed to have specific electromagnetic properties, such as the ability to absorb or reflect certain wavelengths of light.

3. Anisotropy: Metamaterials can have different electromagnetic properties depending on the direction of the incident light. This is known as anisotropy and is a result of the material's structure.

4. Subwavelength structure: Metamaterials have a structure that is smaller than the wavelength of the electromagnetic radiation they interact with. This allows them to manipulate light in ways that are not possible with natural materials.

5. Tunability: Some metamaterials can be tuned to change their electromagnetic properties in real-time. This makes them useful for applications such as adaptive optics and wireless communication.

II .5 Metamaterial Classes

Metamaterials can be divided into two major classes due to approaches to a mathematical description. The first class includes DNG and SNG-structures, whereas the second is PBG-structures or photonic crystals that also termed as photonic bandgap materials. As were mentioned above, the linear size of internal inclusions in DNG and SNG-materials is much smaller than the operating wavelength. Thus such media gen-early are lead to homogeneity and described with the concept of effective medium. The distance between the constituent elements in PBG-structures is equal to about half the wavelength or more. Therefore, photonic crystals cannot be considered as homogeneous media. They are usually described by Bragg reflection, which don't have an important role in DNG and SNG-structures, and other approaches to periodic media are used. After analyzing papers and monographs, which highlighting the basic metamaterial strategies for microwave applications, classification scheme shown in Fig. 3 have been made [26].

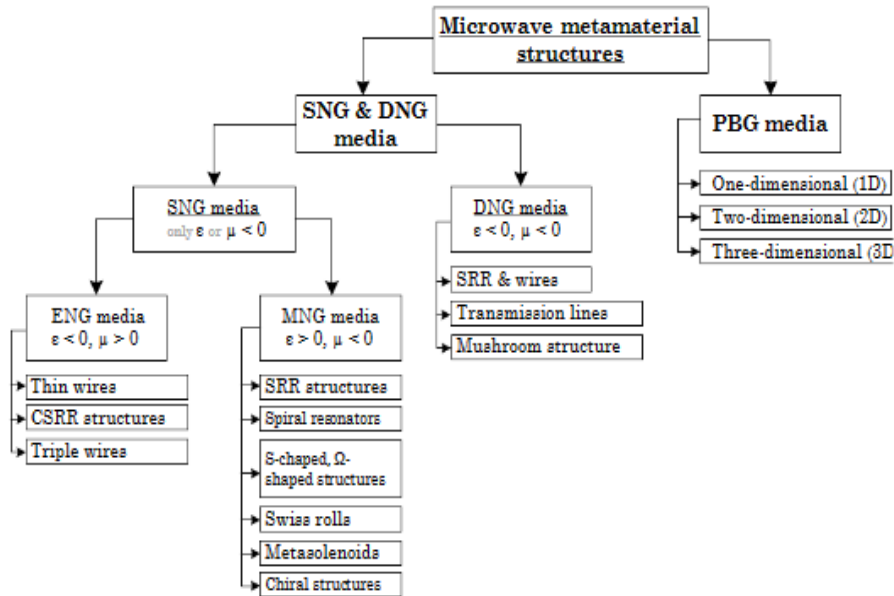


Figure (II-2): Metamaterial classes.

II .6 Metamaterial applications

Due to the exciting and unusual features, metamaterials have found and are finding a lot of applications. Metamaterials can impact on telecommunications, sensing and susceptibility as shown in, across all wave types, but especially electromagnetic and acoustic.

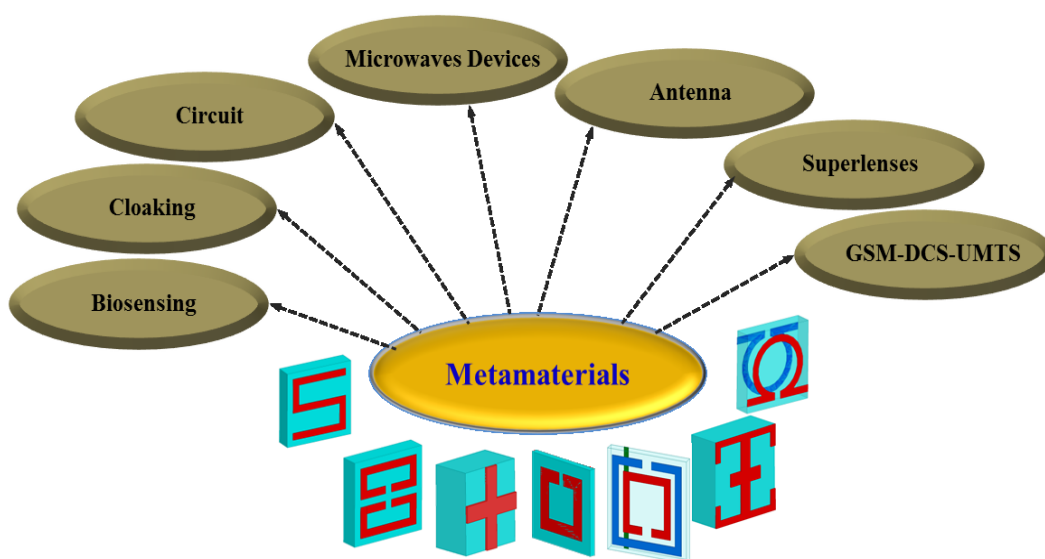


Figure (II-3): Metamaterial applications.

II-6-1. Cloaking devices:

Cloaking devices still attract more and more attention, particularly in the military field. The successful demonstrations of invisible cloaks experimentally in the microwave regime open the possibility to realize cloaking devices [27].

Metamaterials are a basis for attempting to create cloaking devices that can hide objects from electromagnetic radiation or sound waves. The cloak deflects microwave rays, so they circumvent the object inside with little distortion à making it appears almost as if nothing were there at all. Such a device typically involves surrounding the object to be cloaked with a shell which affects the passage of light near it

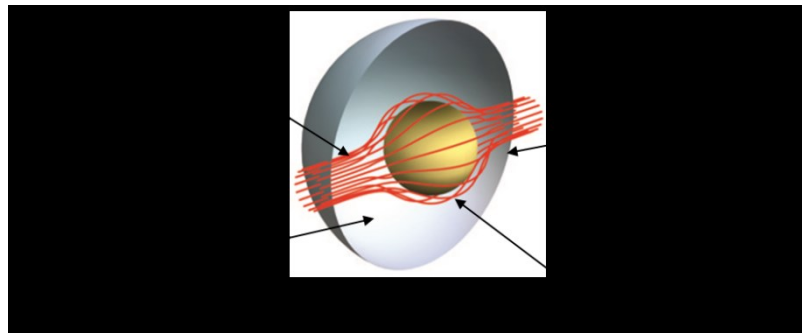


Figure (II-4): Invisibility cloaks.

II-6-2. Antennas:

Metamaterial antennas are a class of antennas used to create antennas that are smaller, lighter, and more efficient than conventional antennas, as well as to improve or increase antenna performance. Various metamaterial antenna systems can be employed to support surveillance sensors, communication links, navigation systems, command, and control systems [28].

The Metamaterials employed in the ground plane surrounding antennas offers improved isolation between radio frequency or microwave channels of (multiple-input multiple-output) MIMO antenna arrays. Metamaterial, high-impedance ground planes can also be used to improve the radiation efficiency, and axial radio performance of low-profile

antennas located close to the ground plane surface. also been used it to increase the beam scanning range by using both the forward and backward waves in leaky wave antennas.

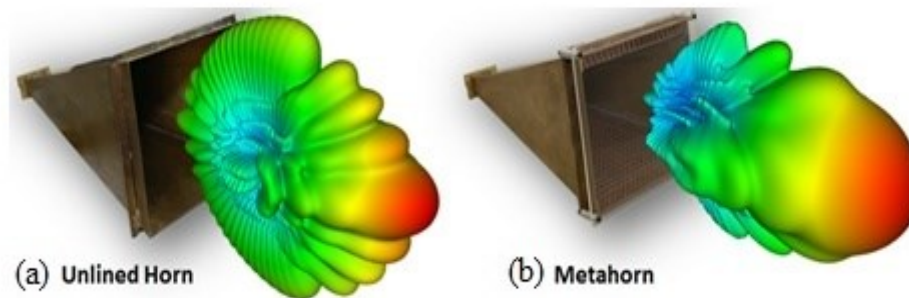


Figure (II-5): rectangular horn antenna (a)-alone (b)-with metamaterial.

II-6-3 Superlens:

The superlens is the most attractive feature for left-handed metamaterial, can be widely used in super resolution medical imaging, optical imaging, and nondestructive detections [29].

A super lens or perfect lens is a lens which uses metamaterials to go beyond the diffraction limit. The diffraction limit is an inherent limitation in conventional optical devices or lenses. In 2000, a type of lens was proposed, consisting of a metamaterial that compensates for wave decay and reconstructs images in the near field and most importantly the both propagating and evanescent waves contribute to the resolution of the image

In 2004, the first superlens with a negative refractive index provided resolution three times better than the diffraction limits and was demonstrated at microwave frequencies. In 2005, the first near field superlens which exceeded the diffraction limit was demonstrate.

The higher focusing resolution will be provided by flat LHM lens if compared to convex dielectric lens and elliptical reflector focusing system. The LHM lens has the potential to acquire higher imaging resolution and easy in-depth scanning, which will simplify the detection system design [30].

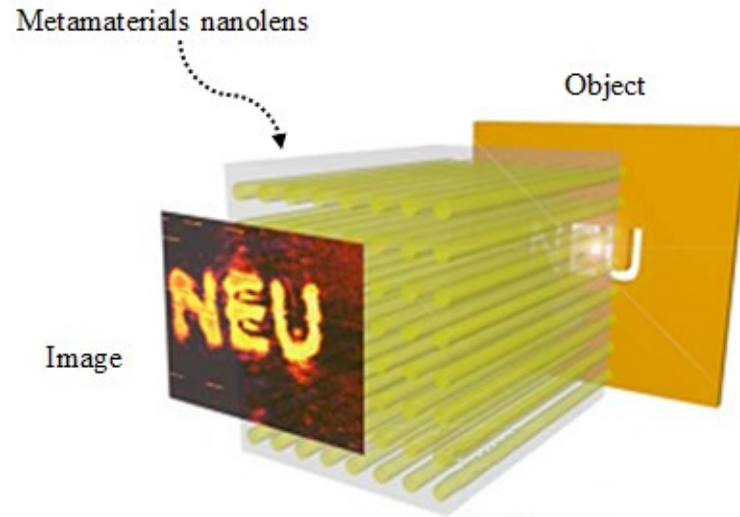


Figure (II-6): Super-resolution imaging using a three-dimensional metamaterials nanolens.

II-6-4. Sensors:

Sensors based on metamaterial absorbers are very promising when it comes to high sensitivity and quality factor, cost, and ease of fabrication. The absorbers could be used to sense physical parameters such as temperature, pressure, density as well as they could be used for determining electromagnetic properties of materials and their characterization.

Metamaterial-based sensors are very popular for its diverse applications in areas such as biomedical, chemical industry, food quality testing, agriculture. Split-ring resonators with various shapes and typologies are the most frequently used structures where the sensing principle is based on electromagnetic interaction of the material under test with the resonator. Overcoming the design challenges using metamaterial sensors involving several constraints such as cost, compactness, reusability, ease in fabrication, and robustness is also addressed.

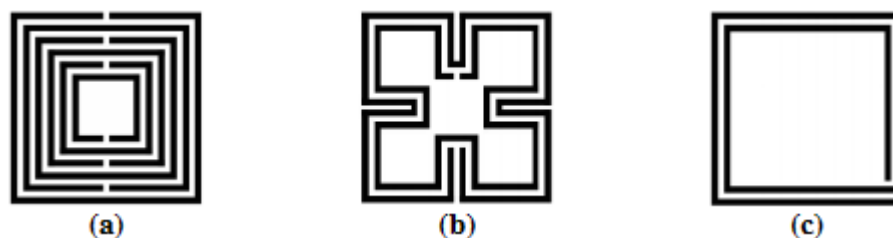


Figure (II-7): Metamaterial unit cells that are used for the sensor (a) Multiple SRR
(b) Sierpinski SRR (c) Spiral Resonator

II-6-5. Energy harvesting:

Recently it has been shown that the Metamaterials can be used to harvest energy from electromagnetic radiation or sound waves, especially in the field of energy scavenging at low intensity. Approaches include algorithmically arranged building blocks at the sub-micron level to achieve the desired order of response against incident energy.

II-6-6. Medical imaging:

Metamaterials can be used in medical imaging techniques such as MRI to improve image quality and reduce scan times.

II-6-7. Communications:

Metamaterials can be used to improve the performance of communication systems by enhancing signal strength and reducing interference.

II-6-8. Defense:

Metamaterials can be used in defense applications such as stealth technology, radar, and sonar.

II-6-9. Consumer electronics:

Metamaterials can be used in consumer electronics such as smartphones and laptops to improve performance and reduce size and weight.

II-6-10. Metamaterial as Absorber:

The first Metamaterial based absorber by Landy (2008) utilizes three layers, two metallic layers and dielectric and shows a simulated absorptivity of 99% at 11.48 GHz as shown in fig7. Experimentally, Landy was able to achieve an absorptivity of 88%. The difference between simulated and measured results were due to fabrication errors [31] [32].

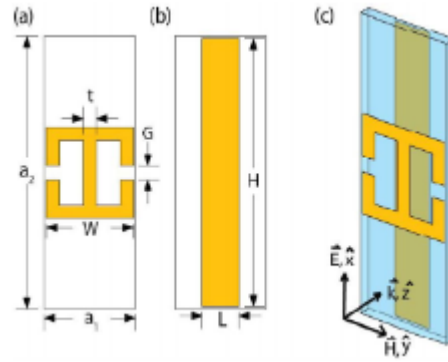


Figure (II-8): (a), (b)&(c) The unit cell is shown with its component

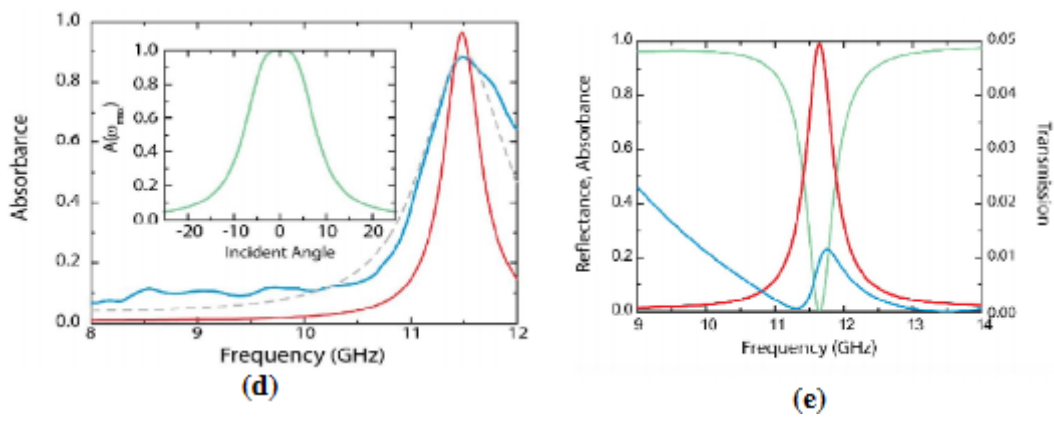


Figure (II-9): (d) Results after fabrication (e) Results after simulation.

II .7 EBG structures using metamaterial technology

II .7.1 Characteristics of EBG Structure

EBG structure is one of the metamaterials with the property to suppress electromagnetic wave (stop band) propagation in a particular frequency band. It is formed from unit cells composed of conductors and dielectrics arranged periodically in either a single row or columns of multiple cells.

Properties of the EBG structure are determined by the PCB material and pattern shape.

The characteristic of the EBG structure to block electromagnetic waves in a particular frequency band can be used in a variety of suppression needs such as mutual coupling between antennas, interference between circuit blocks and noise of a certain frequency [33].

II .7.2 Common EBG Structures

II .7.2.1 Mushroom EBG Structure:

Mushroom type EBG is a conventional three-dimensional EBG consisting of a solid patch with a cylindrical via (Figure (a) (II-7)). An example of the structure's transmission properties is shown in (Figure (c)(II-7)). Mushroom EBG structure configured in this way is known as a composite right/left-handed transmission line, and between the right-handed and left-handed frequency bands is the stop band.

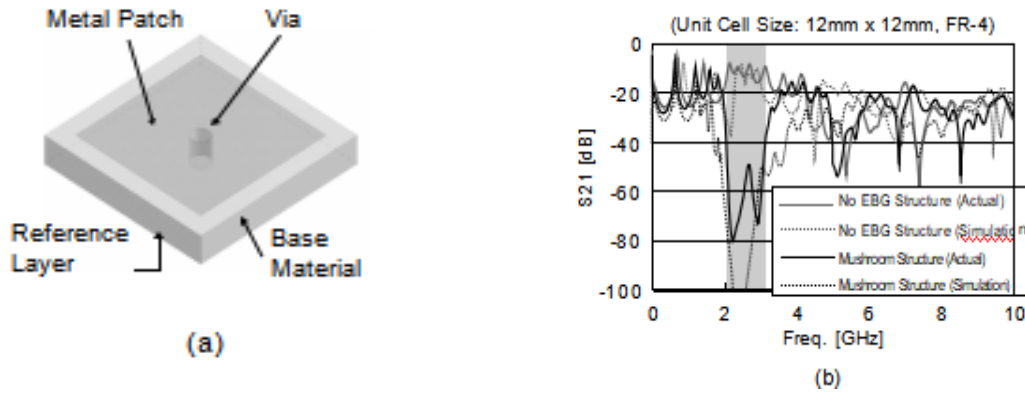


Figure (II-10): Mushroom EBG Structure(a), Example Transmission Properties of Mushroom EBG Structure(b).

The transmission response of mushroom type EBG depends upon the size of the patch, diameter of via and the gap between the unit elements. The transmission characteristic also depends upon the thickness of the substrate and the substrate material used. For a mushroom type EBG, the value of capacitance ‘C’, inductance ‘L’ and resonance frequency f_0 are given by (1), (2) and (3) respectively.

$$C = \frac{W \epsilon_0 (1 + \epsilon_r)}{\pi} \cosh^{-1} \left(\frac{W + g}{g} \right) \quad (1)$$

$$L = 2 * 10^{-7} h \left[\ln \left(\frac{2h}{r} \right) + 0.5 \left(\frac{2r}{h} \right) - 0.75 \right] \quad (2)$$

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \quad (3)$$

II .7.2.2 Via-less EBG Structure

Via-less EBG structure configured in this way can be viewed as periodically-arranged parallel circuits of inductors and capacitors with a stopband attributed to their resonance (Figure (a)(II-8)). Additionally, if the structure is considered in conjunction with the capacitive component formed between the opposing layers, it is possible to give the structure a stopband of the composite right/left-handed transmission line.

Via-less EBG structure does not require via or new layers, and it can be formed only with the patterning of the applicable layer [33].

In a via-less EBG structure, unit cells composed of metal patches and bridge lines to connect them are periodically arranged on a layer that opposes the reference layer (Figure (b)(II-8))

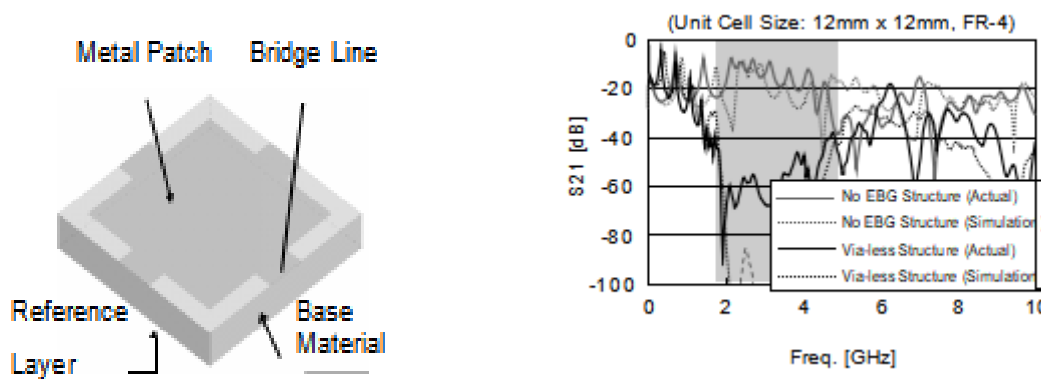


Figure (II-11): Via-less EBG Structure (a), Example Transmission Properties of Via-less EBG Structure (b).

II .7.3 EBG Applications

EBG structures are used as ground planes emulating Artificial Magnetic Conductors (AMC) in a narrow frequency range. and are used also to reduce the mutual coupling between elements.

II .7.3.1 EBG Ground plane

EBG structure has one important feature: the in-phase reflection coefficient for plane waves. This property can be used to design low-profile wire antennas [34]. The low-profile design usually refers to the antenna structures whose height is less than one-tenth.

II .7.3.2 Filters

Thanks to its frequency selective feature, this EBG structure can be used as a filter. By applying three elements as a ground plane for a microstrip line [35].

II.7.3.3 Mutual coupling reduction

The compact EBG structure is analyzed and its dispersion diagram is extracted. The EBG structure dimensions are optimized and inserted between the monopole antennas to reduce the mutual coupling between them.

II.8 The advantages of metamaterials

- Unique properties: Metamaterials have unique properties that are not found in natural materials, such as negative refractive index, which allows for the creation of cloaking devices and other advanced technologies.
- Customizability: Metamaterials can be designed and engineered to have specific properties and functions, making them highly customizable for various applications.
- Efficiency: Metamaterials can be more efficient than traditional materials in certain applications, such as energy harvesting and communication systems.
- Improved performance: Metamaterials can improve the performance of various technologies, such as antennas and sensors, by enhancing their sensitivity and selectivity.

II.9 The Disadvantages of metamaterials

- Limited availability: Metamaterials are still a relatively new technology and are not widely available, which can limit their use in certain applications.
- Complexity: The design and fabrication of metamaterials can be complex and require specialized knowledge and equipment.
- Cost: Metamaterials can be expensive to produce, which can limit their commercial viability in some applications.
- Environmental concerns: The production and disposal of metamaterials can have environmental impacts, which may need to be addressed in the future.

II.10 Conclusion

In conclusion, metamaterials represent a promising avenue for technological advancement. While there are some challenges associated with their development and use, the benefits they offer in terms of unique properties and improved performance make them a valuable area of research. As more is learned about these materials and their potential applications, it is likely that they will become increasingly important in a wide range of industries. Ultimately, the future of metamaterials looks bright, and their continued development holds significant promise for the world of science and technology.

Chapter III:

Design of Metamaterial based MIMO Antenna

III.1 Design of metamaterial-based MIMO antenna for 5G application

Introduction:

The main focus of interest of this chapter is the designing of metamaterial based of MIMO antenna,

Gain and directivity are important antenna parameters where the antennas are designed to transmit and receive signals in a designed direction, the single-element patch antenna has a relatively wide radiation pattern which means low gain and low directivity and hence single-element antenna will not satisfy the requirement of high gain in 5G systems. So, for enhancing the microstrip patch antenna an antenna array is designed and presented here. Antenna array is a collection of single-antenna elements which are connected together and work as one antenna. Increasing the number of single elements causes increasing the antenna gain and the directivity. It is not necessary to connect identical elements together to confirm antenna array but it is preferred for having easier fabrication, we use the EBG (electromagnetic band gap) we use this EBG structure to design an electromagnetic lens, which can be used on the same substrata of the microstrip antenna, for eliminated the surface wave and to enhance the antenna array performances

Finally, we have used 4-element antenna arrays in the handset design, to transmit or receive different signal by using various antennas at the same carrier signal. When the antenna is transmitting its electromagnetic wave, the wave takes different paths because of scattering environment (multipath propagation). So, in simple way we can define MIMO as the using of more than one antenna at the same time

III.1.1 Single element design:

To design a rectangular patch antenna for the application of the 5G communication system we follow the design procedure presented in Chapter 1. We first choose the substrate and determine the resonant frequencies and then calculate the antenna dimensions.

This antenna is designed using RT/duriod 5880 substrate. The dielectric constant of the used substrate is equal to 2.2 and its thickness is equal to 1.575 mm

In this design, we focus on the 28 GHz single band antenna. A gap coupled feed line is used in the design to achieve matching with improvement in antenna bandwidth.

To achieve dual-band operation for the micro-strip patch antenna for 5G communication system, an H-Shaped slot has been made on the patch. The outer dimensions of the **H-shaped** slot are almost equal to the dimensions of (28 GHz) patch antenna designed on the same substrate. Figure (III.1) shows the band slotted single element and Table (III.1) presents all the dimensions of the slotted antenna.

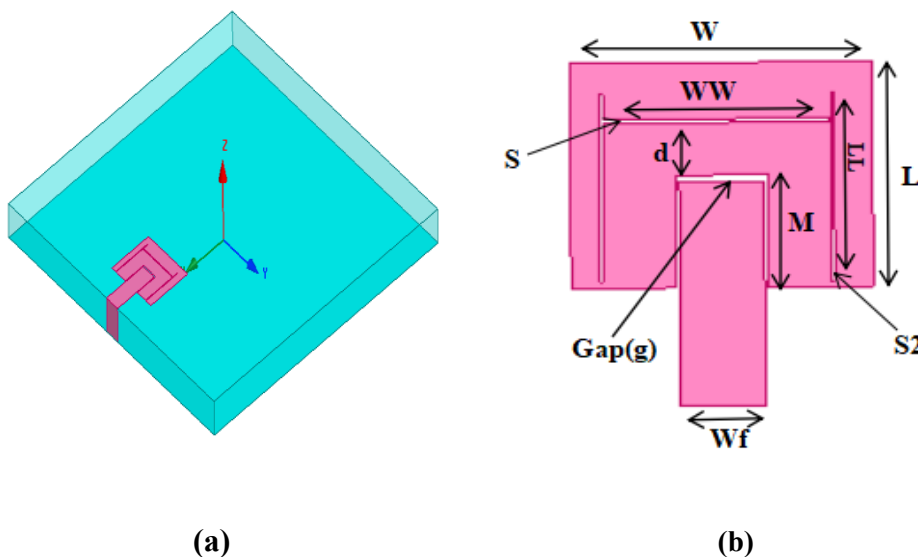


Figure (III.1): Design of Slotted single element patch antenna. (a) 3D design and (b) top view

Table (III.1): Parameters of the single patch antenna.

Parameter	Dimension (mm)
W	4.18
L	3.6
WW	3.2
LL	3
Y	1.8
WY	0.05
Wf	1.179
S	0.0616
S2	0.049
D	0.8

III.1.2 Two element antenna array design:

Basing on the slotted single-element design shown in figure (III.1), a two-element antenna array is designed to improve the directivity and gain of the slotted antenna at frequencies. For achieving the matching, we used quarter-wavelength transformer in the feeding network also used the parallel feeding method as shown in Figure (III.2) The dimensions of transmission lines in feeding network are presented in Table (III.2)

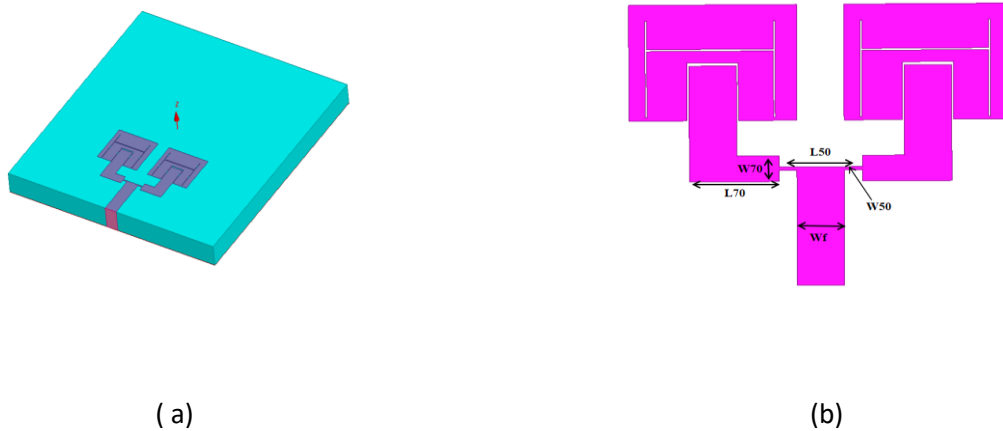


Figure (III.2): Design of Two-element antenna array structure (a) 3D design and (b) top view.

Table (III.2): Parameters of two-element antenna array structure

Parameter	Dimension (mm)
L50	2.08
W50	0.1
W70	0.8
L70	2.229

III.1.3 Four- element Antenna Array Design:

For satisfying 5G wireless system requirements, we have to increase the antenna gain over 13 dBi. So, a Four- element patch antenna array is designed based on the slotted single element Figure (III.1) The antenna elements are fed using a parallel feeding network where quarter-wavelength transformers are used. The structure of the four elements array antenna is shown in Figure (III.3) and the distribution parameters values are shown in Table (III.3)

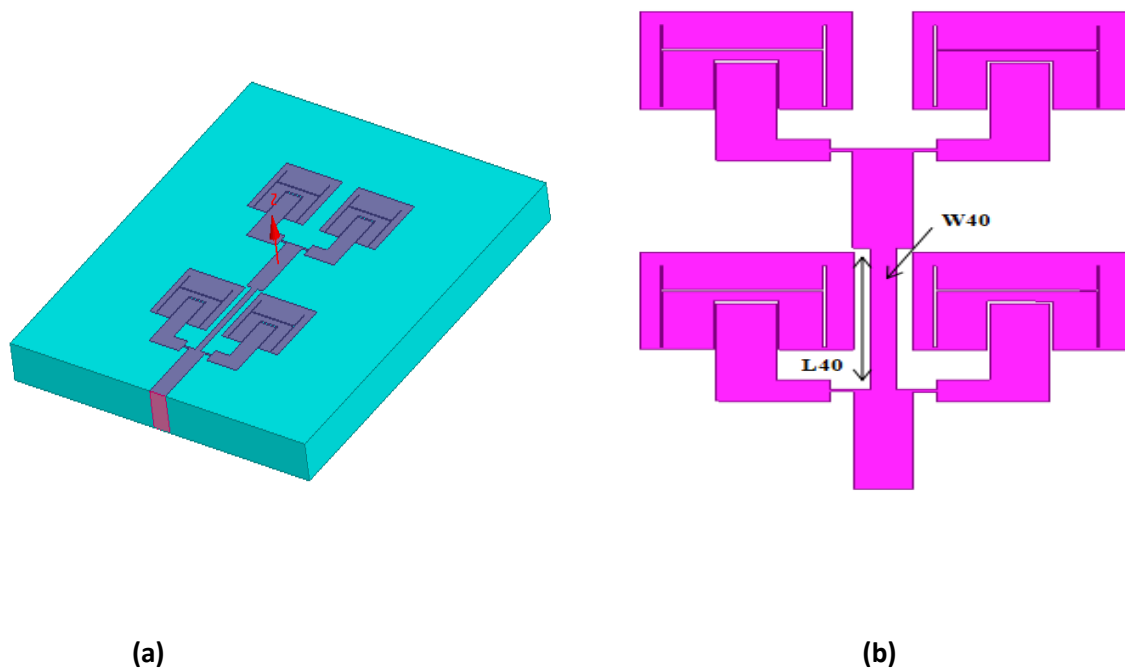


Figure (III.3): Design of Four-Element antenna array (a) 3D design (b) top view

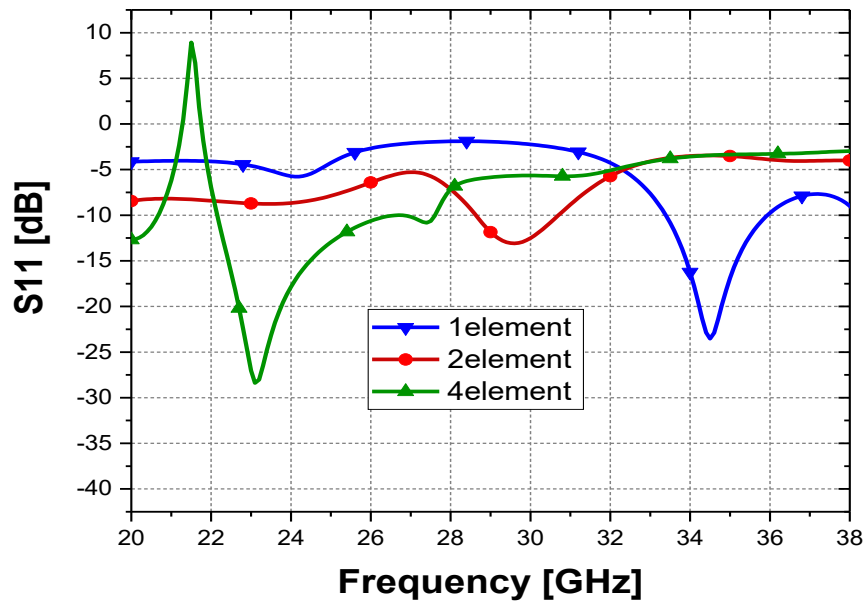
Table (III.3): Parameters of four-element antenna array structure.

Parameter	Dimension (mm)
W40	0.5
L40	5.3

III.1.4 Simulation results :

In this section we compare the results by investigating the effect of changing the increase in the number of antenna elements

From Figure (III.4), it can be seen that the resonance frequency of the antenna array is slightly shifted to lower frequency region when increased the number of elements and we notice an improvement in the results of the refraction coefficient and gain.

**Figure (III.4):** Elements band Simulation result (S11).

The antennas radiation patterns in E and H planes are illustrated in Figure (III.6). It is clear.

from the plot that loading a microstrip antenna with the four elements, reduces the radiation pattern beam width and thereby enhances the antenna directivity. The half-power beam width of the antennas, at the operating frequency in E and H-plane respectively, are observed to be 13.18° and 42.12° for the array antenna.

We observe a half power beam width reduction of about 49% with a four element, in the H-plan and 50%, in the E-plane.

The 3D radiation pattern of the signal element, two and four elements are shown in Figure (III.5).

The maximum realized gains of the single, two and four elements are found to be 8dB, 10.9dB, and 12.9dB respectively. Our proposed antenna design exhibits a gain enhancement, respectively, of 3 dB with a two element and 5 dB, with four elements

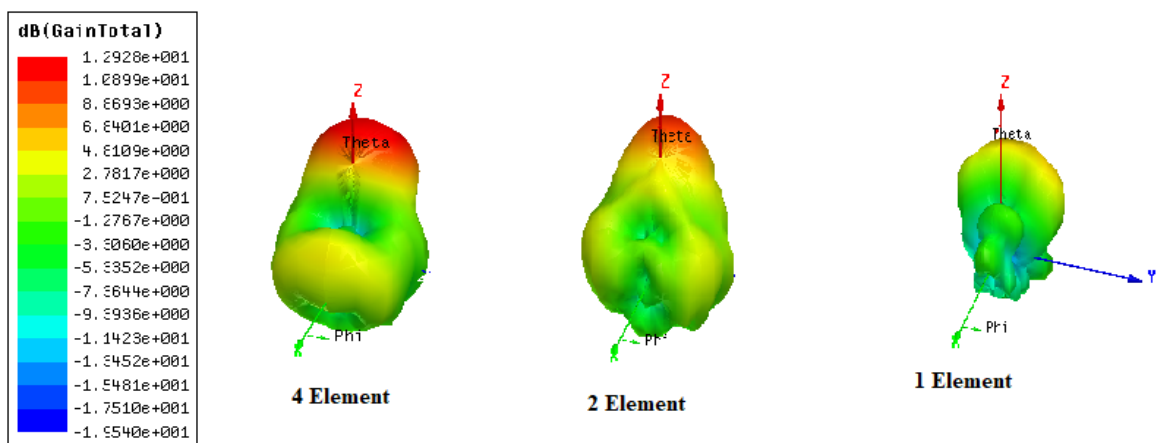


Figure (III.5) : 3D gain

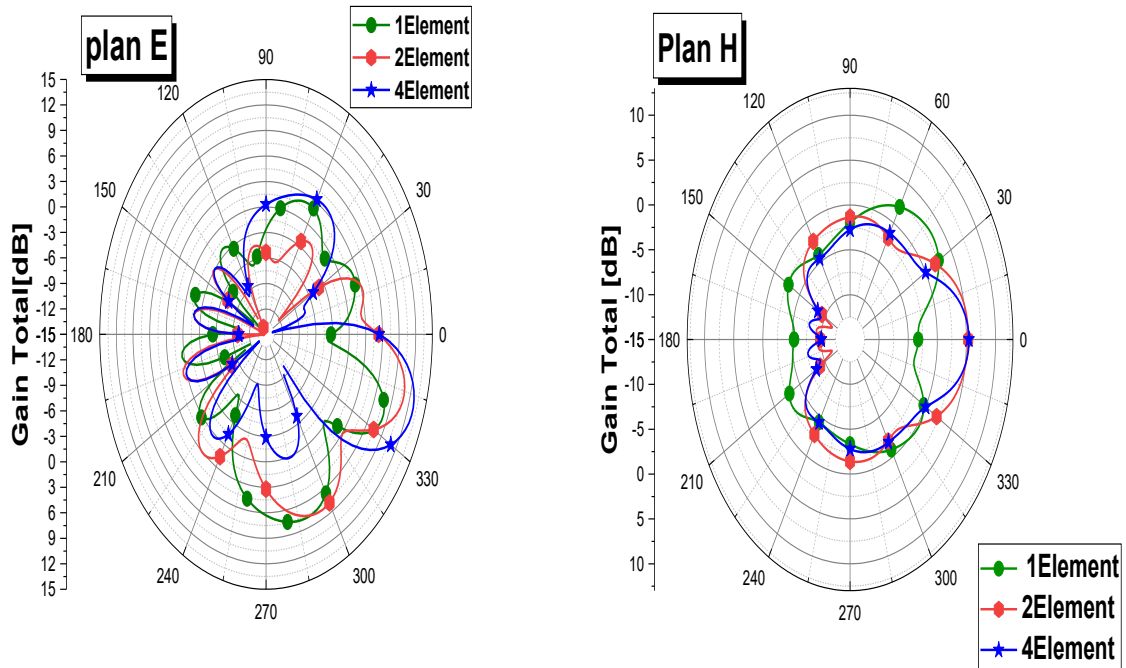


Figure (III.6): Radiation pattern in H and E Planes

From Figure (III.6) and Table (III.4) we note that even the antenna array improves the antenna gain, and reduces the radiation pattern half power beam width to less than 25° in the H-plane: i) it decreases the bandwidth by about 36% while the antenna array shifting the antenna operating frequency by about 3.6 %

Table (III.4): Elements band results.

#	S11(dB)	Band-width(GHz)	Gain(dB)	Θ_{-3dB} (plan E)	Φ_{-3dB} (plan H)
Single Element	-23	1.9	8.17	28.30°	147.74°
Two Element	-13	2.1	10.90	8.51°	55.66°
Four Element	-30	4.3	12.92	13.18°	42.12°

III.2 Design of the metamaterial.

III.2.1-Design and analysis of the metamaterial unit cell.

This section presents the geometry of the proposed metalens unit cell with a ring element. The transmission characteristics of an infinite periodic structure comprised of the proposed unit cell is analyzed, and accordingly, the selection of design parameters is justified., operating in a 28GHz frequency band.

The antenna operating frequency is 28 GHz, which corresponds to a wavelength of 10.7 mm in free space. The maximum dimension of the meta-material unit cell was selected to be much lower than the operating wavelength to satisfy the homogenization conditions [36]. Thus, we chose the period a equal to $\lambda/7 = 1.4$ mm. The conducting strip width w_{cell} , the metallization thickness t , the substrate permittivity ϵ_r and thickness of the unit cell, directly govern the metamaterial electromagnetic properties. In this study, we have fixed some of them namely, t , ϵ_r and d , L_{cell} , a , and we used w_{cell} as a variable design parameter to tune the metamaterial unit cell behavior ($a \ll \lambda$).

The rings will be printed on a dielectric type of substrate "RT/Duroid™" having the following characteristics: [relative permittivity $\epsilon_r = 2.2$]; thickness (subH=1.575 mm)].

Despite the use of split ring resonators in antennas design is not new [37] [38] the use of a simple split ring resonator printed, the unit cell can be considered new, in particular, for mm-wave 5G applications. Figure (III.7) shows the unit cell model of the proposed element as part of a periodic arrangement created using the ANSYS High-Frequency Structure Simulator (HFSS) [39]. The unit-cell is placed inside a waveguide with perfect magnetic conductors (PMC) assigned as a boundary condition to the y-z walls of the model. In contrast, perfect electric conductor boundaries (PEC) are applied to the walls in the x-z plane orthogonal to the incident electric fields. A linearly y-polarized TEM wave is then incident from wave port #1 on the top side, allowing for transmission and reflection coefficients prediction at both port#1 and port#2.

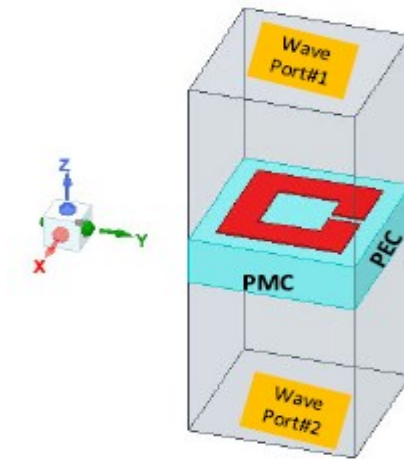


Figure (III.7): Figure 1: Boundary conditions of the metamaterial unit-cell

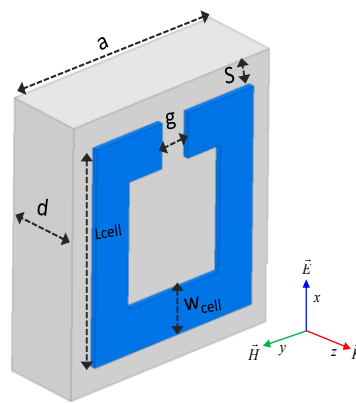


Figure (III.8): Metamaterial Unit cell

Table (III.5): Parameter of Square SRR cell.

Parameter	Dimension (mm)
Dx	1.7
Dy	1.7
Dz	10.71
A	1.7
Wcell	0.35
Gap (g)	0.2

To better control the resonant behavior of the cell according to the polarization of the wave, we have modified the orientation of the cell gap. To do this, four other configurations are studied.

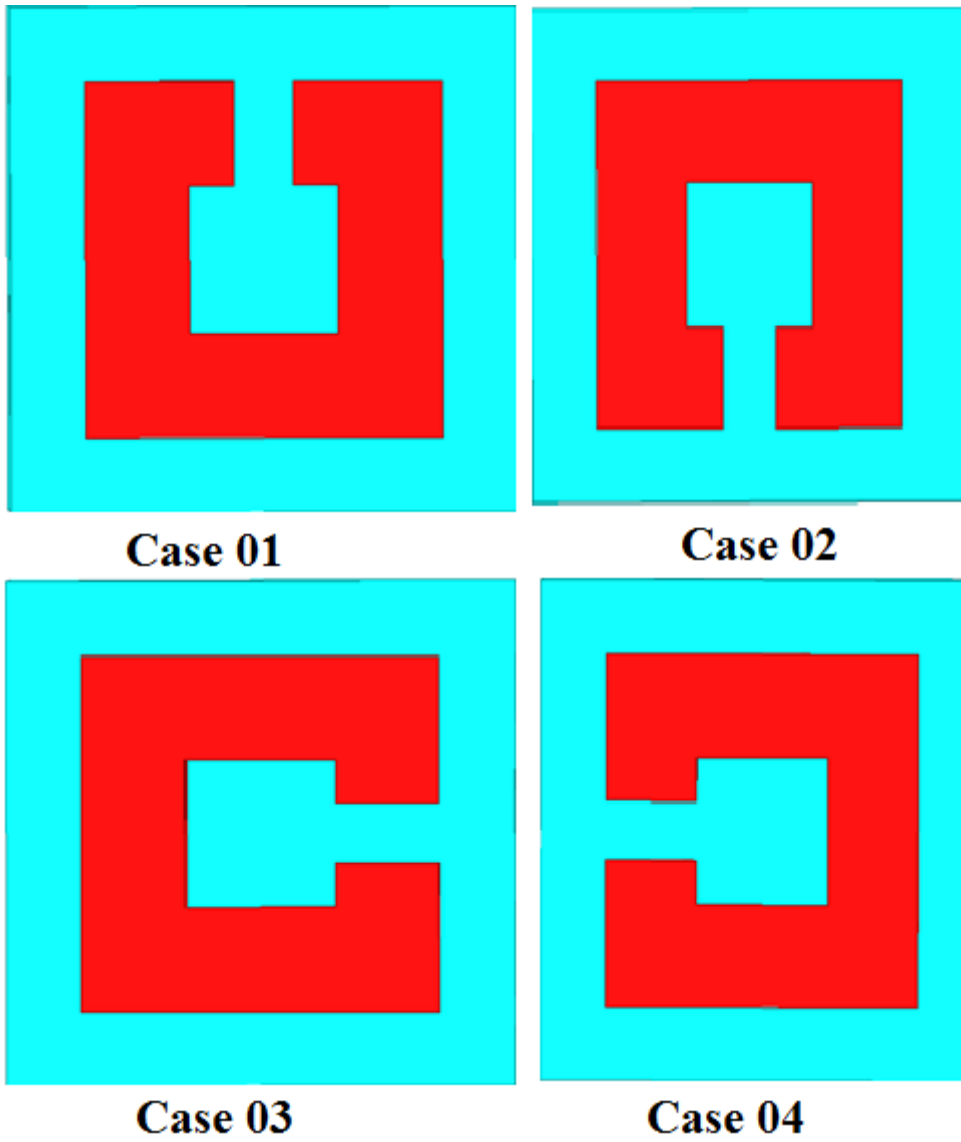


Figure (III.9): Square SRR cell with different orientation of cell gap.

III.2.2-simulation of the metamaterial.

Figure (III.10) and Figure (III.11) shows the predicted transmission coefficient magnitude at different unit-cell cases. It is noticeable that the transmission magnitude improves when the gap cell in y direction (case 1 and 2).and decries when the gap cell in x direction (case 3 and 4).

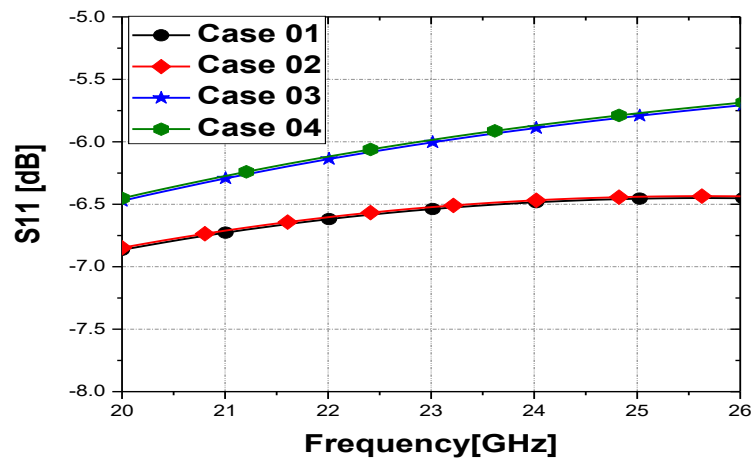


Figure (III.10): reflexion coefficient S11 .

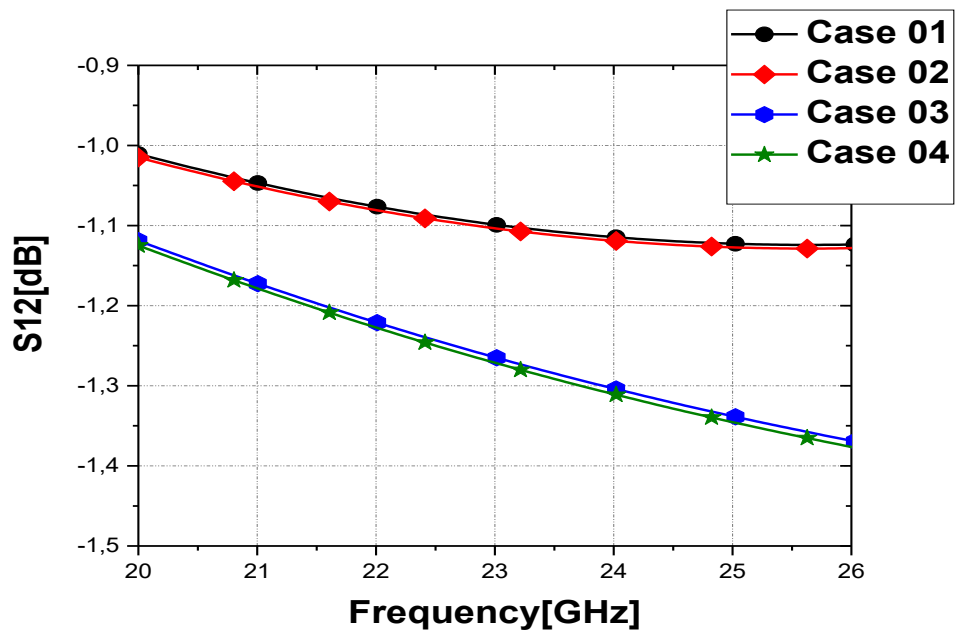
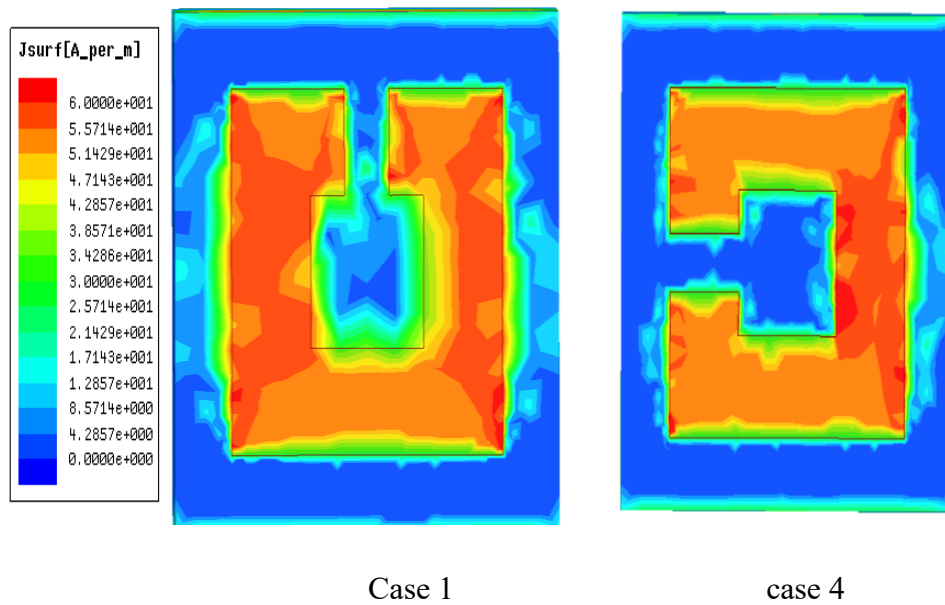


Figure (III.11): transmission coefficient S12.

From Figure (III.10) it can be seen that, for case 1 and 2, the S12 magnitude is very promising, with values exceeding -1 to -1.15 dB from 27 to 26 GHz and from above -1.15 dB to -1.37 dB in the same operating frequency band.

Smaller W_{cell} values, namely, L_{cell} was selected to be a quarter effective wavelength ($\lambda_{eff}/4$) at to support a strong resonance behavior, which is manifested by the current distribution shown in Figure (III.11)

We compare the current distribution between the case 1 in the y direction and case 3 in x direction we note that the current distribution in y direction ,more than current in th x direction, we choose case 1 to applied in array antenna to enhance the antenna performance



III.3 Design and simulation of metamaterial-based an array antenna

Introduction:

Our goal in this section is to enhance the array antennas performances by using the metamaterial case1 mentioned in section. The metamaterials can be applied as an environment of the antenna or as part of the antenna, depending on the parameters of the desired antenna to improve the antenna gain. and bandwidth, to apply metamaterials in an antenna, we must be designing their unit cells, which are considered as homogenized unit cell, The size of the unit cells is calculated, simulated, and optimized, based on the HFSS software.

The unit-cells are arranged in an array with periodicity of 15×15 , to design a layer of the Metamaterial with one, two and three range, - The perspective view of the proposed array antenna with a metamaterial is shown in Figure (III.12)

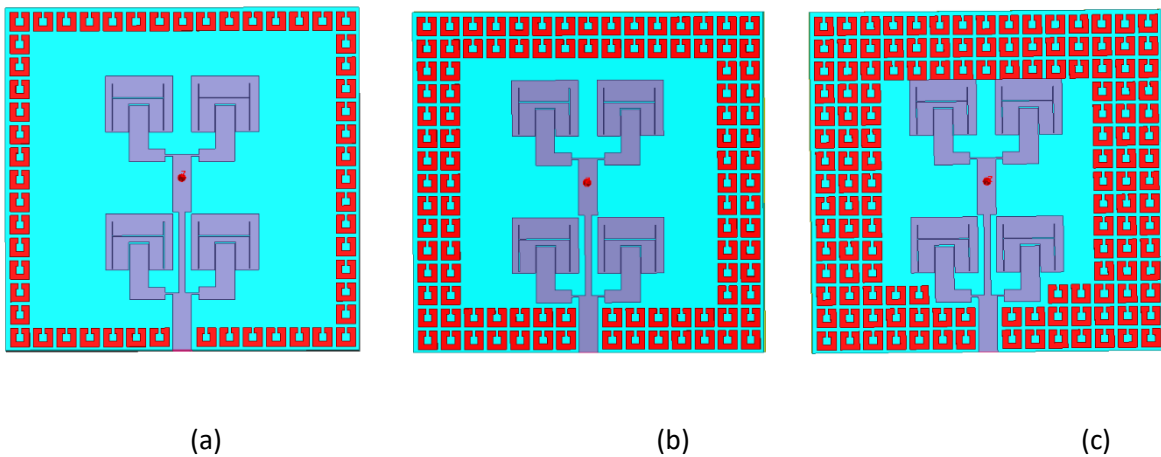


Figure (III.12): Array antenna with metamaterial (a) single range, (b) two range and (c) three range.

From Figure (III.13), it can be seen that the resonance frequency of the array antenna is slightly shifted to lower frequency region, when increased the range of the metamaterial.

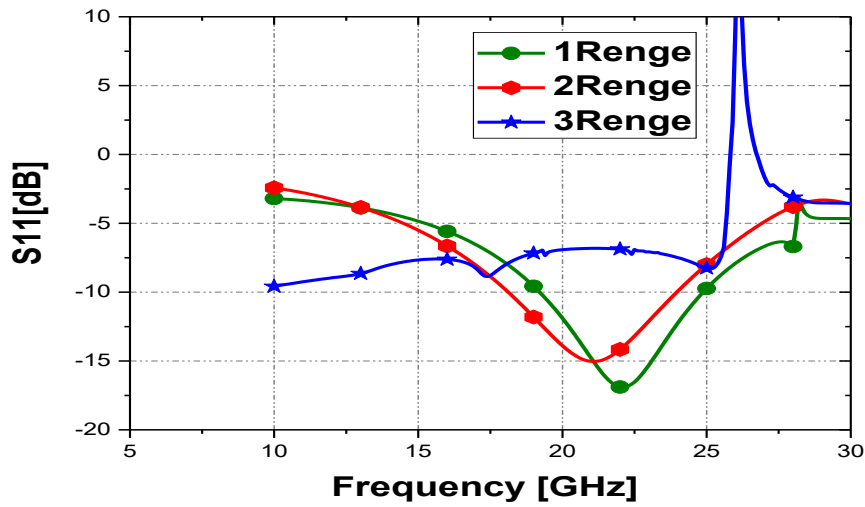


Figure (III.13): Simulated S12 Parameters for ranges.

The maximum realized gain of the proposed array antenna with metamaterial is found to be 20 dB with a signal range of metamaterial

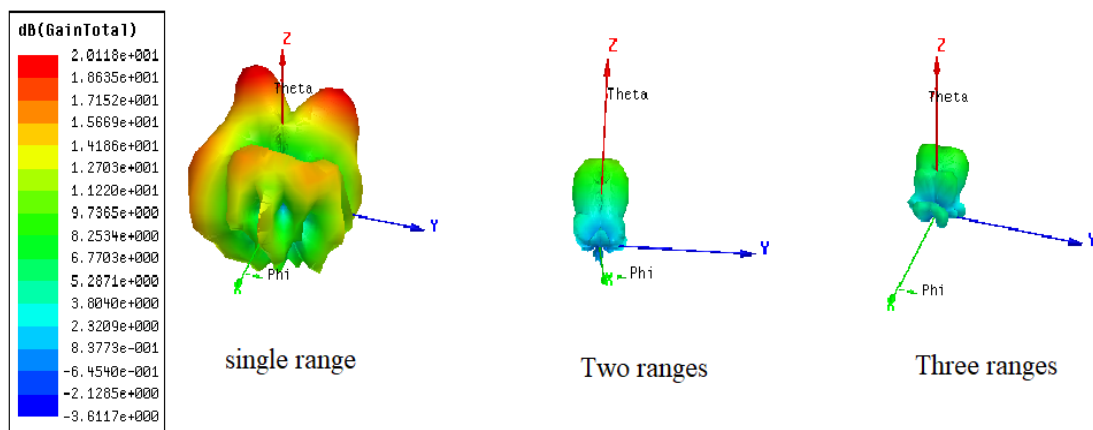


Figure (III.14): 3D gain.

The antennas radiation patterns in E and H planes are illustrated in Figure (III.15). It is clear from the plot that loading a microstrip antenna with the metamaterial reduces the radiation pattern beam width and thereby enhances the antenna directivity. The half-power beam width of the antennas, at the operating frequency in E and H-plane respectively, are observed to be 14.16° and 84.88° , for the array antenna with single range, as shown in table (III.6).

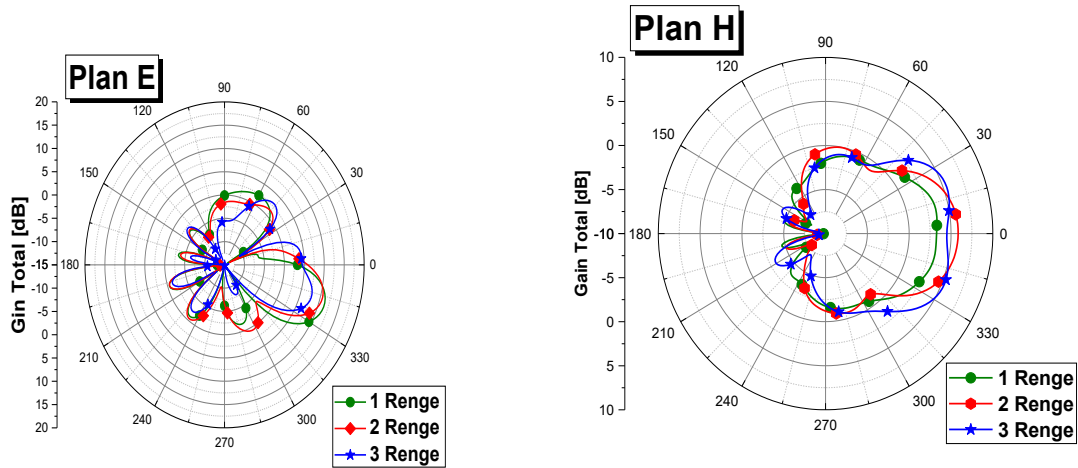


Figure (III.15): Radiation pattern in H and E Planes.

Table (III.6): Ranges results.

#	S11(dB)	Band-width(GHz)	Gain(dB)	$\Theta_{-3dB}(\text{plan E})$	$\Phi_{-3dB}(\text{plan H})$
Single Range	-17	5.7	20.25	14.16°	84.88°
Two Ranges	-15	4.9	10.55	7.12°	64.22°
There Ranges	-10	00	08.30	5.76°	83.52°

We conclude that increasing the number of ranges leads to a decrease in the values of the gain, the bandwidth and the parameter S11 we can fixed the antenna array with singal range

Now we study the influence of the gap g . orientation in the array antenna performances

We study four cases two cases when the gap in the y axe direction and two cases when the gap in x axis direction Figure (III.16).

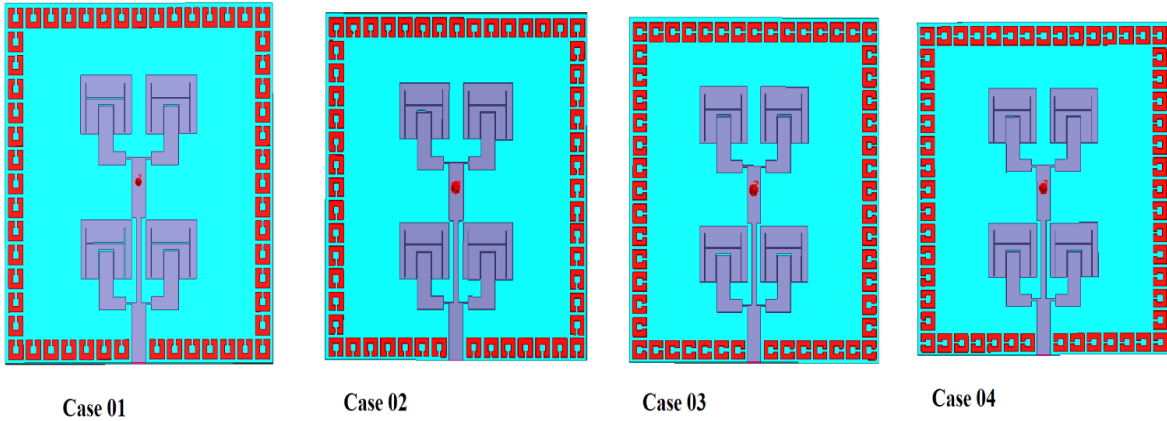


Figure (III.16): Array antenna configuration with the cell gap orientation.

Figure (III.17). shows a good simulated result for the antenna array for the cases where the magnitude of the S11 parameter is equal to -17 dB at 22 GHz, -13 dB at 20 GHz, -16 dB at 23 GHz and -17dB at 23 ,5 GHz for the cases respectively.

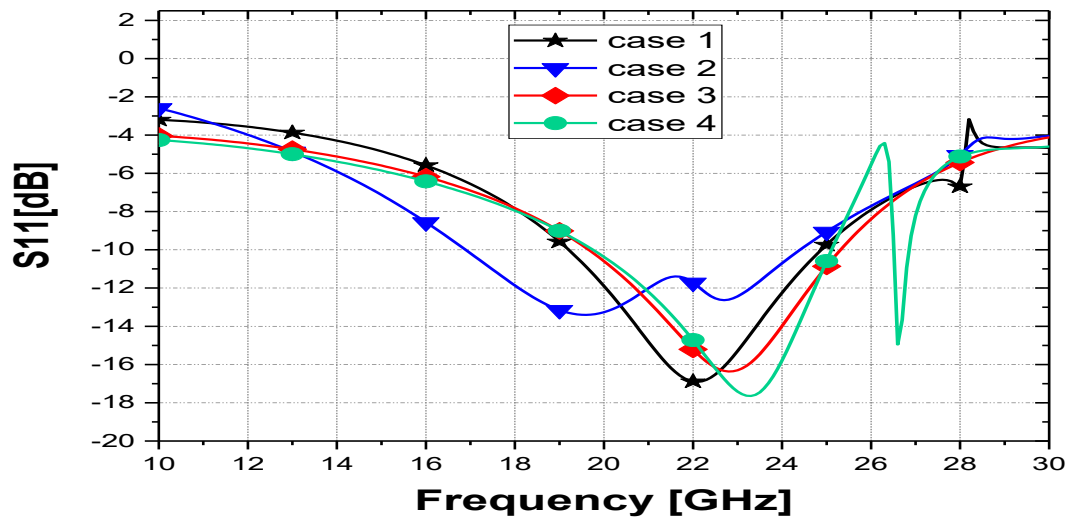


Figure (III.17): Simulated S12 Parameters for the orientation of the cell gap.

The three-dimensional radiation pattern for the cases is shown in Figure (III.18). The maximum realized gain for the case 1 is 20.1dB

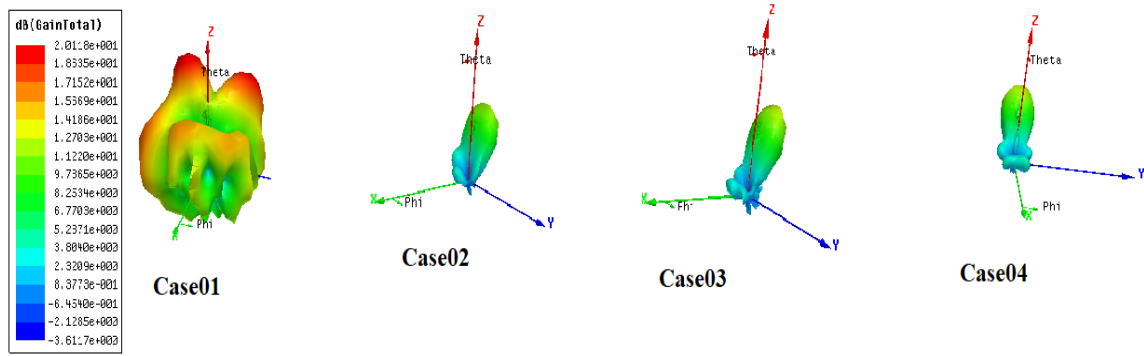


Figure (III.18): Simulated Gain for the orientation of the cell gap.

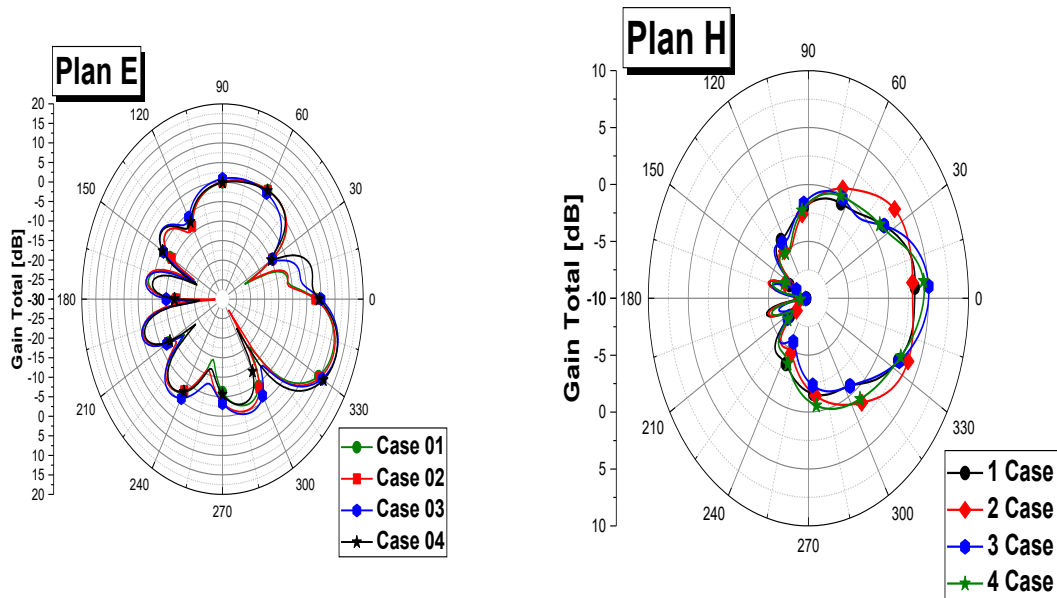


Figure (III.19): The orientation of the cell gap Simulation result Plan H and Plan E.

Finally, we have summarised the privios results in Table (III.7) the entire

Table (III.7): Cases results.

#	S11(dB)	Band-width(GHz)	Gain(dB)	$\Theta_{-3dB}(\text{plan E})$	$\Phi_{-3dB}(\text{plan H})$
Case 01	-17	5.7	20.25	14.16°	84.88°
Case 02	-13	00	11.90	14.56°	130.08°
Case 03	-16.30	5.6	12.91	14.56°	61.76°
Case 04	-17	5.3	12.06	16°	60.52°

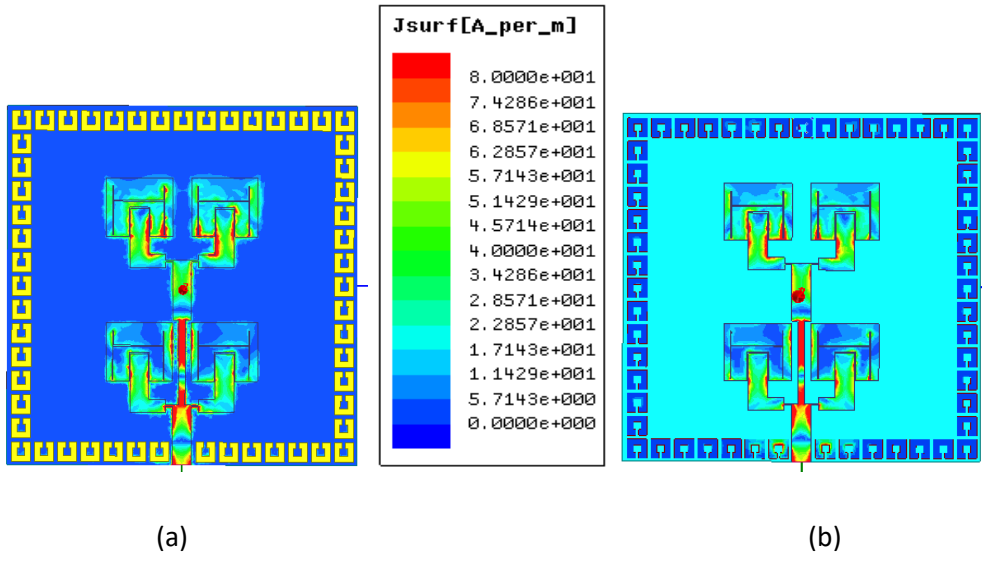


Figure (III.20): The current distribution (a) case 1 and (b) case 2

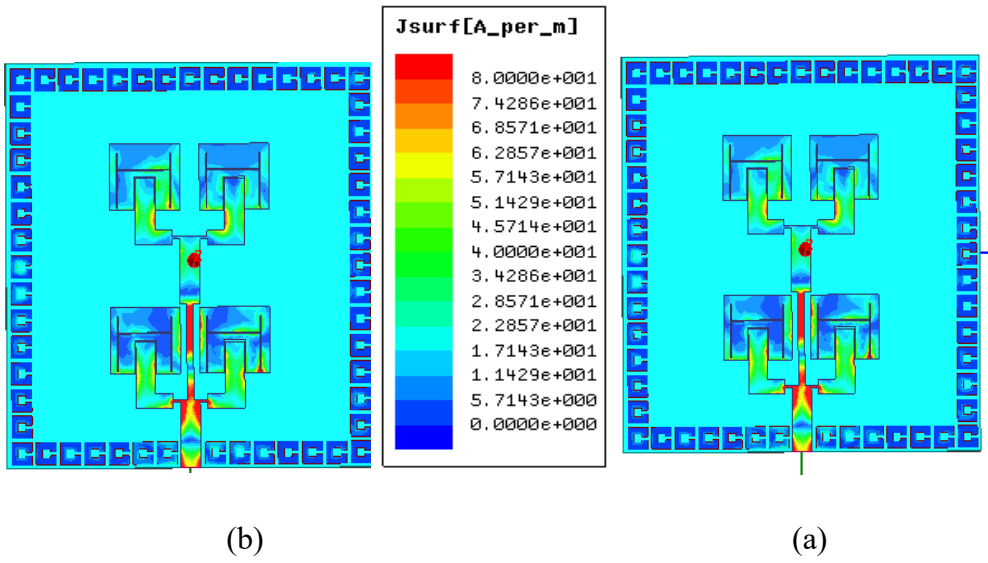


Figure (III.21): The current distribution (a) case 3 and (b) case 4

Effective dielectric constant.

We demonstrate the increasing of the antenna gain by the calculated of the effective permittivity of the antenna system

Effective dielectric constant of the antenna is calculated by using the following formula:

When $\left[\frac{W}{H} < 1\right]$:

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[\frac{1}{\sqrt{1 + 12 \left(\frac{H}{W}\right)}} + 0.4 \left(1 - \frac{W}{H}\right)^2 \right]$$

When $\left[\frac{W}{H} > 1\right]$:

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \left[\frac{\epsilon_r - 1}{2 \sqrt{1 + 12 \left(\frac{H}{W}\right)}} \right]$$

W = Width of the transmission line

H= the thickness of substrat

ϵ_r = Relative permittivity of the dielectric.

ϵ_{eff} = Effective dielectric constant of the antenna system

The effective permittivity of the metamaterial is represented in figure

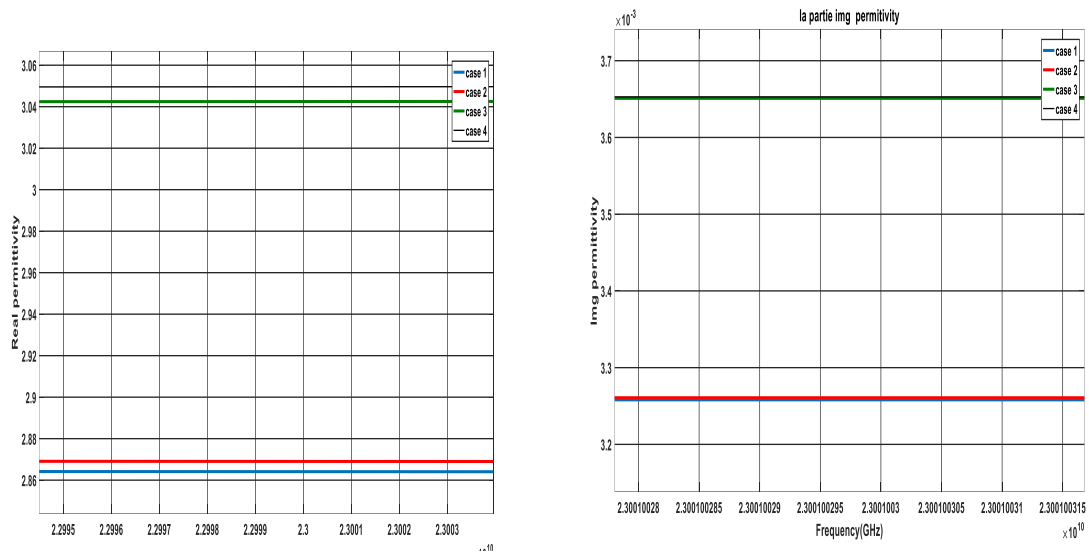


Figure effective permittivity of the metamaterial unit cell (a) real part and (b) imaginary part

Table show the values of the effective dielectric of the array antenna system

It can be seen that from this table when the effective permittivity of the antenna is increase the gain increase

Table values of the effective permittivity

		H	W	ϵ_r	ϵ_{eff}
With-out Mita		1.575	1.179	2.2	1.7407
With Mita	Case1			2.864	2.3704
	Case2			2.869	2.1537
	Case3			3.042	2.260
	Case4			3.05	2.265

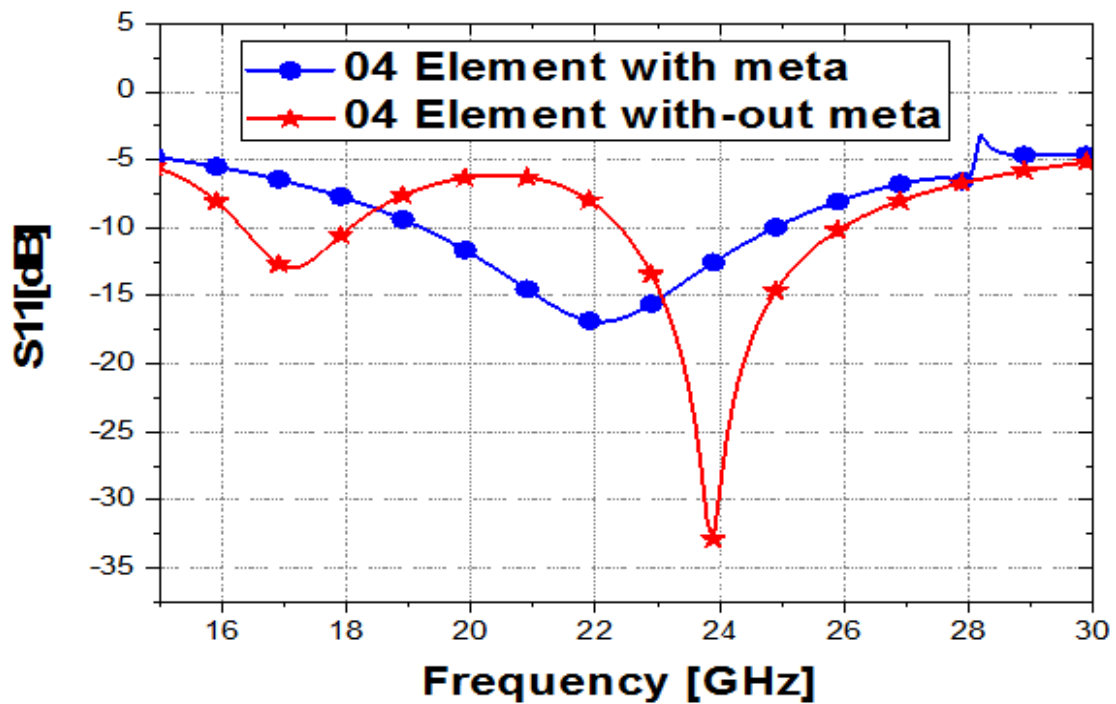
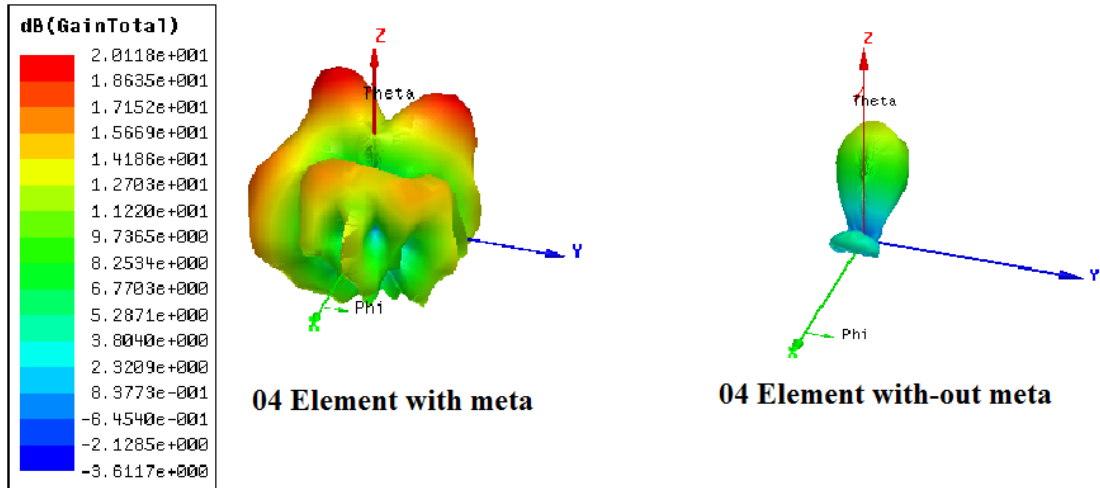


Figure exhibits the change of the antenna gain and reflection coefficient

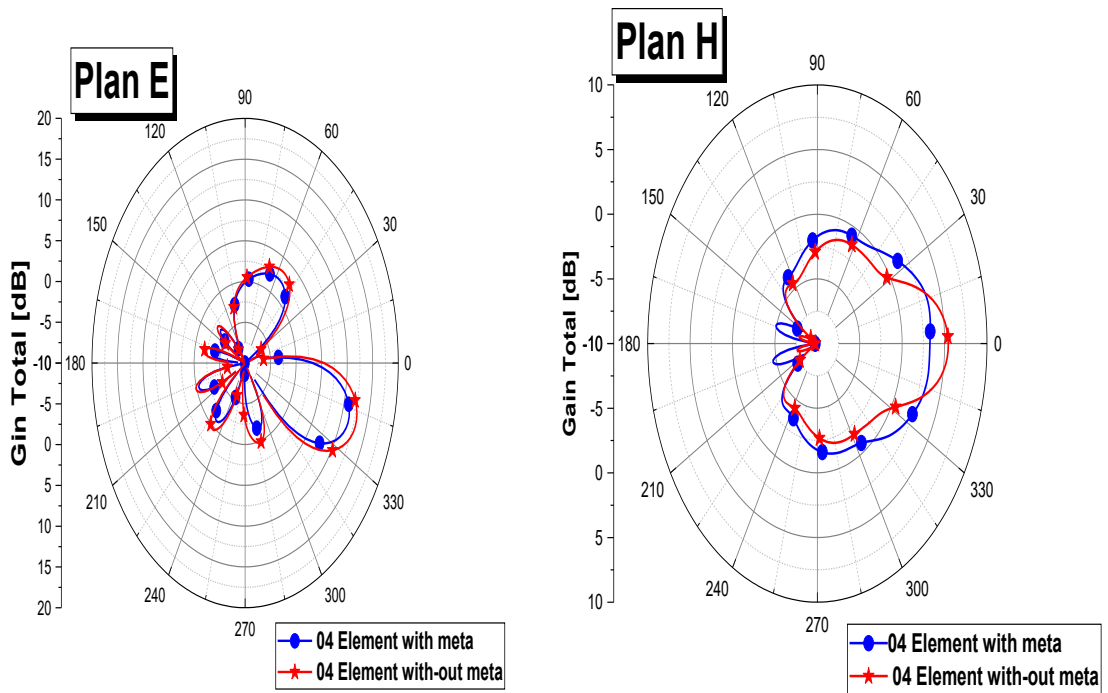
(S11) when we used the metamaterial, the proposed design utilizes an array antenna with meta-lens to improve the gain and bandwidth

The 3D gain and far-field radiation patterns shown in Fig. 1 and 2 It is quite clear how the use of the meta-lens narrowed the broad far-field pattern of the array antenna with metamaterial to a much more directive beam.

Simulated S11 Parameters for four-element antenna array with-out and with metamaterial.



Simulated 3D Gain for the antenna array with and without metamaterial.



Simulation result Plan H and Plan E for four-element antenna array with-out and with metamaterial.

We surmised the Results of the antenna array with and without metamaterial in table 4.

Table 4: Characteristics of the antenna array with and without metamaterial

#	S11(dB)	Band-width(GHz)	Gain(dB)	$\Theta_{-3dB}(\text{plan E})$	$\Phi_{-3dB}(\text{plan H})$
04 element with- out meta	-30	4.3	12.92	13.18°	42.12°
04 element with meta	-17	5.7	20.25	14.19°	84.88°

III.4 Design of 5G MIMO Antenna for Base Stations:

III.4.1- Design of Base Stations

The 4-element antenna array is now being used to service 5G communication systems by realizing the MIMO feature to improve the quality of communication links.

we have used 4-element antenna arrays in the handset design as depicted in Figure (III.22). 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

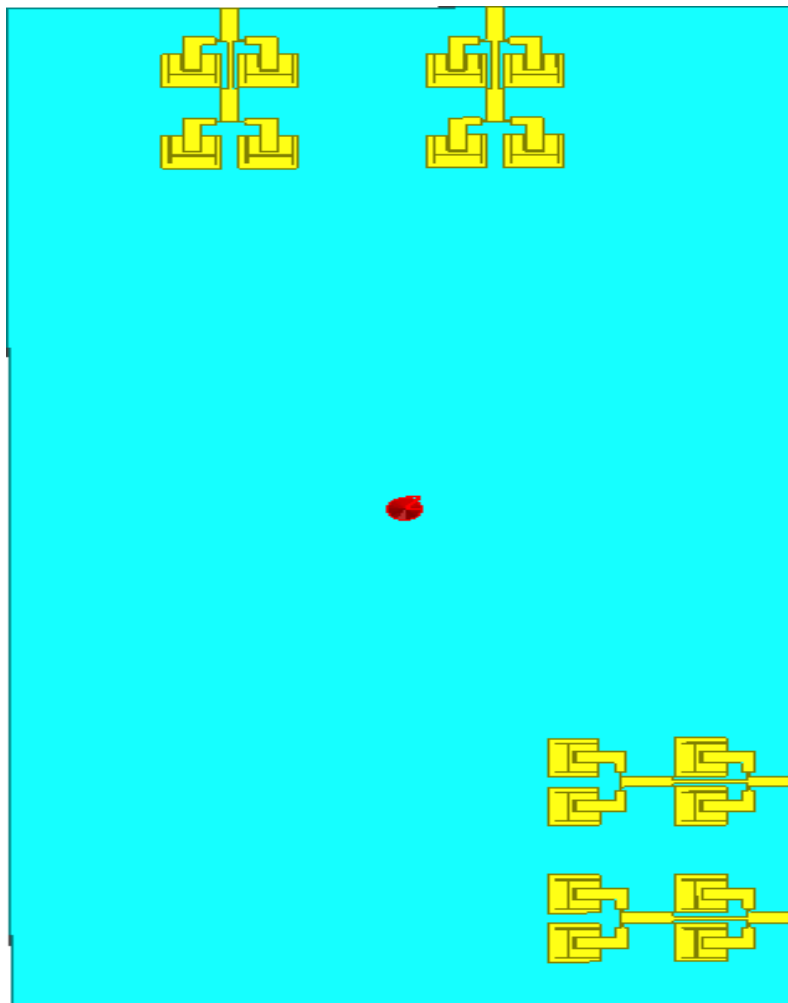


Figure (III.22): Handset Design.

The distribution of the antenna gave the polarization feature to the design where 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 (>3 GHz). Hence, the proposed antenna design is a good candidate for handsets for 5G communication systems.

Figure (III.23) to show the simulation results of S11

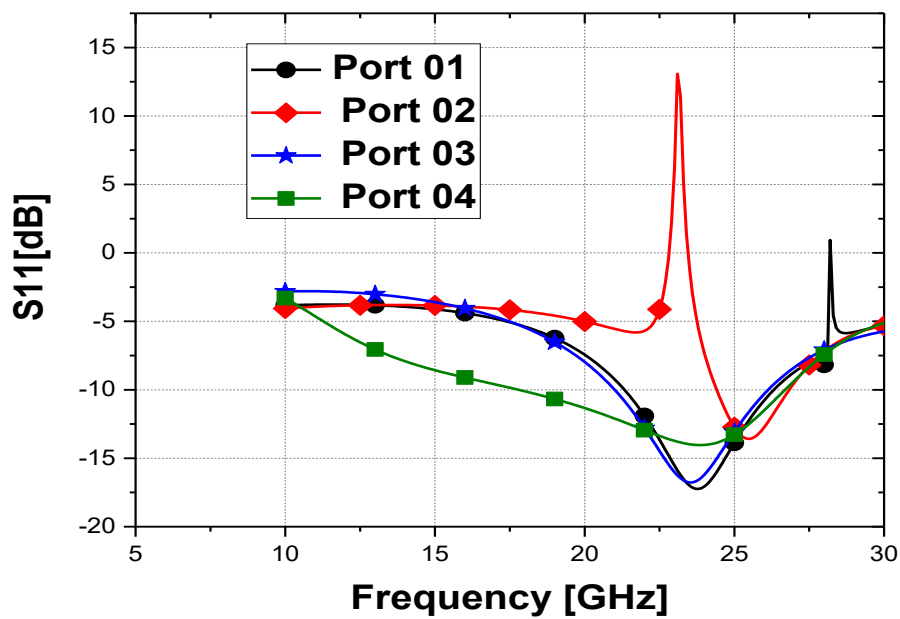


Figure (III.23): Simulated S12 Parameters for Base Stations MIMO.

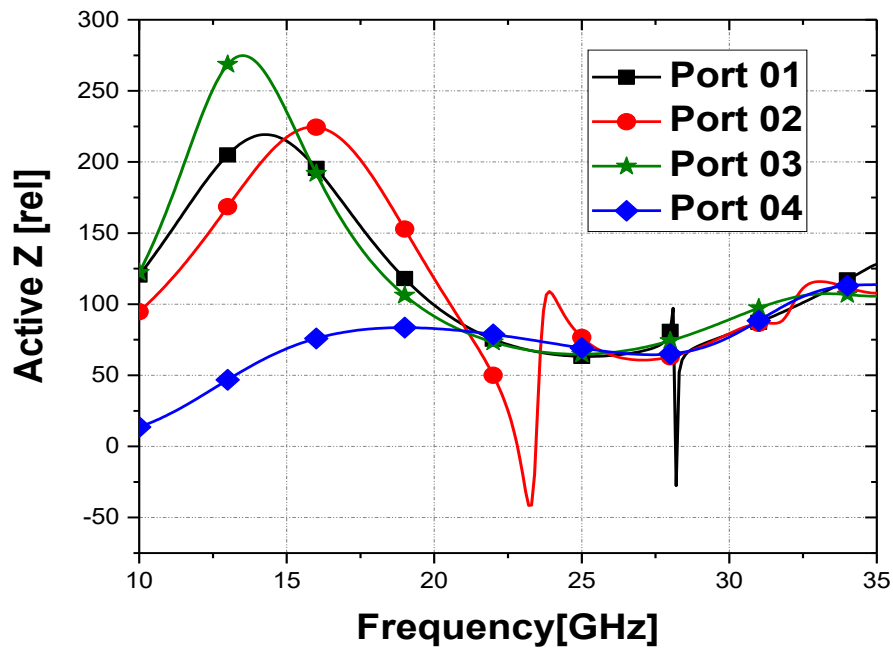


Figure (III.24): Simulated Active Z (rel) Parameters for Base Stations MIMO.

The 3D radiation pattern of the array antenna are shown in Figure (III.25).

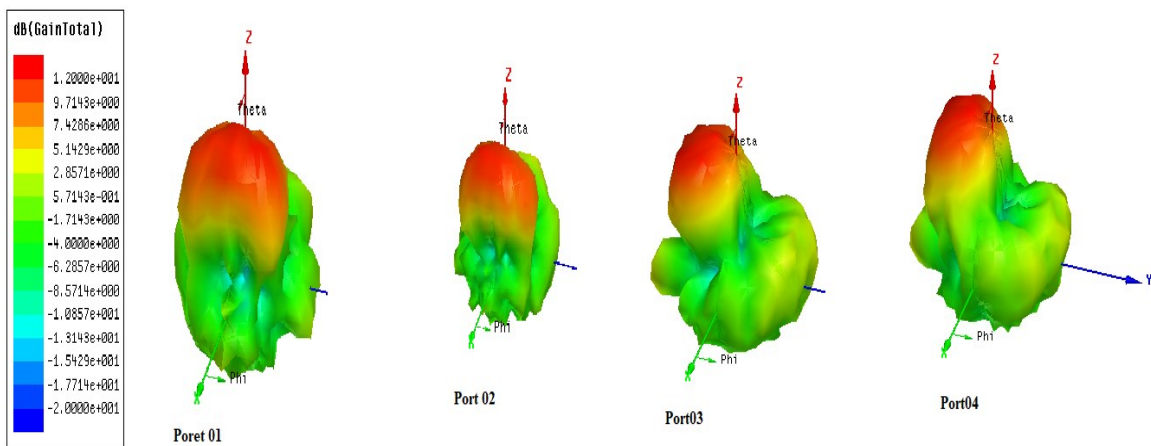
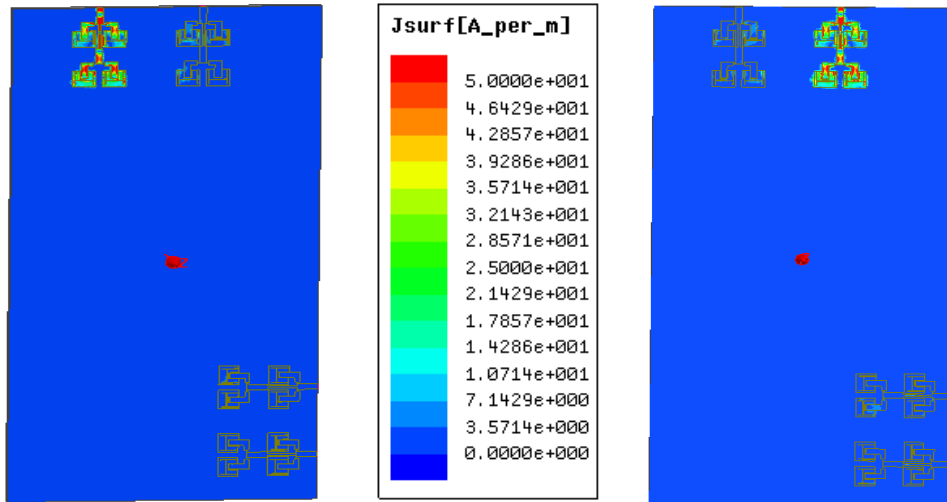
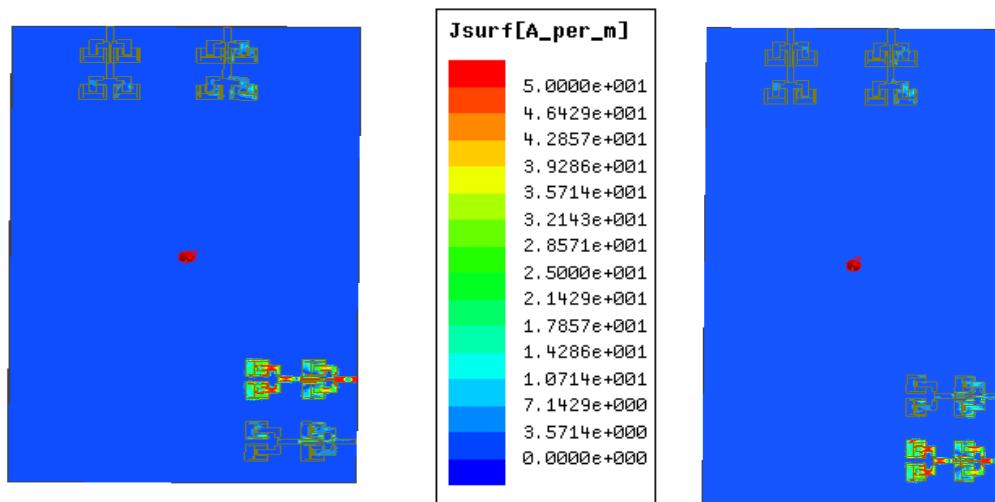


Figure (III.25): Simulated of 3D Radiation pattern for Base Stations MIMO antenna.



(a)

(b)



(c)

(d)

Figure (III.26): current distribution of the MIMO for base station.

III.5.Conclusion

In this chapter , the studies and research that have been discussed have focused on the design, optimization and performance evaluation of four element MIMO systems based on metamaterials for communication 5G networks. The simulation results of the final system developed confirmed the advantages of the proposed idea not only from the point of view of mutual coupling but also in terms of weight reduction, size and gain in diversity. The suggested antenna presents a good Reflection Coefficient ($S_{11}=-17\text{dB}$), (bandwidth=5.7GHz) and gain ($G=20\text{ dB}$) and the current distributed over the whole substrat. This is beneficial for their integration into telecommunications systems.

Conclusion

Using logiciel of simulation program, in the first chapter a new design of band antenna array has been designed for serving 5G wireless communication systems. The antenna operates at the frequencies 28 GHz. 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 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 where the gain is more than 12 dB at the frequency. After that we look for achieving more features for the 5G communication system, and where The refraction coefficient is -30dB, The bandwidth is than 4 GHz.

In the second chapter, a square-shaped single-ring SRR unit cell is modeled by using a suitable one-port resonant circuit representation that accounts for the conductor loss and dielectric loss effects as well. Capacitive and inductive coupling effects between adjacent SRR unit cells are also described by the one-port equivalent circuit approach. To better control the resonant behavior of the cell according to the polarization of the wave, we have modified the orientation of the cell gap. To do this, four other configurations are studied. So, the metamaterial based of MIMO antenna is an excellent for the 5G communication systems.

Finally, The designed base station (has four 4-element antenna arrays) achieved many features like MIMO configuration, good realized gain, high bandwidth. So, it is an excellent base station for the 5G communication systems.

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