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Slotted micro-strip patch antenna design for 5G mobile communication systems.

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Dedication

Lokmane

I dedicate my work to my mother for her love, encouragement, and sacrifices, and to my father (soul mate), for his support, affection, and trust in me that he has shown to all of my family members and friends.

Riyad

I dedicate my humble effort to those who are dear to my heart:

I wouldn't be where I am now if it weren't for my grandparents and parents.

Thank you for all of your sacrifices, prayers, adoration, and support.

My brothers and sisters for their unwavering support and encouragement.

To my whole family for their unwavering support throughout my academic career.

My friends, as well as everyone who has supported and helped me during this end-of-cycle project.

Without forgetting all of my professors, whether they were from primary, secondary, or higher education.

Acknowledgment

Lokmane and Riyad

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We'd want to express our gratitude to our supervisor, Dr. TELMMAR Mohamed Nasr eddine, for his tremendous availability, encouragement, criticisms, and advice, all of which greatly aided in the completion of this project. It is here that we convey our heartfelt thanks.

We'd want to express our gratitude to all of the jury members for the honor they have bestowed upon us by accepting to judge our project.

We'd want to express our gratitude to the professors at the University Yahia Fares.

We'd want to express our heartfelt gratitude to our loving parents and family.

Everyone who helped in any way to make this small project a success will find an expression of our heartfelt appreciation here.

Abstract

ملخص

تعتبر تقنية الاتصالات المتنقلة 5G ثورة في القطاع اللاسلكي. نظرًا لأن مستخدمي الاتصالات المتنقلة لديهم زيادة مستمرة في الطلب والمتطلبات، فإن التكنولوجيا مدفوعة للتطور وفقًا لاحتياجات المستهلكين. اليوم، نشهد العديد من الخدمات والتطبيقات الجديدة التي لم نشهدها من قبل، مثل المركبات ذاتية القيادة أو الذكاء الاصطناعي أو الجراحة عن بعد. للتعامل مع الخدمات الجديدة، كان لا بد من استعداد المشغلين اللاسلكيين لدعم زيادة حركة البيانات بمقدار ثلاثة أضعاف. للقيام بذلك، كان على الباحثين إيجاد سعة أكبر في الأطياف اللاسلكية الجديدة الأخرى. ستشمل شبكات G5 المستقبلية العديد من التطورات التكنولوجية الحديثة. قبل نشر أي نظام اتصالات، يلزم التخطيط. تعد عملية تخطيط الشبكة وتحسينها أمرًا بالغ الأهمية لمشغلي الشبكات اللاسلكية. الغرض من هذه الذاكرة هو نشر شبكة G5 في سيناريوهات مختلفة. ويمثل الفصل الاول مقدمة لمختلف نظم الاتصالات المتنقلة. بعد ذلك، يقدم الفصل الثاني لمحة عامة عن المفاهيم الأساسية لـ G NR5. وأخيرا، سيصف الفصل الثالث دراسة حالة نشر الشبكة المتنقلة ويناقش النتائج ويختتم باستنتاج عام ومنظورات للمشاريع المقبلة .

الكلمات الرئيسية: 5G, هوائي, موجات المليمتر, المايكروبان الهوائي.

Résumé

Conception d'antenne patch microruban à fentes pour les systèmes de communication mobile 5G.La technologie de communication mobile 5G est considérée comme une révolution dans le secteur de communications sans fil. Comme les utilisateurs de la communication mobile ont une augmentation constante de la demande et des exigences, la technologie est poussée à évoluer en fonction des besoins des consommateurs. De nos jours, nous observons un grand nombre de nouveaux services et applications que nous n'avons jamais vus auparavant, tels que les véhicules à conduite autonome, l'intelligence artificielle ou la chirurgie à distance. Pour faire face aux nouveaux services, les opérateurs sans fil devaient être prêts à supporter une augmentation de trois ordres de grandeur en termes de trafic de données. Pour ce faire, les chercheurs ont dû trouver une plus grande capacité dans d'autres nouveaux spectres sans fil. Les futurs réseaux 5G comprendront de multiples avancées technologiques de pointe. L'objectif principal de cette mémoire est de concevoir une antenne microruban à fentes pour desservir les systèmes de communication 5G en réalisant toutes les caractéristiques importantes des systèmes de communication sans fil récents. Le chapitre 1 présente le contexte et la motivation sous-jacente au sujet actuel. Le chapitre commence par une discussion sur la nécessité d'inventer la technologie 5G chez des ondes millimétriques. De plus, les défis de l'utilisation des bandes millimétriques pour la communication mobile sont discutés avec les technologies mobiles existantes à basse fréquence. Le chapitre 2 présente la théorie essentielle pour les antennes microruban à fentes, suivi du chapitre 3 qui se

concentrera sur la conception de l'antenne à fentes et à ondes millimétriques avec la discussion des résultats obtenus et se termine par une conclusion générale et les perspectives pour les futurs projets.

Mots clés : 5G, Antenne, Ondes millimétriques, Antenne microban.

Abstract

5G mobile communication technology is being hailed as a game-changer in the field of wireless communications. Due to the ongoing increase in demand and expectations among mobile communication users, technology is being pushed to evolve in response to consumer needs. Today, we see a slew of new services and applications that we've never seen before, such as self-driving cars, artificial intelligence, and remote surgery. To meet the demands of new services, wireless operators needed to be prepared to sustain a three-fold increase in data traffic. To do so, researchers have to look for greater capacity in new non-linear specters. The future 5G networks will include a number of cutting-edge technological advancements. Prior to the deployment of any communication system, it is necessary to prepare ahead. For operators of wireless networks, the process of network planning and optimization is critical. The goal of this memory is to design of slotted microstrip patch antenna for 5G mobile communication systems.5G mobile communication technology is considered a revolution in the wireless communication sector. As the number of mobile communication users has a constant increase in demand and requirements, the technology is pushed to evolve according to the needs of the customers. Nowadays, we observe a lot of new services and applications that we have never seen before, such as self-driving vehicles, artificial intelligence or remote surgery. To cope with the new services, wireless operators had to be prepared for a three-order-of-magnitude increase in data traffic. To do this, the researchers had to find greater capacity in other new wireless spectra. Future 5G networks will include multiple cutting-edge technological advancements. The main objective of this dissertation is to design a slotted microstrip antenna to serve 5G communication systems development by investigating all the important features for recent wireless communication systems. In the first time, we present the background and motivation behind the current topic. The chapter begins with a discussion of the need to develop 5G technology at millimeter waves. Additionally, the challenges of using millimeter bands for mobile communication are discussed with existing low-frequency mobile technologies.in the second time we present the essential theory for slotted microstrip antennas, followed by the third part which will focus on the design of the slotted and millimeter wave antenna with the discussion of the obtained results and ends with a general conclusion.

Keywords: 5G, Antenna, Millimeter waves, Microstrip antenna.

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General introduction

Antennas have become our world's eyes and ears, our ties to the space in which we live; they are an important and necessary aspect of our civilization. The antenna is a crucial component that serves two purposes: Those who are in charge of broadcasting electromagnetic waves and their reception, the latter of which is also located at ground level, There are no standards. Theory and technology of printed antennas have grown in popularity, quick, and they were one of the most innovative technologies at the time of its development. They have modern microprocessor systems quickly found a wide range of applications.

The first chapter discusses the differences between 2G, 3G, and 4G, followed by a description of 5G technology. In the second chapter, we discussed the concept of an Antenna, its role, types, and application domains, as well as the importance of Maxwell's equations in understanding propagation phenomena. The fundamental characteristics of all antennas, such as gain, performance, impedance input, and the radiation diagram, are all discussed, and it has covered the history of photonic crystals as well as the notion of photonic crystals. It has shown one-dimensional, bi-dimensional, and tridimensional antennas, as well as microstrip antennas and their structure, as well as the current form of patch microstrip elements, their benefits and drawbacks, and their uses. In addition, photonic crystals and their properties are discussed.

Finally, in chapter three, using CST, we analyzed and simulate a rectangular patch antenna. The dimensions of the microstrip rectangular patch antenna were calculated for the design of the antenna's conception, and the procedure was put to the test. Then there are the major parameters including the S parameter, VSWR, gain, directivity, and radiation efficiency. After that, in part 2, we treated the slot antenna, which is made up of a shape of U slot, and we defined its parameters, and in part 3, we combined the second design with photonic crystals, adding cylinder airs and treating its parameters.

Chapter 1

Generalities on mobile communication networks

Chapter 1 Generalities on mobile communication networks

1.1 Introduction

As the need arise, first generation was developed around 1980s by Nippon Telegraph and Telephone (NTT) in Tokyo. So, Japan was the first country to commercialize 1G. 1G is based on analog signals based on Advance Mobile Phone Service (AMPS). Frequency Division Multiple Access (FDMA) scheme of multiplexing was used in 1G. Due to disadvantages like very less capacity and analog technology, 2G was introduced in 1990s based on GSM in Finland. 2G had many advantages like radio signals in 2G are digital, offered better security compared to 1G, made better and efficient use of spectrum available and also had an added facility of text services. Its improved version also included (GPRS) General Packet Radio Service which allowed internet access. With more number of users using mobile phones to access internet, faster and robust internet connectivity was needed. The concept of Code Division Multiple Access (CDMA) and Wideband Code division multiple access (WCDMA) was introduced in 3G. NTT DoCoMo first commercially launched it in Japan in early 2000s. [1]

3G also had an advantage that it was backward compatible with present 2G systems.

4G also known as IMT-Advanced was first launched in 2010 to implement the only packet-switching technique. It is integrated with one Core Network and several Radio Access Networks (RANs) and provides a complete IP-based network of 100 Mbps to 1 Gbps speed with a frequency of 2–8 GHz. [2]

Since the range of coverage was smaller due to high speed, it became necessary to incorporate multiple smart antennas to support long-range communication. [3]

Good Quality of Service (QoS) and data rates in 4G support services with better clarity; such services include but are not limited to Mobile Television, High Definition Television (HDTV) content, Digital Video Broadcasting (DVB), Video Chat, Multimedia Newspapers, and High-Quality Live streaming. 4G offers ultra-low latency compared to 3G. [4]

1.2 The second generation (2G)

2G is based on GSM (Global System for Mobile Communication) technology. 2G system used combination of TDMA (Time Division Multiple Access) and FDMA (Frequency Division Multiple Access). Due to this more users were able to connect at a time in a given frequency band.

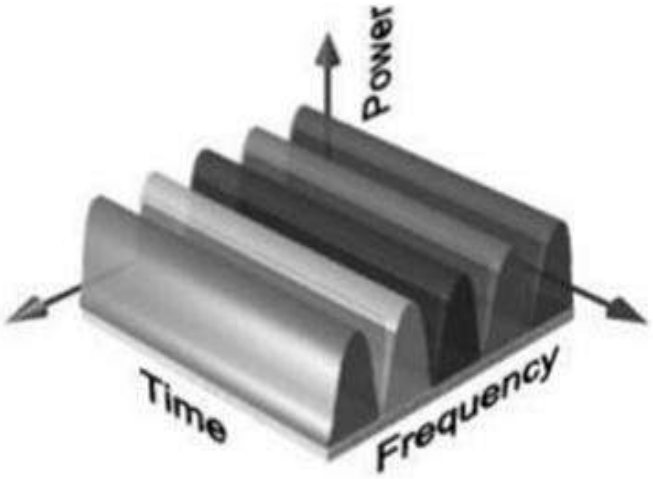


Figure 1-1 Multiple Accesses [5]

As shown in the **Figure 1-1**, a specific frequency slot is divided into time slots, so multiple user can use a specific frequency slot. The GSM system uses 25 MHz frequency spectrum in a 900 MHz band. A speed of around 14.4 Kbps is obtained in basic 2G network. The core network used in 2G is (Public Switched Telephone Network) PSTN. Circuit switching is used in GSM. As the need to send data on air interface increased, GPRS (General Packet Radio Service) was clubbed with existing GSM network. Due to this optimal speed up to 150Kbps can be reached. Still, as the need arise to increase the data rate; Enhanced Data GSM Environment (EDGE) was introduced, which increased the amount of data rata four fold times. [6]

It was also feasible to make an upgrade on current GPRS system. EDGE can also be considered 2.5G.

1.3 The third generation (3G)

3G systems use CDMA (Code Division Multiple Access) and WCDMA (Wide Band Code Division Multiple Access). CDMA is a technique in which a unique code is assigned to each user using the channel at that time. After assigning a unique code, completely available bandwidth is utilized efficiently in it. Due to this very large number of users can use the channel at the same time compared to TDMA and FDM.

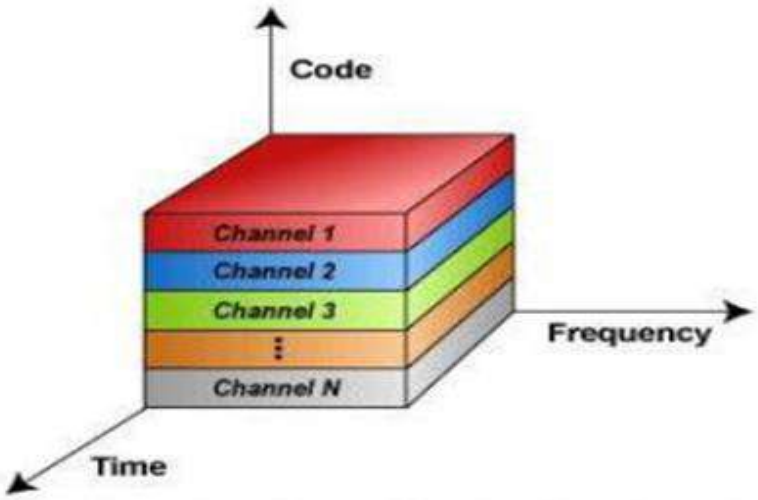


Figure 1-2 CDMA Technique [5]

As shown in **Figure 1-2**, a unique code is assigned to each user due to which N number of channels can be formed at a time. 3G uses 15 MHz to 20 MHz frequency spectrum and the frequency band for 3G is from 1800 MHz to 2500 MHz. A maximum speed of around 2 Mbps is achieved in basic 3G system. WCDMA also known as UMTS (Universal Mobile Telecommunication System) uses much larger career frequency due to which more amount of users can be accommodated at compared to CDMA. [7] The core network used in 3G systems is combination of Circuit switching and Packet switching.

To further increase the speed of data, HSPA and HSPA+ (High Speed Packet Access) was introduced. Due to HSPA+ networks can be upgraded to run at broadband speeds. The concept of MIMO (Multiple Input Multiple Output) was first introduced in HSPA+. Due to this data rates can reach to as high as 42 Mbps. [8] HSPA and HSPA+ can be considered as 3.5G and 3.75G respectively. The modulation technique used in HSPA+ was 64-bit QAM.

MIMO is a method in which concept of multipath propagation is used to improve the radio link. Same signal are received multiple times on receiver side. Due to this, the probability of error is decreased and overall performance is improved. [5]

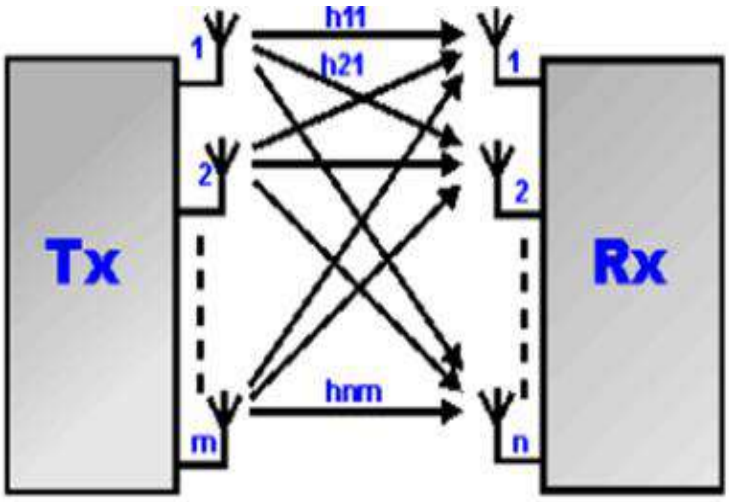


Figure 1-3 General Outline of MIMO System [5]

Another advantage in 3G system is of Hand-off. In this, user equipment is connected to two towers simultaneously due to which call drop don't take place during hand-off.

1.4 The fourth generation (4G)

LTE (Long Term Evolution) is a 4G mobile communication standard based on GSM/EDGE and UMTS/HSPA technologies. LTE uses Multi carrier CDMA or OFDM (Orthogonal Frequency Division Multiplexing). In OFDM, high data rate modulating stream is divided and then placed onto many slowly modulated narrowband closed-spaced subcarriers. [5]

The frequency band used in 4G is from 2000 MHz to 8000 MHz and uses a frequency spectrum of 5 MHz to 20 MHz. A maximum downlink speed of around 100 Mbps and uplink speed of around 50 Mbps is achieved in LTE systems. Due to such a high data rate, it can support bandwidth hungry applications like online gaming, live streaming of high definition video and voice over IP.

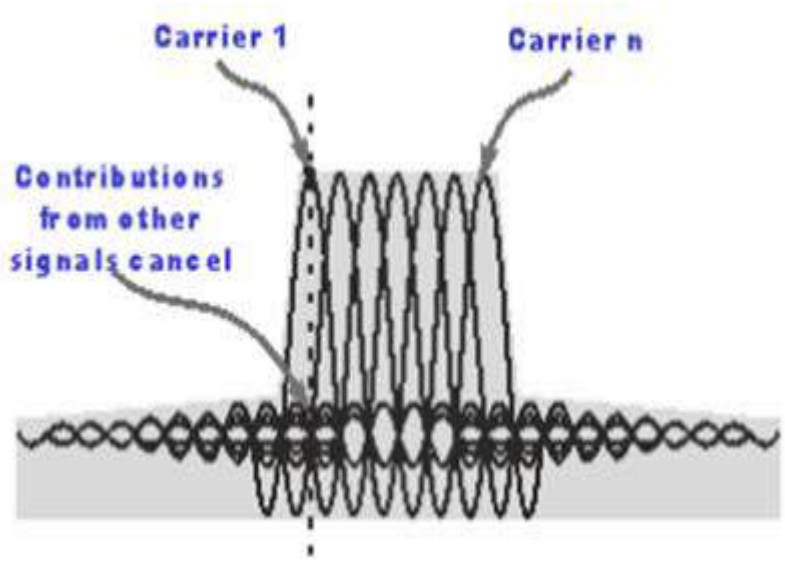


Figure 1-4 OFDM Spectrum [5]

The core network type used in 4G is IP based. 4G network has very low latencies, a wider channel and carrier aggregation up to 100 MHz. The two common modes of LTE are LTE FDD and LTE TDD.

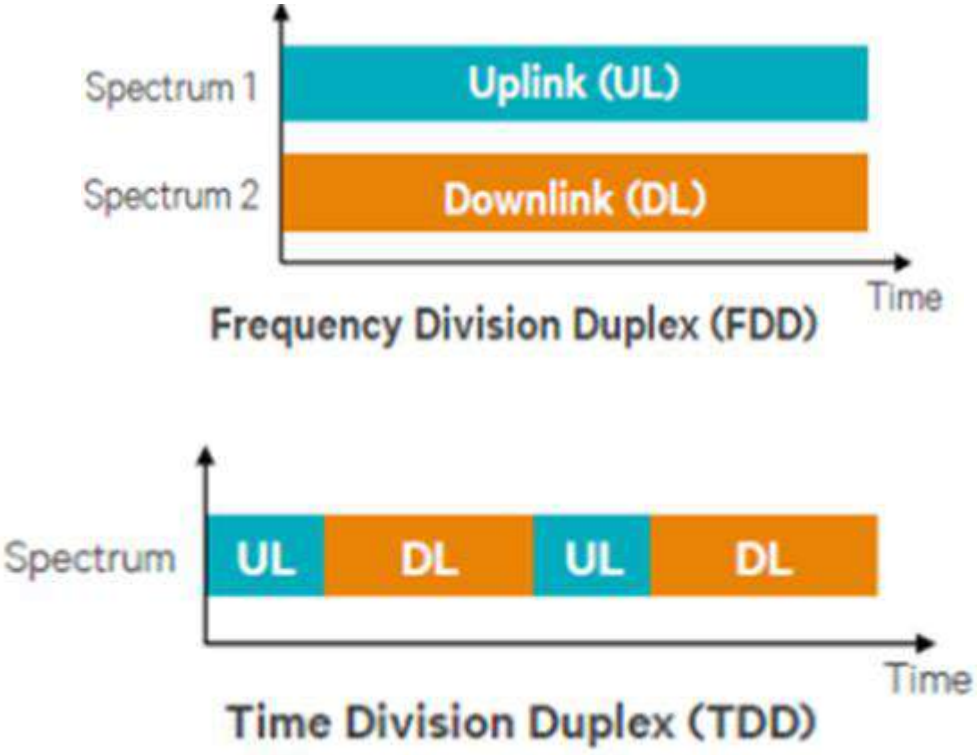


Figure 1-5 Two common modes of LTE [5]

1.5 5G technology

The 5G technology is a new revolution in the mobile market. Operators will be able to respond to market demands and serve billions of connected devices thanks to this technology, which will result in a high data volume, low latency, and likely lower costs. In this first

chapter, we'll describe a theoretical presentation on the 5th generation, whose formal name is IMT-2020, beginning with a brief historical overview and a description of the 5G's goals in comparison to the previous generation of mobile networks (4G). By demonstrating its architecture, as well as emerging technologies like as millimeter waves, small cells, massive MIMO, beamforming, and full duplex, as well as the many categories of applications for this generation, as well as frequency allocation.

1.5.1 5G objectives

5G is expected to have a significant influence on society. The need for more data on a wireless network, as well as the need for a higher-quality service, is among the factors that have led to the development of the 5G network. One of the most significant advantages of 5G is its ability to create a global network. [9]

The 5G revolution aims to achieve the following goals:

- Ensure high-speed internet access through a smartphone or tablet.
- Identifying the best debts (1 Gb per second).
- Having larger data packages: the data volume must be increased by 1000 times.
- Aim for a transmission time of less than 10 milliseconds.
- Having a shorter "latency" time gives the appearance that the network is more responsive.
- Having More Antennas: The number of terminals that may be connected by an antenna must be 100 times higher, although the number of antennas is mostly determined by the frequency used.

1.5.2 The characteristics of 5G

The fifth generation of wireless networks promises a slew of technological advancements. The parts that follow aim to clarify the performance of 5G networks and to question the parties involved on how a generic 5G service may be defined. The 5G service might be defined by all or some of the performance criteria listed below.

A. Throughput

In comparison to current technologies, the arrival of 5G will significantly increase spectral efficiency. The introduction of new techniques, such as:

- MIMO and beam formation, which allow for the creation of directed beams of light using base stations with a large number of emitters/receptors, thereby limiting the signal's power where it isn't needed. The management of bundles allows for the spatial separation of

communications that use the same frequencies, as well as the limitation of potential interference between communications and cellular units.

- Reductions in the weight of signaling in radio transmission lines, allowing for the optimization of the bandwidth dedicated to useful traffic.
- A better use of the useful spectrum by the carrier, particularly huge radio conduits, in order to optimize the MHz debit
- The dynamic management of the structure of radio trams in TDD mode, including a quick adaptation of descending and ascending ratios in function of traffic to reduce interference and adapt the bandwidth to the traffic asymmetry in real time.

This improved spectral efficiency must be translated for users into a significant increase in bandwidth while also providing ultra-high-bandwidth services (eMBB).

The provision of mobile ultra-high-definition 5G access outside of buildings, for example, should achieve a theoretical descent rate of at least 100 Mbit/s in 10 MHz, which corresponds to a theoretical descent rate of 1 Gbit/s in a simplex band of 100 MHz.

B. Latency

Another expected benefit from 5G is a reduction in communication latency, allowing for the provision of connected services that require high responsiveness but could only be delivered in a controlled environment. This improvement is the result of, among other things, the following techniques:

- Temporary acquittal of radio packages with a significantly reduced boucle.
- In the case of TDD, dynamic management of radio transmission structure.

The provision of a low-latency 5G mobile access point outside of buildings, for example, should allow for a round-trip time of less than 5 milliseconds (ms).

C. Dense connectivity

In comparison to existing technologies, such as 4G, the 5G technology should allow for a significant increase in the number of connected objects per unit of surface. This expansion is made feasible, in part, by high-speed connection protocols that use a small percentage of the available bandwidth.

The provision of a massive access point for 5G-connected objects, both outside and within buildings, should, for example, allow for a connection density of many hundreds of thousands of objects per square kilometer.

D. Trustworthiness

Some of the new uses envisaged for 5G networks need increased connection reliability with a low rate of inaccessibility.

The 5G technologies of dual connectivity and quick retransmission of HARQ data packets could help to decrease packet losses and make connections more reliable.

The virtualization of several aspects of 5G networks should improve their resiliency, and hence the reliability of network connections.

The provision of a very reliable 5G connection outside of buildings, for example, might be available 99 percent of the time.

E. Modulation

The modulation will be of the order QAM-256 (8 bits of information), thanks to improvements in the 5G link efficiency via antennae or signal processing technology. These modulations offer outstanding spectral efficiency and have allowed for extremely high data debits.

F. Accessibility technologies include:

The 5G technology is based on the OFDMA transmission technology.

G. Wave-forming forms

Despite the fact that OFDM requires the use of a cyclic prefix, which has had a lot of success and still has a lot of advantages, 5G uses other optimum waveforms that will be used until at least 2040.

Several types of 5G antennas include:

- FBMC: By dividing the frequency spectrum into several sub- carriers that are very close together and filtering them individually, it is capable of providing a very high level of spectral efficiency.
- UFMC: differs from FBMC in that instead of filtering each sub- carriers individually, UFMC divides the signal into a number of sub-bands that it filters. After that, it may be used to improve symbol interoperability protection.
- GFDM: GFDM is a flexible multi-port transmission technology that shares many similarities with OFDM. The main difference is that the carriers are not orthogonal to one other. GFDM improves the control of out-of-band emissions and lowers the average power/puissance ratio. [10]

1.5.3 NOMA Multiplexing

For the fifth generation of mobile networks, non-orthogonal multiple access (NOMA) systems have gotten a lot of attention in the last several years.

The main reason for NOMA's acceptance in 5G is its ability to use the same time and frequency resources to provide services to many users, hence improving user and system throughput. It employs a superposition code at the transmitter level, allowing the SIC (successive interference notification) receiver to distinguish between users in both the ascending and descending links.

There are two basic NOMA techniques: the realm of power and the code domain. [11]

Multiplexing in the code domain has the potential to improve spectral efficiency; nevertheless, it requires a high transmission bandwidth and is difficult to implement in current systems. In contrast, power multiplexing is straightforward to implement since no major changes to the existing network are required. Furthermore, no additional bandwidth is required to improve this efficiency. [12]

1.5.4 5G network architecture and services

A 5G network consists of a 5G access network (AN) and a 5G central network (5GC). [13]

The access network is made up of a new generation radio access network (NG-RAN: New Generation Radio Access Network) [14], which uses the new radio interface 5G (NR) [15], and/or a non-3GPP AN (for example, WiFi, xDSL, etc.) connected to a 5G base network. The various network entities are connected by an underlying TCP/IP transport network that handles the QoSdiff-serv.

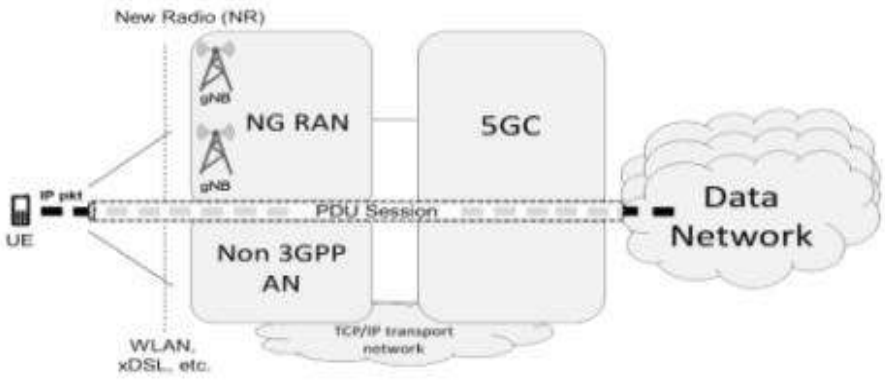


Figure 1-6 5G network architecture

A 5G network, like previous generations, connects the user's equipment (UE) to external data networks. PDU Session is the name of the 5G connectivity service.

From a transport standpoint, a PDU session consists of a series of NG tunnels in 5GC and one or more radio supports on the radio interface. Finally, this collection of "pipes" connects the UE to its control functions as well as the external data network for user traffic exchange. One of the most important tasks of a mobile network is to dynamically establish and release tunnels and porters in order to track user movements and states (inactive, connected, etc.).

A PDU session is quite similar to an EPS in LTE, with the exception of the QoS model and the user data units that are charged. In fact, a PDU session may transmit not only IP packets from the user's perspective, but also Ethernet or non-structured frames, allowing for layer 2 communications across UE groups.

The QoS 5G models are based on the new notion of flux QoS [16], where a flux is the finest granularity of QoS differentiation. Different QoS fluxes can coexist in a single PDU1 session.

Figure 1-7 depicts the divisions between 5G functions performed by the NG-RAN and 5G nodes. In general, the NG-RAN is responsible for establishing, maintaining, and disseminating portions of PDU sessions that pass over the radio interface.

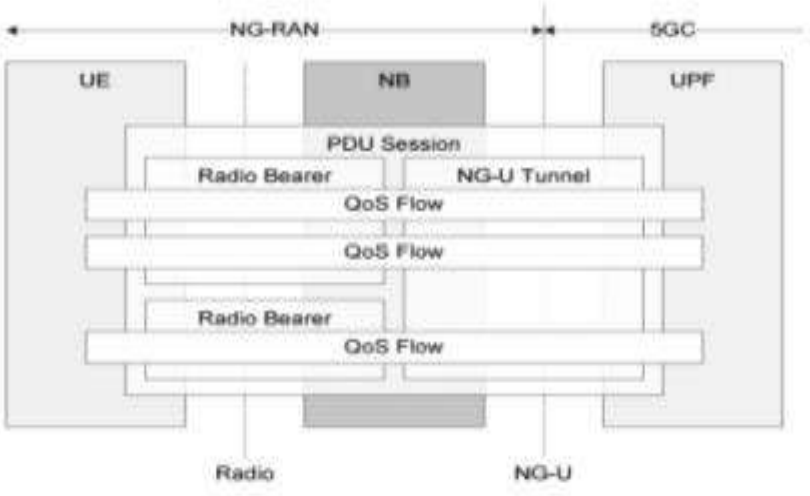


Figure 1-7 5G network architecture

1.5.5 Frequency bands

The 5G generation is the first to be able to operate on three different radio spectrums: low, medium, and high.

- The 5G low-band operates on frequencies less than 2GHz. It's about the oldest cell-frequency frequencies. It covers a huge area, but there are no big channels

available, and the majority is used by 4G. The 5G band is lower, therefore it's slower, and it's similar to the 4G. [17]

- The medium-band 5G uses frequencies ranging from 2 to 10 GHz. This covers the majority of current WiFi and cellular frequencies. [17]
- In 5G high-bandwidth mode, up to eight 100MHz channels can be used. The millimeter waves are a completely new concept. Its waves with a frequency range of 20 to 100 GHz. Previously, these waves have almost never been used for large-scale public applications. [17]

Mobile phone networks seek a balance between low-band frequencies to adequately cover the whole population, and high-band frequencies to ensure adequate capacity in areas where traffic demands are the highest. [18]

1.5.6 Enabling technologies for 5G networks

The 5th generation makes use of ultra-high frequency diffusion, i.e. millimeter waves, to transfer massive amounts of data quickly, despite the fact that the range of transmission is limited. For this, new technologies such as Massive MIMO and multi-cell processing are proposed, as well as new technologies such as Massive MIMO and multi-cell processing to ensure single-gigabit connections. The principles of these new technologies will be developed in the next years.

1.5.7 The millimeter waves

The millimeter waves are radio-electronic waves that operate at frequencies ranging from 30 to 300 GHz. Electronic devices communicate across a certain frequency range that is currently less than 6 GHz, but this band is extremely congested, and the more connected objects there are, the greater the degradation of service performance. We must use a higher frequency and a wider spectrum of frequencies for controlling and processing big amounts of data across long distances. On the one hand, higher frequencies allow for the transfer of more data per second, but on the other hand, increasing the frequency spectrum might result in an increase in the number of transmission channels. These two enhancements help to disorganize the network. Millimeter waves, on the other hand, are difficult to penetrate through obstructions, have a short range, and are easily absorbed by trees or rain. A second technology, such as a network of small antennas [19] [20], was introduced to solve these problems.

1.5.8 Beamforming

Beamforming, also known as spatial filtering or beam formation, is a technique that assists base stations in determining an appropriate route for delivering data to a user by concentrating the signals from multiple antennas into a single, powerful beam, reducing the energy used by the transmitter's secondary lobes. At the receiver level, beamforming is a spatial multiplexing technique that combines received signals in such a way that they are added in one direction while rejecting signals from other directions and treating them as interferences. The use of beamforming allows intelligent antennas to increase spectral efficiency and data debit for millimeter-wave. [21] [22]

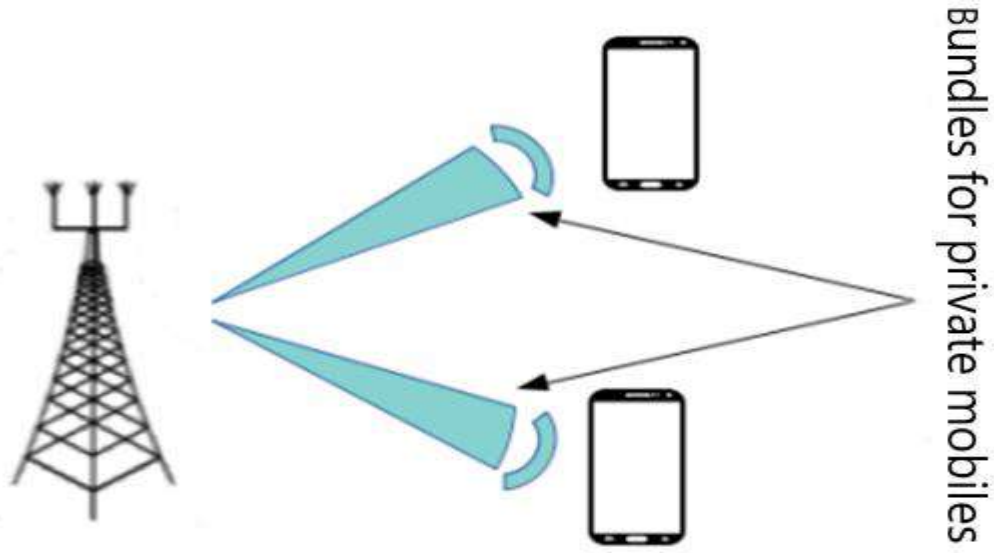


Figure 1-8 Beamforming with two beams

1.5.9 Full duplex

Today's base stations and mobile phones rely on transmitter-receivers. If they send and receive data at the same time, they should be used in a role switch; if users want to send and receive data at the same time, they should use different frequencies to avoid interfering. With 5G, meteors-receptors will be able to send and receive data at the same time and at the same frequency. This technology, known as duplex integral for signal transmission, has the potential to quadruple the network's capacity. [22] [23]

1.5.10 The 5G standard

Font 3G and the IMT-Advanced (4G), the IMT-2020, as defined by the ITU, aim to bridge the gap between global mobile communications and the technologies that will enable wireless communications by 2020. To put it another way, to designate the entire set of 5G standards. During a recent ITU-R working meeting, a decision was made to extend the

program "IMT for 2020 and Beyond," which began in 2012 and aimed to bring together all of the world's work on 5G. [24]

1.5.11 Microstrip antenna (printed antennas)

The Microstrip antenna, also known as the printed antenna, is made up of a substrate with a metallic mass plan on one side. On the other side of this substrate, a metal patch allows surface currents to be supported, resulting in electromagnetic radiation **Figure 1-9**. [25]

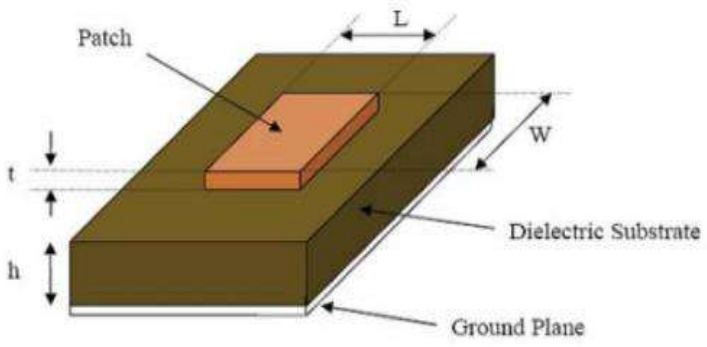


Figure 1-9 Microstrip antenna structure

Depending on its frequency of resonance, the patch antenna has many forms and may be integrated into a variety of applications.

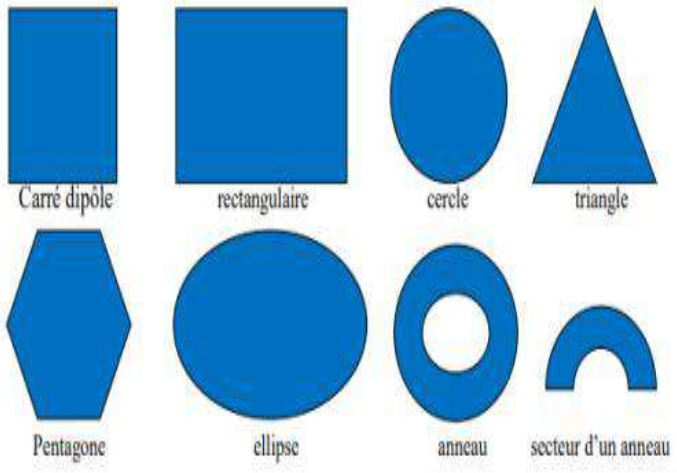


Figure 1-10 Different forms of a patched antenna

1.5.12 Advantages and drawbacks of patch antennas

When it comes to printed antennas, there are both benefits and limitations.

Comparison to other types of antennas:

- It has a light weight, a small size, and a small shape.
- It's easy to make and doesn't cost a lot of money.
- We have clever antennas, which is a relief.
- He believes in linear and circular polarization.
- A patch can handle resonant double and triple frequencies.

Inconveniences:

- Limited bandwidth.
- Demonstrated ability to manage power.
- Excitation of surface waves.

1.5.13 Techniques of feeding

Several methods are available for feeding microstrip antennas. These methods can be divided into two categories: touch and non-contact. The RF power is sent directly to the patch through a connection element such as a microstrip line in this kind of contact. An electromagnetic field coupling is used to transfer power between the microstrip line and the resonant patch of the non-contact kind. The microstrip line, the coaxial probe (contact alimentation), the aperture coupling, and the proximity coupling are the four most often used alimentation procedures (contactless power supply).

1.5.13.1 Line feed via microstrip

In this case, a microstrip line is directly connected to the radiating element, as shown in **Figure 1-11**, and the point of junction can be on the patch's symmetry axis or completely deballed to allow for better impedance adaption. [26] This sort of nutrition is simple to implement and model, but it can result in a parasitic radiation that can be significant, as well as a passing band of between 2 and 5%. [26]

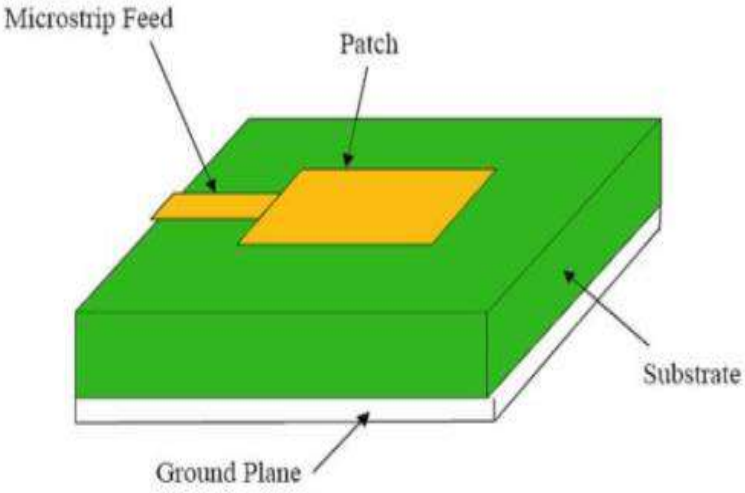


Figure 1-11 microstrip Line Alimentation

1.5.13.2 Alimentation by coaxial probe

The coaxial alimentation is shown in **Figure 1-12**; in this case, the central conductor (internal) is connected directly to the radiating element (patch) after passing through the dielectric and mass plan, and the conductor exterior is connected directly to it. The advantage of this method is that it may be applied to any patch location with ease of manufacturing and minimal parasitic radiation. [27]

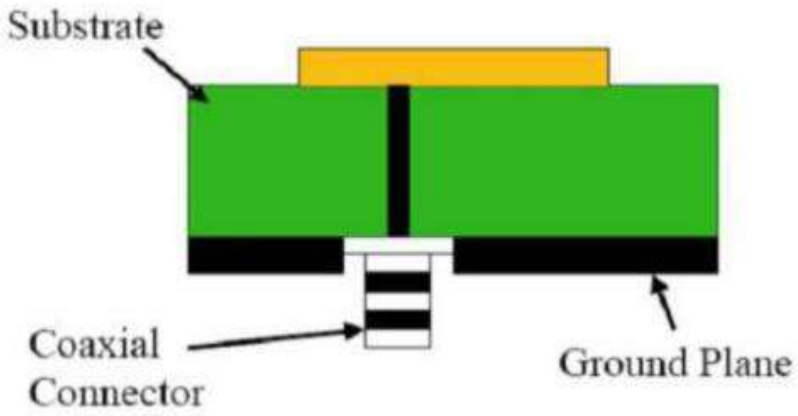


Figure 1-12 Alimentation via coaxial probe

1.5.13.3 Alimentation accompanied with a door opening

The radiation patch and the alimentation line are separated by the mass plan in this alimentation approach, as shown in **Figure 1-13**.

The connection between the patch and the alimentation line is made through a hole or a slot in the mass plan. [28]

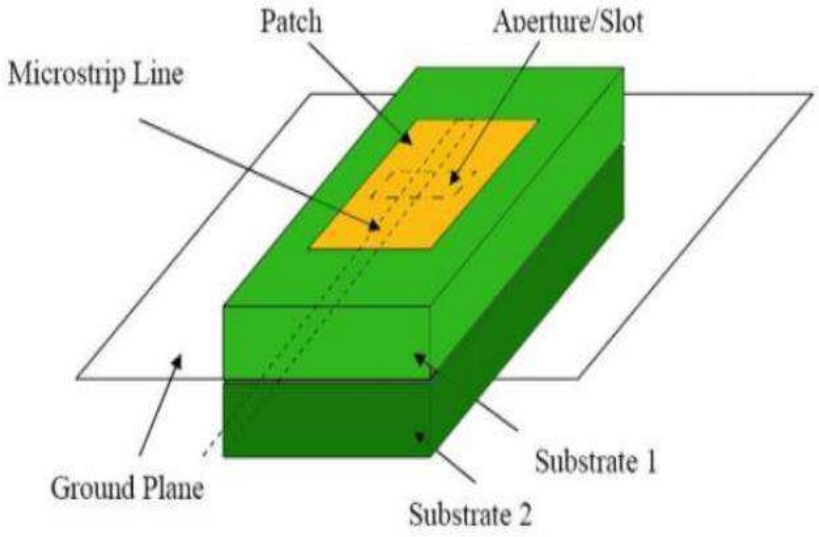


Figure1-13 Alimentation accompanied with a door opening

1.5.14 Advantages and disadvantages of 5G

I. The Benefits of the Future 5G Network:

- An increase in data rates: the 5G network will allow users to travel faster with 10 times faster data rates than 4G.
- Increased reactivity due to a ten-fold reduction in latency
- An increase in connectivity capabilities, with many more users being able to join at the same time while maintaining a high-quality connection
- A solution to the surge of mobile traffic caused by the billions of connected objects that will fill our daily lives in the future,
- A reduction in energy consumption: this technology is more efficient when it consumes less energy, which will have a positive influence on battery life.

II. The 5G network's drawbacks:

However, there are certain concerns about the 5G network, particularly in terms of radiation exposure. In fact, at a time when the influence of radiofrequency on human health and the environment is being debated, the arrival of 5G, like the arrival of 4G, will need the installation of new antennas to provide a good 5G coverage of the territory.

To determine if 5G poses a health risk, current pilot studies will allow for the measurement of public exposure to radio waves.

The dangers of 5G have also been revealed in terms of network security. In fact, the 5G network allows for the definition of priorities, allowing for better resource management based on consumption. In reality, 5G network connections will vary depending on the needs of the connected devices. For example, a tele-surgery device that requires a lightning-fast

connection and zero latency will benefit from a 5G network that is faster than your smartphone. However, the technological advancements that 5G will bring do not guarantee network security in the first place. [29]

1.5.15 Applications

The 5G revolution is expected to be more than just about speed. The debit is also rather high, allowing a large number of people or objectives to connect at the same time. However, development does not stop there. In fact, the latency has been reduced to 1 millisecond. The three main categories of usages can be grouped together by citing different cases of use and user needs:

mMTC-Massive Machine Type Communications (communications massive de type machine): in 5G systems, examples of use cases include the automation of industrial processes through the use of massive machine type communications. This use case necessitates a high level of service quality in terms of energy consumption reduction, improved connectivity, and high reliability. [30]

MBB-Enhanced Mobile Broadband (evolved mobile broadband): in major urban areas with high user density, there is a growing need for access to multimedia content, services, and data. This demand will result in bandwidth requirements, which will result in a high mobile data rate. Whatever the reception scenario, its use also addresses high-coverage and high-constant-debit requirements. [31]

URLLC-Ultra Reliable and Low Latency Communication: in future applications, URLLC-Ultra Reliable and Low Latency Communication will be used. High levels of responsiveness and dependability are required. Needs that are particularly prevalent in autonomous vehicles, industrial digitization, remote surgery, and intelligent electrical networks .

In the world of 5G, the following three use cases in various application domains are depicted in the diagram [30]:

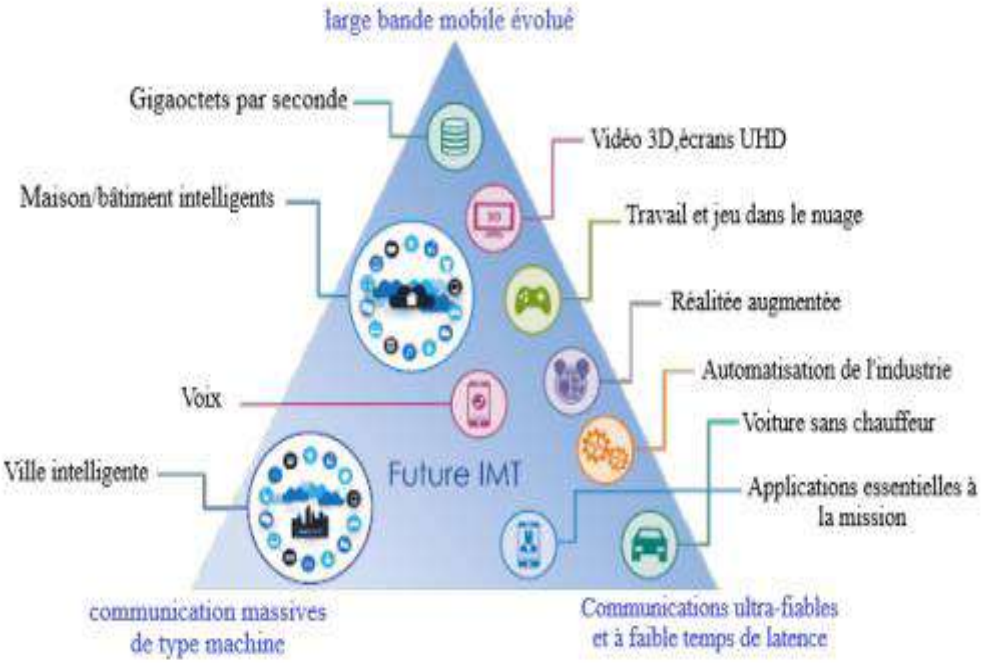


Figure 1-14 Use-case scenarios for the IMT-2020 [32]

1.6 Conclusion

In this chapter, we've given a high-level overview of 5G technologies, including the standard's goals, design, and usage categories, as well as the many technologies. Each one comes with a slew of benefits as well as drawbacks. Among these technologies, we've mentioned intelligent antennas, which allow for spectrum and energy efficiency, full duplex, which helps to double the capacity of a channel, and Small cell combined with millimeter-wave waves for a big bandwidth.

Chapter 2

Generalities on antennas and photonic crystals

Chapter 2 Generalities on antennas and photonic crystals

2.1 Introduction to antennas

A radio frequency antenna is a device that can receive and/or transmit radio waves, an antenna is a radio electric device that allows you to radiate or transmit data or capture electromagnetic waves as a receiver. The antenna is a critical component of a communication system, and its main characteristics are described below:

- Return loss.
- Gain.
- Radiation pattern
- The system's quality and reach.

2.2 History of antennas

In 1865, Maxwell synthesized a number of experimental laws discovered by his forefathers (laws of electrostatics, magnetism, and induction, to name a few). However, this synthesis was only feasible because Maxwell was able to surpass the work of his predecessors by introducing a "manifold chain" called the "conductor of motion" into an equation, whose presence ensures the unification of the edifice.

Maxwell first published his theory in 1865, in the form of twenty unknown equations. Maxwell had already rewritten his theory in the form of eight equations in the two-volume A Treatise on Electricity and Magnetism in 1873. Only later, in 1884, did Oliver Heaviside rewrite these equations in the form of equations four vectorial and scalar equations with partial derivatives that we are familiar with, Maxwell has some equations:

$$div\vec{D} = \rho \quad (1)$$

$$div\,\vec{B} = 0 \quad (2)$$

$$\mathrm{rot}\,\vec{E} = -\partial\vec{B}\,\partial t \quad (3)$$

$$\mathrm{rot}\,\vec{H} = j + \partial\vec{D}\,\partial t \quad (4)$$

With:

P is Charge Density Volumetric Density and ε being the electrical permittivity (F/m). ε0 is the dielectric permittivity in vacuum of 8.85e12F/m , and εr is the relative permittivity and

are related as ε = ε0× εr. Besides, μ is the magnetic permittivity (H/m), note that μ0 is the dielectric permittivity in the vacuum 4e-7F/m, with μr being the magnetic relative permittivity and are related as μ = μ0× μr. In the last, σ is the electrical conductivity of the environment (S/m). [33]

2.3 General Theory

A radio electronic antenna converts existing electrical currents in the conductor, or a transmission line (tension and current) to electromagnetic waves in the space (electrical and magnetic fields). In contrast, the electrical field is converted into an electrical signal during the reception.

2.3.1 Isotropic antenna

The isotropic antenna is a fictitious antenna that radiates the same field in all directions. It serves as a guide for determining the "gain" of antennas. [34]

2.4 Features

The following are the most important features:

2.4.1 Frequency of use

An antenna is typically used with signals centered on a specific frequency for which the antenna has the best capabilities for emitting or receiving electromagnetic energy in the surrounding space.

The resonance frequency of an antenna is determined first by its own dimensions, but there are also elements that have been added to it that can be approximated.

A return loss threshold of -10 dB determines the minimum and maximum usage frequencies; the difference between the two frequencies corresponds to the bandwidth.

- **For example:** a traditional antenna is a half-wave length dipole

- Antenna that responds to frequency. This has a length of a half-wavelength of a wave and a bandwidth of about a 1% in practice, and at high frequencies, the conductor's diameter is less important than the length of the wave which increases the bandwidth significantly.

- **Generally speaking:** The bandwidth of an antenna decreases as the antenna becomes smaller in comparison to the half wave dipole there are no large banded and compact antennas. At the very least, with reasonable losses. When the diameter of the conductor increases, so does the bandwidth of antenna flair.

Some so-called "multi-band" antennas can work properly on discontinuous frequency band segments without the use of a special device.

Others require the use of an impedance circuit adapter in order to function properly. [35]

2.4.2 Antenna Impedance

The notion of antenna impedance is a generalization of the notion of impedance used for other passive components (resistances, compensators...) in antennas.

Is thus a complex relationship observed between tension and current at the start of a broadcast. The importance of this concept is critical for ensuring optimal energy transfer between antennas and the devices that are connected to them using adaptation strategies.

An antenna connected to its two access points is thus a dipole with a complicated impedance R+jX, where R and X represent the antenna's resistance and reactance, respectively. The resistance of an antenna R is the sum of two forms of resistance that represent the various uses of the absorbed energy. The first Rp is the resistance to losses caused by the Joule effect in the antenna. The second Rr is the radiation resistance, which is proportional to the useful energy emitted by the antenna in the space around it. [34]

Frequently, antenna designers strive for a clean R= 50 ohm and X= in order to feed the antenna over a 50 Ohm (rarely 300 or 600 Ohm) or 75 Ohms line.

In fact, the ideal antenna should have a pure resistance to its feeding line. Equal to this line's "characteristic impedance" The alimentation line will then work "in matching mode progressive." This is the situation. It is almost often sought after at frequencies above 30 MHz since it optimizes the energy transfer and, more importantly, ensures the delivery of a reliable signal without imposing any restrictions conditions for the length of this line. The measurement of the standing wave ratio allows you to ensure that the line is operational. However, for low frequencies, it is sometimes impossible to obtain impedance. 50 Ohms of resistance Intercalate between the antennas. And an impedance transformer on the supply line with the goal of transforming the complex impedance of the antenna to a pure resistance, usually 50 Ohms. This is an antenna adapter, or "adaptation device." The adaption device is sometimes made up of the line itself. As a result, it becomes critical, and the stationary distance ratio rises. [35]

2.4.3 The resonance

An antenna is said to be on a frequency if the imaginary jX term is null at that frequency. The power absorbed by the antenna is the power absorbed by the resistance R.

The resistance Rr is sometimes referred to as fictive since it is not subject to the Joule law :in fact, unlike true resistance, the power absorbed by this resistance is transformed into electr omagnetic radiation. [35]

2.4.4 Polarization

The polarization of an antenna is determined by the electrical field E of the target. As a result, a horizontal dipole half wave has horizontal polarization, while other antennas have elliptic or circular polarization. In this terrestrial reception optic, the antenna "type Yagi" attenuates the signal of a factor 10 or (20 dB) throughout its rotation from horizontal to vertical polarization for the same transmitter. The difference between the received polarization and that of the antenna causes attenuation, which can be total if the polarization is perpendicular. When the transmission and reception antennas are oriented in an asymmetrical manner, such as with failing or unstable satellites, circular polarization is used. [35]

2.4.5 Diagram of the Radiation

The isotope antenna, which radiates in all directions in the same way, is a theoretical model that is impossible to achieve in practice. In reality, an antenna's energy is distributed unevenly throughout space, with particular directions being prioritized: these are the "radiation lobes." The radiation pattern of an antenna allows you to see these lobes in three dimensions, either horizontally or vertically, including the most critical lobe. The proximity and conductibility of the ground or conductor masses surrounding the antenna can have a significant impact on the radiation diagram. Antenna measurements are taken in an open space or in an anechoic chamber. [35]

2.4.6 Directivity

The antenna's directivity is a key feature to consider while choosing an antenna. An equidirective or omnidirectional antenna radiates in the same direction in all horizontal directions. A directional antenna has one or two "primary" lobes that are significantly more essential than the others. it will be much more directive because the most critical lobe will be close. The beam width corresponds to the size of the main lobe between 3 dB attenuation angles. The size of an antenna is an important factor in determining its direction. Antennas with high gain and directivity will continue to be large in comparison to the length of the

wave. In fact, there are mathematical relationships (Fourier transformations) between spatial characteristics and the diagram of propagation. [35]

2.4.7 **Gain**

The gain is the increase in power emitted or received in the primary lobe. It's because the energy is focused in one direction, similar to how light energy can be concentrated using a mirror and/or a convergent lentils. It's measured in decibels relative to the isotropic antenna. For an antenna, the mirror can be made up of a reflector (plane or parabolic screen) in a Yagi antenna, for example. [35]

2.4.7.1 Seconder lobes

Antennas near the primary lobe have relative minima and maxima called "secondary lobes," which are attempted to be minimized. Large-directivity antennas also have weak and irregular lobes in all other angles, which are referred to as "diffuse lobes."

The general level of these secondary lobes describes the antenna's sensitivity to interference (in telecommunications) or image quality (in sensing). A low-gain direction can be used to eliminate a dangerous signal (in reception) or to avoid radiating in an area where it might interfere with other emitters. [35]

2.4.7.2 Vertical angle of departure

When an antenna is close to the ground, especially at high and medium frequencies, is determined by the distance from the ground. In the horizontal plane, this results in a loss of gain. The performance of an antenna in relation to ionospheric propagation modes is determined by the angle of the main lobe in the vertical plane « departure angle ». [35]

2.4.8 **Efficiency**

The total amount of power emitted in all directions determines the effective radiating power. The relationship between the power supplied by the transmission line and its output determines its performance. [35]

- **The radiation resistance:** The energy absorbed by the radiation resistance is really the energy radiated by the antenna.

- **The ability to withstand losses:** The energy absorbed by this resistance is dissipated by the antenna as heat, which is joule in the resistances or lost in the diodes. The ratio between these two resistances determines the yield. If the loss resistance against the radiation resistance is low, an antenna will yield a good return. Antennas of the type dipole half wave or monopole have far higher radiation resistance than loss resistance,

hence their yield is good. However, if the antenna's dimensions are small in comparison to the half-wave dipole, its radiation resistance will be reduced. This is when the real problem of will emerge, and it will be necessary to look for ways to reduce loss resistance as well (better conductor quality, larger conductors, etc.). When considering the power applied at the transmission line's entrance, the yield is obviously lower, as a portion of the energy is dissipated in this line. The losses in decibels per unit of length for a given frequency characterize a line. However, if the line becomes the home of stationary waves as a result of the disconnection, the losses in the line will be even greater. [36]

The efficiency defines the effective radiation power; non-radiation power is dissipated thermally in the form of conductors, and other components, limiting the tolerable power. The maximum tolerated power depends on the electrical field before priming at each point of the antenna, in the lines, points, guides, supports, and isolates. The most critical component is the transmission line, whether coaxial or guide: its diameter, as well as its dielectric, must be adjusted. [36]

2.4.9 Dimensions and shapes



Figure 2-1 a rotating HF multiband antenna of the Yagi type

The shape and proportions of an antenna are extremely variable: the antenna of a mobile phone is sometimes undetectable because it is stored inside the case or is limited to a small growth on the device, but the Arecibo radio telescope's parabola is over 300 meters in diameter. To put it another way, for the same frequency of use, the dimensions of an antenna will be significantly larger, resulting in a higher gain and a narrower primary lobe. Antennas directions can be fixed for point-to-point connections or relative for mobile communications. Satellite tracking antennas can be oriented in azimuth (horizontal direction) and site (height above the horizon). [36]

2.4.10 **Elemental antennas**

Elemental antennas can be used alone or as network elements, as well as the source of a reflector system or as parasite elements. These antennas only allow for linear polarization.

2.4.10.1 Isotropic antenna

This is an improbable theoretical reference that would spread out in all directions. it is only used as a guide for calculating profit .The dipolar antenna, also known as the "dipole half wave " or "doublet half ," is made up of a conductor with a length equal to the half-length of an wave its characteristic impedance is resistant and close to 73 ohms for an isolated dipole in space. [36]

2.4.10.2 The "monopole" antenna

It is made up of a length-equaling quart-length-of-wave element that is perpendicular to a conductor plan. It acts as a half wave -dipole, the conductor's plan acting in the mirror. His characteristic impedance is half that of the dipole, or around 37 ohm. Its shape is determined by the frequency, ranging from a VHF "parapluie antenna" to a kilometric "nape antenna." [36]

2.4.10.3 Slot antenna

At high frequencies (hyper frequencies), waves are easier to manipulate than currents and tensions; a radial fete attached to a wave guide is equivalent to a dipole attached to a symmetrical line (duality). [36]

2.4.10.4 Array antennas

Elemental antennas can be linked together in one or two-dimensional networks, increasing gain and directionality. The phase and amplitude of individual excitations can be changed to alter the diagram of an antenna network. [36]

2.4.10.5 Yagi-Udo antenna with parasitic elements

It's the most well-known to the general public: it is used to receive analogue or digital terrestrial television. The number of elements determines its gain and direction. This is a type of an antenna network in which the parasitic elements are fed by coupling, depending on their length. [36]

2.4.10.6 Patch antenna

A planar antenna, also known as a patch, is a plane antenna with a radiating element that is usually a square conductor separated from a conductor plan by a dielectric lame. Its implementation resembles a double-faced, substrate-printed circuit and so lends itself to industrial manufacture. [36]

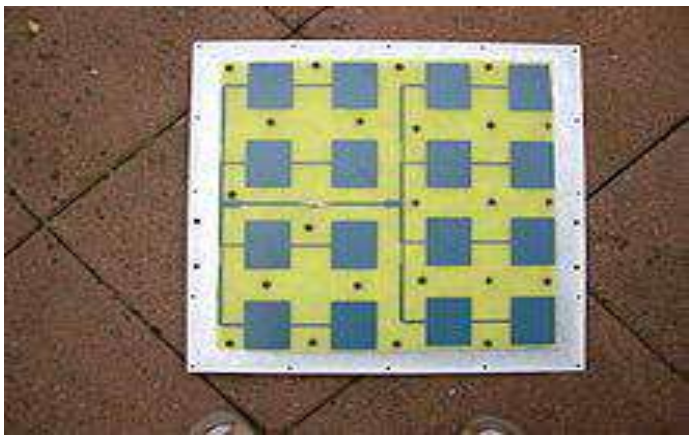


Figure 2-2 Patched 16-antenna network

The notion of a patch antenna first appeared in the 1950s, but it was not fully developed until the 1970s, when it became popular due to the miniaturization of radio communication systems. This sort of antenna can be used alone or as part of a network. [36]

2.4.11 **Fields around an antenna**

When an antenna is used for broadcasting, it only creates a plane wave at a particular distance. In the environment of the antenna, four zones can be distinguished as one gets further away from it:

2.4.11.1 Zone of Active Fields

The E and H fields, which are dependent on the tensions and currents on these conductors, are located very close to the components of the antenna. Near a high-tension wire, there will mostly be a field E, and near currents, there will primarily be a field H. [36]

2.4.11.2 Rayleigh Zone (Rayleigh Zone)

Even if the E/H ratio is already close to 377 Ohms, there is a zone where the power per unit of surface decreases slightly as distance increases. This zone, which is most noticeable for gain antennas, extends up to a distance equal to the square of the antenna's dimension (measured in a perpendicular direction to the direction of interest), divided by half wavelength. [36]

2.4.11.3 Fresnel Zone

Beyond the Rayleigh zone, the E/H ratio is balanced at 377 ohms.

However, when the antenna is large, there are significant changes in the fields, as well as ripples. In this zone, it is still impossible to measure the antenna gain. In the direction of maximum radiation, the various parts of the antenna that were previously in phase at infinity are no longer in phase. [36]

2.4.11.4 Fraunhofer Frostings zone

It is defined as follows: In this zone, if one moves indefinitely in the same direction, one notices that the difference in distances between the antenna locations is no longer variable. The various parts of the antenna are supposed in the direction of maximum radiation. They stay in phase indefinitely, and they stay in phase well. One could consider this zone, which extends indefinitely, to be an aircraft, with planes, planes The size of the fields shrinks by 1/r, the power per unit of surface shrinks by 1/r2, and the size of the fields may be measured. The gain of the antenna It is also only in this zone that the radiation diagram is valid. This zone begins at a distance equal to twice the square of the largest dimension and is perpendicular to the desired direction, divided by the wavelength. For high-gain antennas, this distance could be quite significant.

It's crucial to know how to define the Fraunhofer zone if you want to measure the gain of a high-gain antenna. For example, the Fraunhofer zone begins at more than 60 meters on the axis of a 1 m diameter for a parabolic antenna operating at 10 GHz. [36]

2.4.12 **Environment effect**

The environment around an antenna is not always clear. While fixed high-frequency antennas are usually well shielded from nearby obstructions, this is not the case with mobile antennas, which are sometimes integrated into larger systems.

This is the case, for example, with quarter-wave antennas integrated into portable radio communication systems, or with radio modems linked to computer systems, which are frequently installed in cramped places, The antennas for medium and low frequencies, on the other hand, will be influenced by the sun due to their size Metal objects placed at a distance of the order of the length of a wave can produce a shadow effect in the direction of the wave if their size is of the order of the length of the wave or greater, but it's more of a case of "masque" than of properly defined disturbances. [36]

It is known that the addition of conductors near a radiating element can be used to change the characteristics of that element's radiation; however, the presence of corps conductors in the immediate vicinity of the antenna will cause unwelcome disruptions in the operation of the antenna. In general, the frequency of an antenna’s resonance is determined by its capacity in relation to its surroundings, particularly around the venters of tension. As a result, if a body when the conductor is close to the antenna's extreme (tension vent), an audible signal will be heard. Resonance frequency is being reduced. If the body is large in size and attached to the

ground or mass, there will be an additional charge. Collapse of radiation resistance, since the electrical field lines will be rejoined Instead of dispersing into space, the masses take a short patch. [36]

The inductance of parties subjected to a current venter affects the frequency of resonance of an antenna, As a result, if a conductor is placed parallel to a current venter and is long enough to be the seat of intuit currents, the inductance of the antenna will decrease and the frequency of resonance will increase, This explains why, for a quarter-wave antenna, nearby conductors do not have the same effect whether they are at the summit (tension vent) or near the base (venter de courant), If the entire length of an antenna is parallel to a conductor or a mass of metal, the two effects listed above will combine: the resonance frequency will be little changed, The resistance to radiation will be influenced by this plan conductor parallel to the antenna, If the distance on the plan is very close to the fourth wave, this effect will be very strong: in this case, there will be no antenna, only a line, and the abonnement will be effected.

For low-frequency antennas parallel to the ground, the ground will undoubtedly represent this conductor plan; In general, one should keep an antenna far enough away from the plan de masse or the ground to prevent the resistance to radiation from evaporating. [36]

Although a re-adaptation of the antenna is possible, the band width of the antenna will be reduced, and if the radiation resistance is reduced as compared to the ohm resistance, the yield will be reduced, sometimes, one tries to reduce the entanglement of an antenna by bringing it closer to a metallic design. As a result, we must be aware of the following issues: Patch antennas can be seen here. [36]

2.4.13 **Mechanical realization**



Figure 2-3 Plemeur-Bodou Radom

An antenna is protected by a redeem, which is an impermeable shield.

2.5 Substrates with a Bandgap

A new technology has evolved in the last decade that could be the key to producing ultra-wideband micro strip antennas. This technology manipulates the substrate in such a way that surface waves cannot form, resulting in increased antenna efficiency and bandwidth while lowering side lobes and electromagnetic interference. Photonic Crystals are present in these substrates. [37]

2.5.1 Photonic Crystals in History

Photonic crystals are a type of periodic metallic, dielectric, or composite structures that have a forbidden band of frequencies in which wave's incident from different directions destructively interfere and hence cannot propagate. The bandgaps can be in one, two, or three-dimensional planes, depending on the dimensional periodicity of the crystal structure, with the amount of complexity rising When the dimensions grow larger. [38]

Eli Yablonovitch, while at Bell Communications Research in New Jersey, developed and produced the first photonic-crystal structure in 1991. As seen in **Figure 2-4**, Yablonovitch created the crystal structure by physically drilling millimeter-sized holes into a material with a high dielectric constant. This patterned material, dubbed "Yablonovite," prevented incident microwave signals from propagating in any direction along a unit sphere — in other words, it had a three-dimensional effect bandgap26, 27. This framework has become the foundation for most of this field's research, with applications that are still in use today. [38]

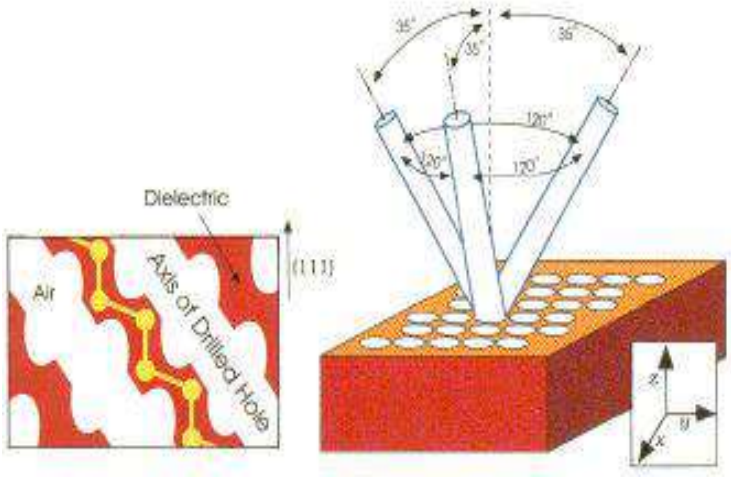


Figure 2-4 Technique used to fabricate the first 3D PC structure, the Yablonovite

Because of its three-dimensional character, the bandgap rejects incident energy from all directions around a unit sphere, making it a superior reflector or mirror.

Instead, the bandgap in a 2-D photonic crystal only occurs within a plane, allowing propagation along only one axis of the crystal. Because the "rejection plane" might be in the

plane of the patch to prevent surface wave production, this is an ideal circumstance for micro strip antenna designs. A triangular lattice, as seen in **Figure 2-5**, is an example of a 2-D photonic crystal. The next section will go into the intricacies of this lattice structure and how a bandgap is generated, as well as several other topics. Crystals' fundamental properties. [38]

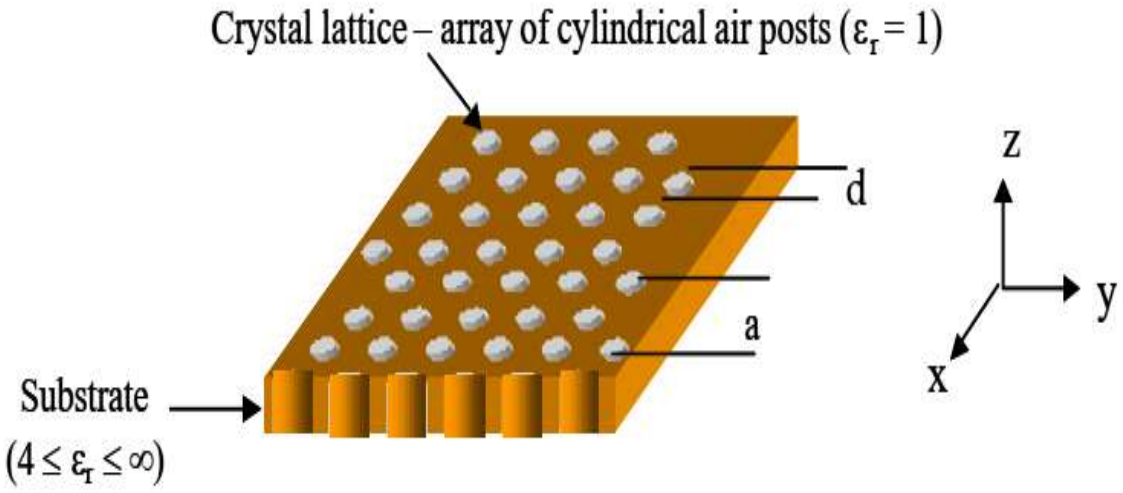


Figure 2-5 photonic crystal structure patterned with a triangular crystal lattice

The crystal lattice is of cylindrical air posts in a high dielectric substrate

2.5.2 **Photonic Crystal Basic Properties**

2.5.2.1 The Cellular Unit

A crystal is defined as "a homogeneous solid created by a recurring, three-dimensional pattern of atoms, molecules, or forms, with fixed distances between constituent pieces," according to the American Heritage Dictionary of the English Language. The unit cell of a crystal is this self-replicating pattern. The unit cell for the triangular crystal lattice illustrated in **Figure 2-6**. The crystal geometry (shape, thickness, etc.) as well as the material properties (dielectric or magnetic) and the lattice spacing (represented as dimension "a" in **Figure 2-6**) of each individual atom or molecule are all stored in the unit cell. The periodicity in the crystal is provided by this replicating unit cell. And is in charge of the bandgap's placement and size. [38]

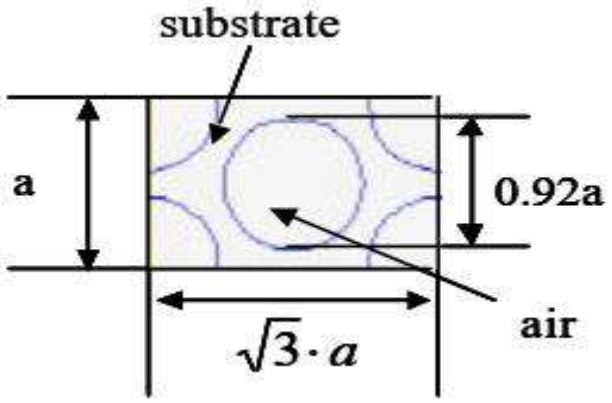


Figure 2-6 illustrating the unit cell of the triangular crystal lattice

2.5.2.2 The Gap in the Band

In a high dielectric material with integrated photonic crystals, a bandgap is obtained as a first order approximation when an incident electromagnetic field propagates with a guide-wavelength (i.e. f r c e = l) nearly equal to the crystal's lattice spacing29. For high index materials, this crude estimate locates the center of the bandgap, which can stretch higher than 10% of the center frequency 29. **Figure 2-7** depicts a typical transmission coefficient (s12) plot for a 2-port network constructed on a photonic crystal substrate, such as a micro strip transmission line. This graph shows that when port 1 of the transmission line is activated, the energy is attenuated by nearly 20dB as it travels from port 1 to port 2. Consequently, the A stopband filter response is introduced by the photonic crystal. [38]

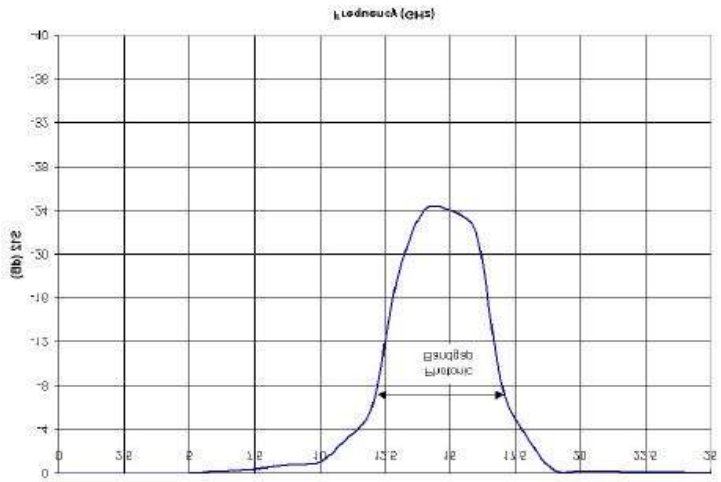


Figure 2-7 Transmission loss plot illustrating a bandgap in a micro strip transmission

The creation of the bandgap is indeed influenced by the crystal's periodicity, but it is also influenced by the refractive index (dielectric constant) ratios between the base material (the substrate as a whole) and the crystal's impurities. [38]

For the bandgap to occur, the refractive index ratio must be at least 2:1 (substrate-to-impurity) 30. The broadest bandgap is obtained for the 2-D triangular structure when the impurities (the cylindrical post) are made of air (err =1) and the base material has a high dielectric constant (for example, err =10). With correct crystal spacing's, a 10:1 dielectric (3.16:1) ratio would satisfy the index requirement and generate a broad bandgap. This explains why a high dielectric constant is required; Patch antennas are developed on a photonic crystal substrate as a substrate. [38]

2.5.2.3 Periodicity defects

A photonic crystal functions similarly to a band stop filter, rejecting energy propagation over a specific frequency range. However, once a flaw is inserted into the crystal that interrupts the periodicity, an area to localize or "trap" electromagnetic energy is created. A passband response is formed in this region. At microwave frequencies, this ability to confine and steer electromagnetic energy has various practical applications, including filters, couplers, and, most notably, antennas. [38]

This seemingly simple concept of embedding imperfections in a photonic crystal structure presents a novel approach to micro strip (patch) antenna design. The concept is to create a patch antenna on a 2D photonic crystal substrate, with the patch acting as a "fault" in the crystal structure. A crystal array of cylindrical air holes is imprinted into the patch antenna's dielectric substrate in this scenario. By not patterning the area under the patch, a flaw in the photonic crystal is created, causing the EM fields to be localized. The periodicity of the photonic crystal in that plane prevents surface waves from developing in the XY plane of the patch. [38]

Surface wave suppression improves operational efficiency; all of this has to do with bandwidth and directivity. While decreasing side lobes and coupling, two fundamental challenges in micro strip antenna design. A photonic crystal patch antenna was created using these concepts. The analytical characterization of photonic crystals and how to integrate photonic crystals with micro strip antennas are covered in the next section.

2.6 The s_{11} Reflexion Coefficient

When an incidental signal changes its propagation environment or encounters a new interface, one portion of the incidental signal is reflected and the other component is sent into the new environment. An antenna's coefficient of reflection is defined as the ratio of incident wave amplitudes to reflected wave amplitudes. [39]

With impedance antenna Z connected to the source by a characteristic impedance line Z_s (often equal to 50), the coefficient of reflection may be calculated as follows:

$$s_{11} = \frac{(Z_e(f) - Z_0)}{(Z_e(f) + Z_0)}$$

With:

Z is the antenna's entrance impedance and Z_0 is the characteristic impedance (generally equal to 50). Besides, the coefficient of reflection module is often expressed in decibels (dB) and is designated as $|s_{11}|$. It is defined as follows:

$$s_{11}\text{dB} = 20\log s_{11}$$

The coefficient of reflection may be used to determine an antenna's adaptability quality.

In fact, as his module approaches infinity, the antenna becomes more appropriate. Often, an antenna's resonance frequency is the one with the lowest reflection coefficient.

Chapter 3

Slot antenna design: Simulations and results

Chapter 3 Slot antenna design: Simulations and results

3.5 Introduction

In this chapter, a rectangular micro strip patch antenna is examined and its properties are simulated using CST Studio Suite. The length of the micro strip patch rectangular antenna is calculated in the antenna design. The substrate provides mechanical resistance to the antenna's overall design, and surface waves propagate through it as well. If we modify the substrate material and thickness of a micro strip antenna, the system's performance changes as the dielectric constant (r) changes.

There are a wide range of substrate materials available for designing patch microstrip antennas with desirable mechanical, thermal, and electrical properties for use in plane and conformal antenna designs.

3.6 Software

This experiment is an introduction to CST software (Computer Simulation Technology) which is powerful numerical full electromagnetic simulator. It simplifies solving complex structures as it solves for Maxwell’s equations numerically inside the structure. CST gives a complete insight about the E and H fields behaviors within the structure in either time or frequency domain. It also enables prediction of designed circuit response before going into the complicated and costly process of fabrication.

This experiment introduces the following:

• Creating new project

• Setup a new design

• Creating a microstrip antenna design

• Results extraction and evaluation

3.7 Rectangular microstrip patch antenna

Using the CST studio software, a simulation of a microstrip antenna was created.

Work on designing a microstrip antenna with a microstrip alimentation line. On 29 GHz the frequency ranges from 20 to 36.

We drew out the mass plan. After that, we create the substrate, the patch, the alimentation line, and the antenna. [39][40]

We're working on a patch rectangular.

All of this is seen in **Figure 3-1**.

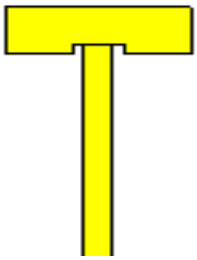


Figure 3-1 The rectangular microstrip antenna

This antenna is in the shape of a T, and it was created through a series of parameter changes.

3.8 Antenna design

This table **(Table 3-1)** shows the parameters of the microstrip antenna structure (feeder, substrate, patch, cylinder and slot). We define the parameter and its millimeter value, along with a brief discussion of each parameter.

Table 3-1 The parameters of the microstrip antenna structure

Name	Expression	Value
w	25	25
l	25	25
h	1,6	1,6
t	0,0035	0,035
wp	7	7
lp	2,5	2,5
wc	2	2
wf	1,05	1,05
lf	(1/2)-(lp/2)	11,25
lc	0,5	0,5
rm	1,2	1,2
ws	0,2	0,2
ls	0	0

3.9 Simulation outcomes

3.9.1 Return loss and bandwidth

Figure 3-2 depicts the antenna return loss simulation. At 29 GHz, a return loss of -10 dB is obtained.

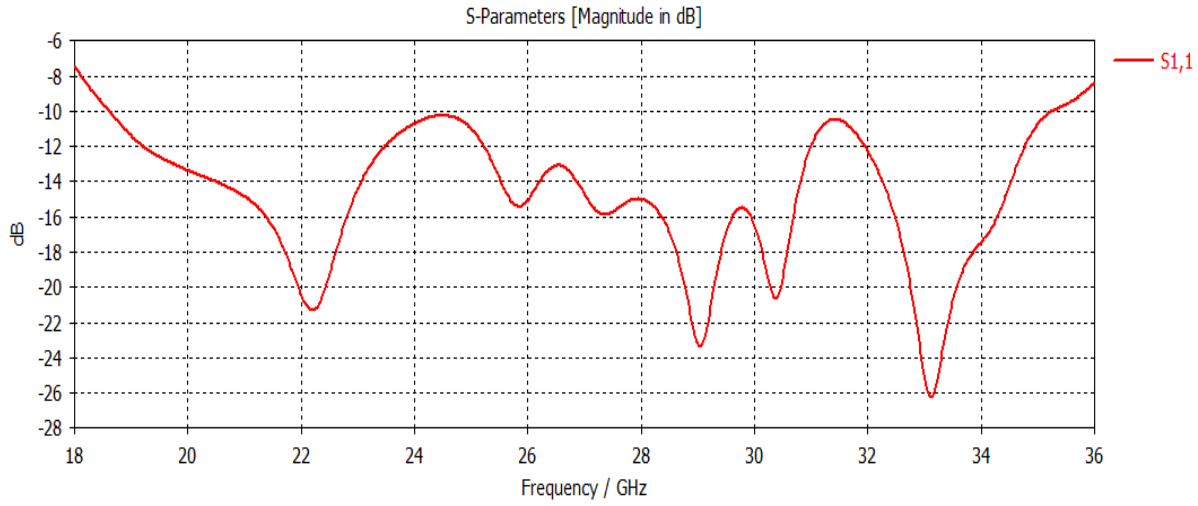


Figure 3-2 S-parameter of microstrip antenna

The bandwidth is defined as the frequency range in which particular antenna parameters are within the operating range.

3.9.2 Voltage standing wave ratio (VSWR)

The relationship of this antenna's permanent stationary wave at 29 GHz is shown in **Figure 3-3**. The VSWR must be less than 2 in order to have a good antenna design. If the VSWR is more than 2, that means the reflection coefficient is greater than -10 dB.

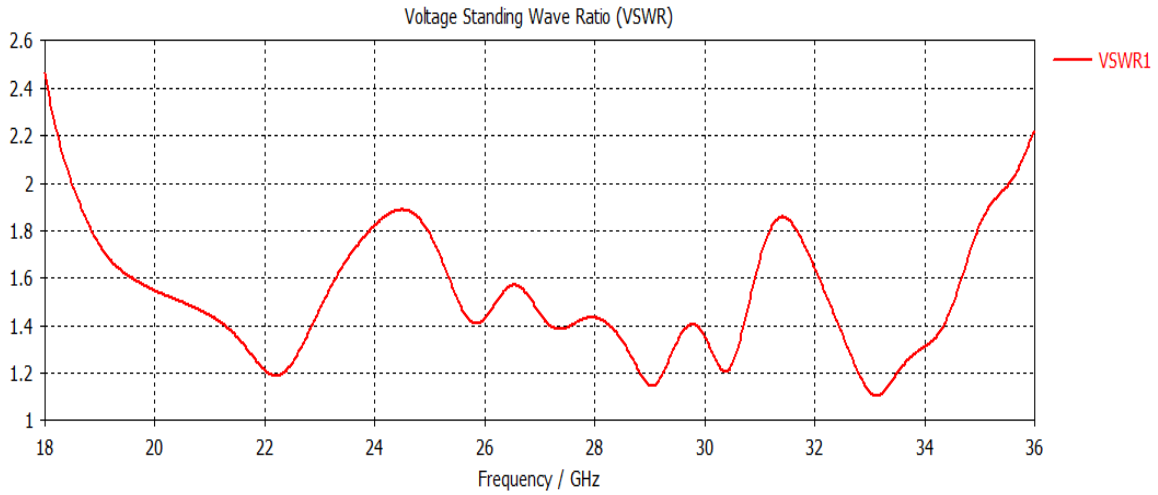


Figure 3-3 VSWR at the microstrip antenna resonance frequency

3.9.3 Gain

The gain curve is shown in **Figure 3-4** below. A gain of 4.88 decibels has been achieved.

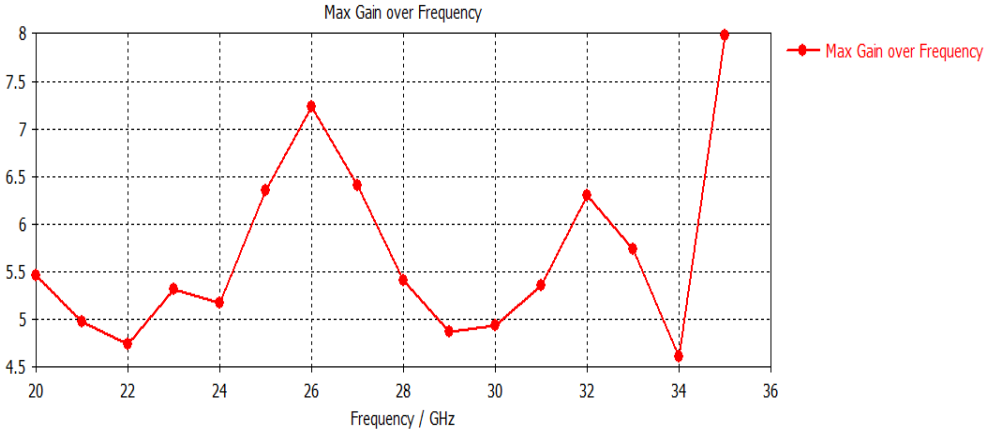


Figure3-4 Achieved Gain for microstrip antenna

3.9.4 Directivity

In order to transmit or receive power, it is desirable to maximize the pattern of radiation of the antenna's response in a fixed direction. Similarly, the directivity is solely determined by the shape of the radiation pattern. As shown in **Figure 3-5**, the designed antenna has a directivity of 4.88 dB at 29 GHz.

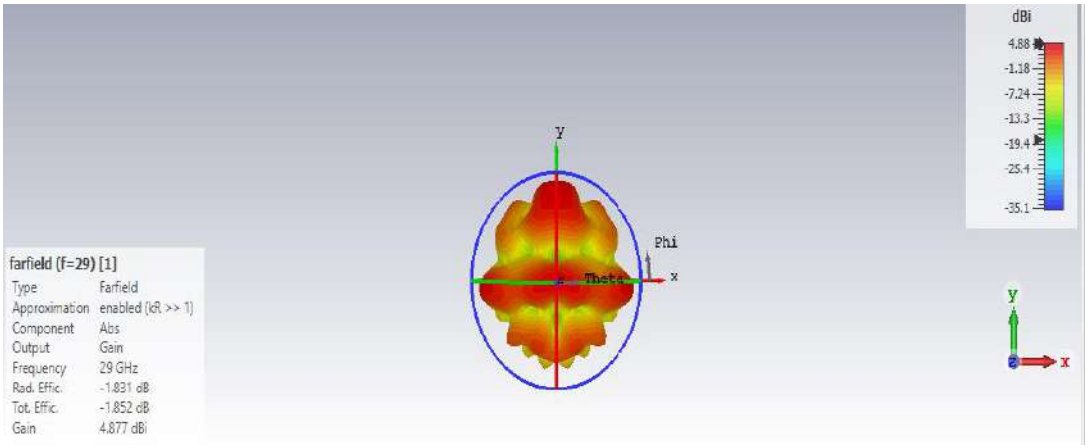


Figure 3-5 3D representation of microstrip antenna directivity

The simulations show a microstrip rectangular antenna, with a gain of Gr= 6.22 dB. According to **Figure 3-6**, the front-to-back ratio is also quite good.

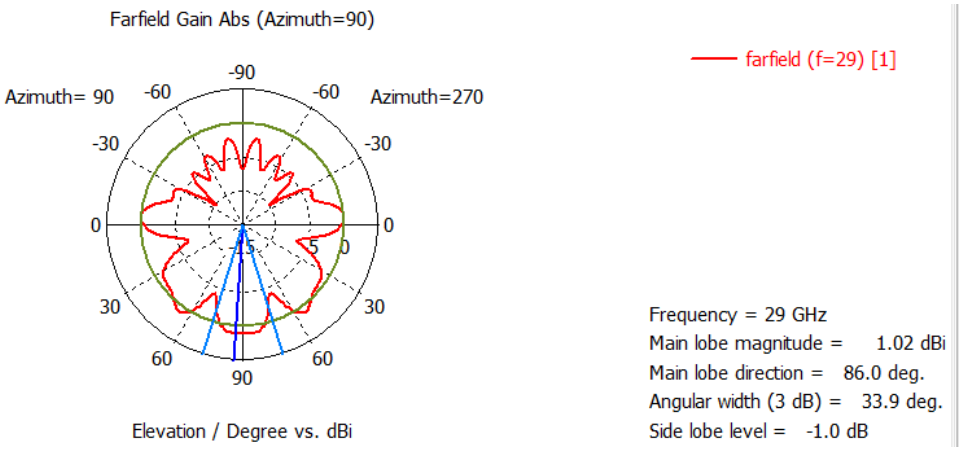


Figure 3-6 Polar diagram of the microstrip antenna elevation angle

3.9.5 Radiation efficiency

The radiation efficiency curve is shown in **Figure 3-7**. It represents dispersed power in the diagram below. As evidenced by the value of 94 percent at 29 GHz.

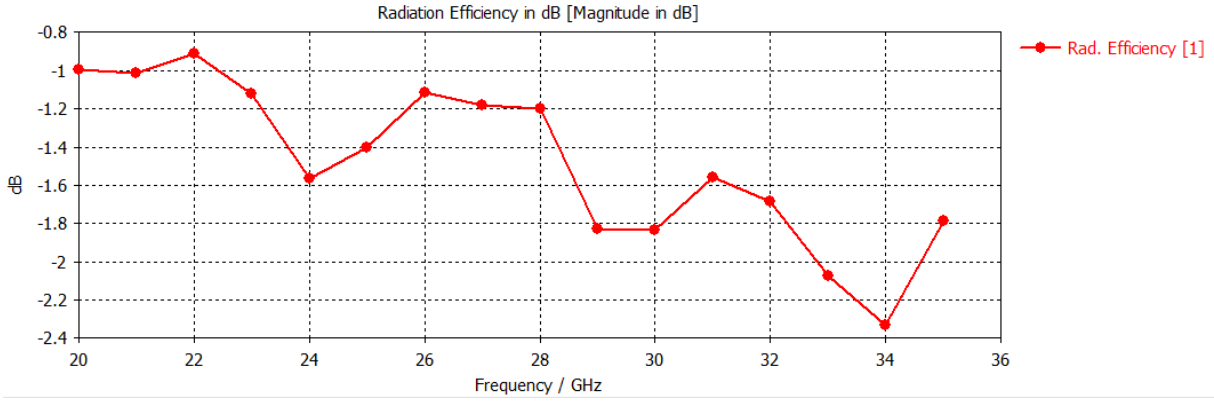
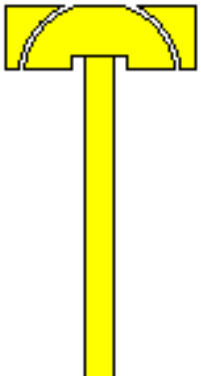


Figure 3-7 The microstrip antenna ability to refract light

3.10 Second manipulation



This antenna is in the shape of a T with a Semi circle on the rectangle, and it was created after several parameter changes.

3.10.1 Design presentation

Table 3-2 presentation of the slot microstrip antenna structure's parameters

Name	Expression	Value
w	25	25
l	25	25
h	1,6	1,6
t	0,035	0,035
wp	7	7
lp	2,35	2,35
wc	2	2
wf	1,05	1,05
lf	(1/2)-(lp/2)	11,325
lc	0,5	0,5
rm	3	3
ws	0,2	0,2
ls	-1,5	-1,5

3.10.2 Simulation results

3.10.2.1 S-parameter and bandwidth

Figure 3-8 shows the antenna return loss simulation. At 29GHz, a return loss of -10dB is obtained.

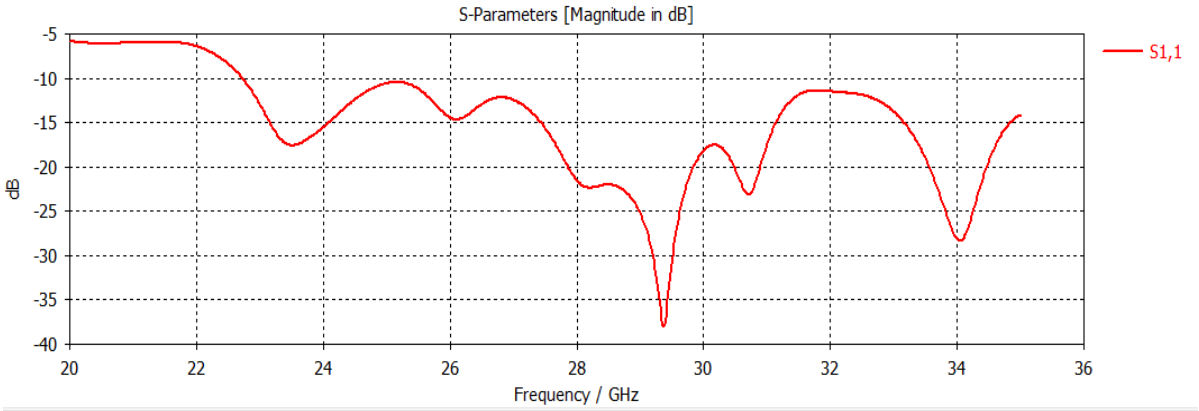


Figure 3-8 S-parameter of a microstrip patch antenna

A bandwidth is a frequency range in which some of the antenna's parameters are inside the operating range.

3.10.2.2 The stationary on-the-ground report (VSWR)

The permanent stationary wave ratio of this antenna at 29 GHz is shown in **Figure 3-9**. The VSWR must be less than 2 in order to have a good antenna design. If the VSWR is more than 2, that means the reflection coefficient is greater than -10 dB.

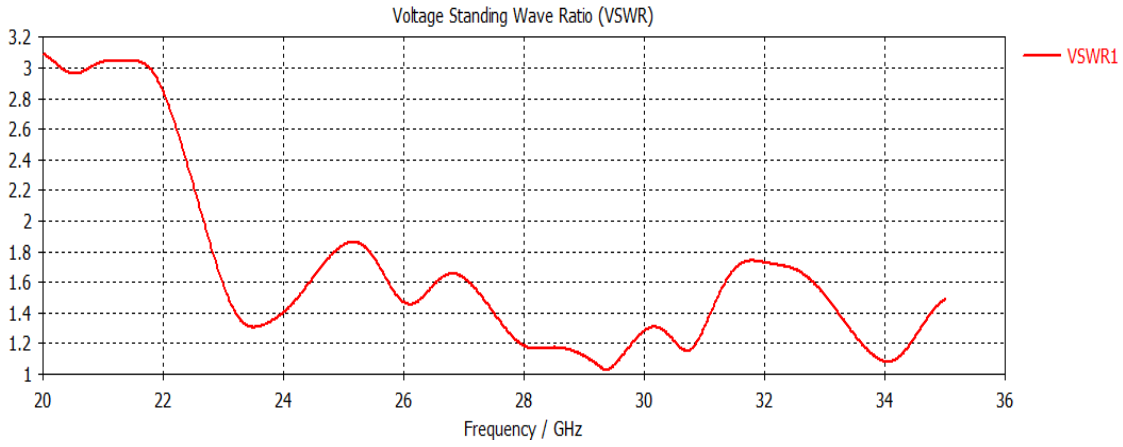


Figure 3-9 VSWR at the slot microstrip antenna resonance frequency

3.10.2.3 Gain

The gain curve is shown in **Figure 3-10** below. A 5.9dB gain in Crete has been achieved.

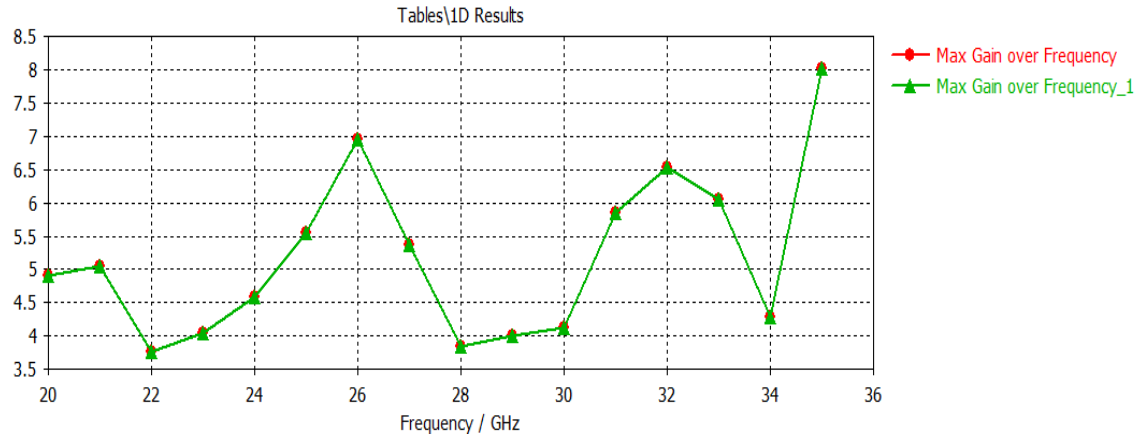


Figure 3-10 for the slot microstrip antenna a profit was made

3.10.2.4 Directivity

It is desirable to optimize the pattern of radiation of the antenna's response in a fixed direction in order to transmit or receive power. Similarly, the form of the radiation diagram is the only determinant of directivity. At 29 GHz, the planned antenna achieves a directivity of 5.9 dB, as illustrated in **Figure 3-11**

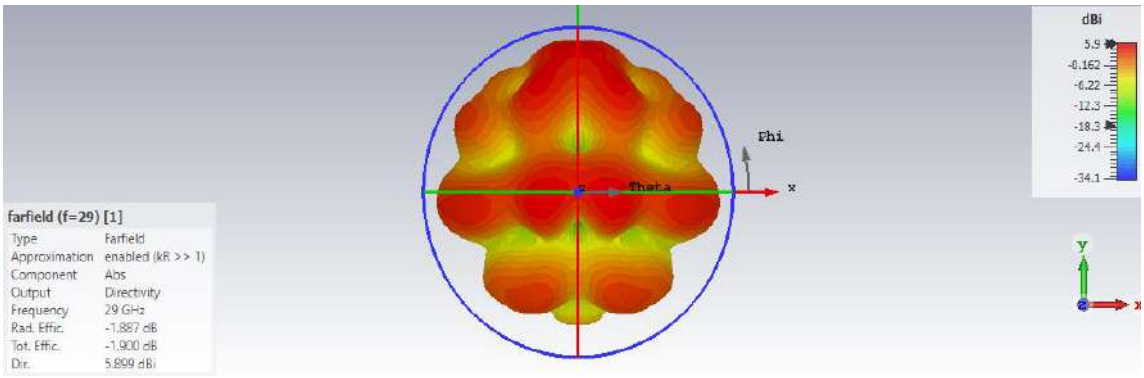


Figure 3-11 3D representation of the slot microstrip antenna directivity

The simulations show a slot microstrip rectangular antenna, with a gain of Gr= 6.22 dB. According to **Figure 3-12**, the front-to-back ratio is also quite good.

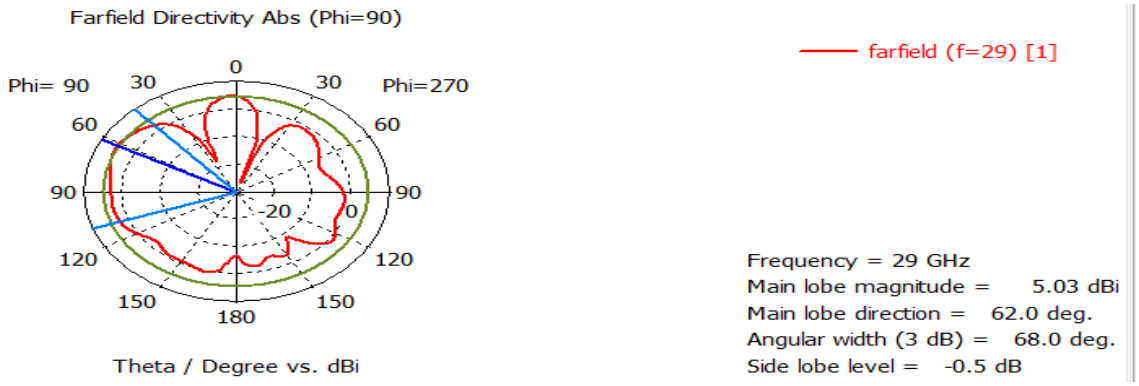


Figure 3-12 Polar diagram of the elevation angle of the slot microstrip antenna

3.10.2.5 Radiation efficiency

The radiation efficiency curve is shown in **Figure 3-13**. It represents dispersed power in the diagram below. As indicated by the value of 96 percent at 29 GHz.

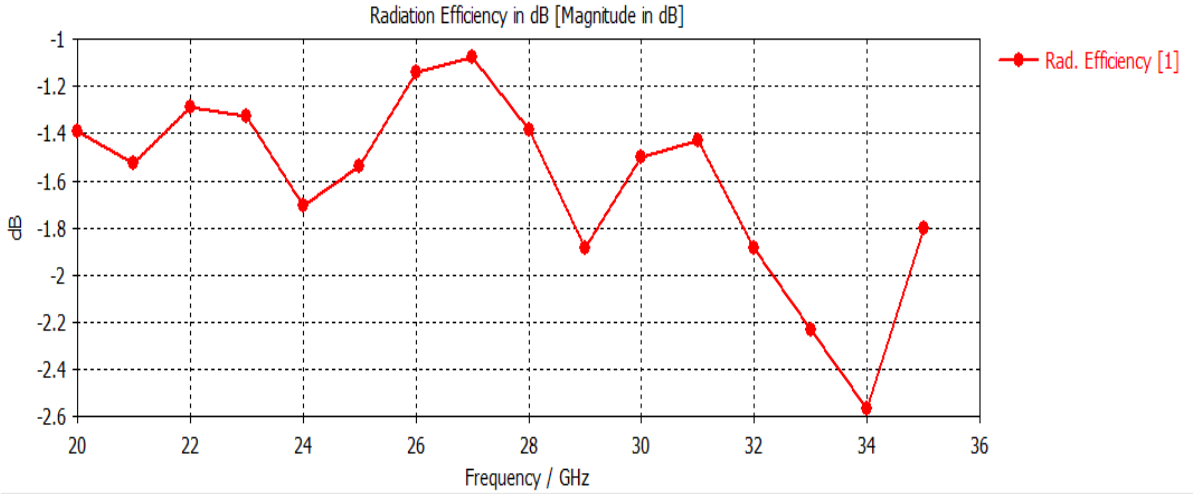


Figure 3-13 The slot microstrip antenna tiny ruban's ability to refract light

The photonic crystal structure

The photonic crystal structure in this section is made up of cylinders enrobed in Rogers RT5880 dielectric material, with a dielectric thickness of 2.55 mm. Furthermore, the pores have a radius of 0.864 mm. Several copies of this cellule are linked together to create a PBG structure, as seen in **Figure 3-14**. Using Studio to simulate in the CST Micro environment in order to analyze its characteristics. Because of the structure's nature and recurrence, the design charge may be reduced by defining requirements for electrical limits in the upper and lower levels, magnetic limits in the front and back, and open space limits on the right and left.

3.10.3 Third manipulation

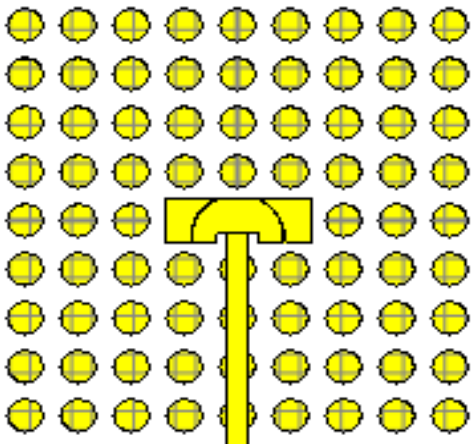


Figure 3-14 Photonic crystal structure

This antenna is in the shape of a T with a half-sphere on the rectangle, as a result of several parameter changes and the addition of photonic crystal.

3.10.3.1 Table presentation

Table 3-3 The parameters of slot microstrip antenna based on photonic crystals structure

Name	Expression	Value
w	25	25
l	25	25
h	1,6	1,6
	0,035	0,035
wp	7,0409112344801	7,040911234
lp	2,3721344284452	2,372134428
wc	2	2
wf	1,05	1,05
lf	(1/2)-(lp/2)	11,3139327857774
lc	0,5	0,5
rm	2,2513627000563	2,2513627
ws	0,046143688380464	0,046143688380464
ls	-0,87719893344965	-0,877198933449650
a	2,55	2,55
rad	0,8645039604320	0,86450396

3.10.3.2 S-parameter and bandwidth

Figure 3.15 shows the antenna return loss simulation. At 29GHz, a return loss of -10dB is obtained.

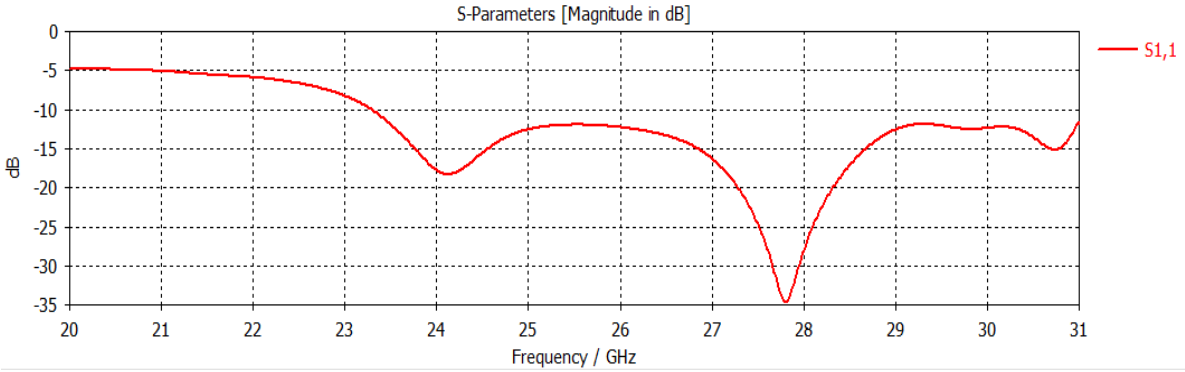


Figure 3-15 Parameter S of a slot microstrip antenna based on photonic crystals

A bandwidth is a frequency range in which some of the antenna's parameters are inside the operating range.

3.10.3.3 The stationary on-the-ground report (VSWR)

The permanent stationary wave ratio of this antenna at 29 GHz is shown in **Figure 3-16**. The VSWR must be less than 2 in order to have a good antenna design. If the VSWR is more than 2, that means the reflection coefficient is greater than -10 dB.

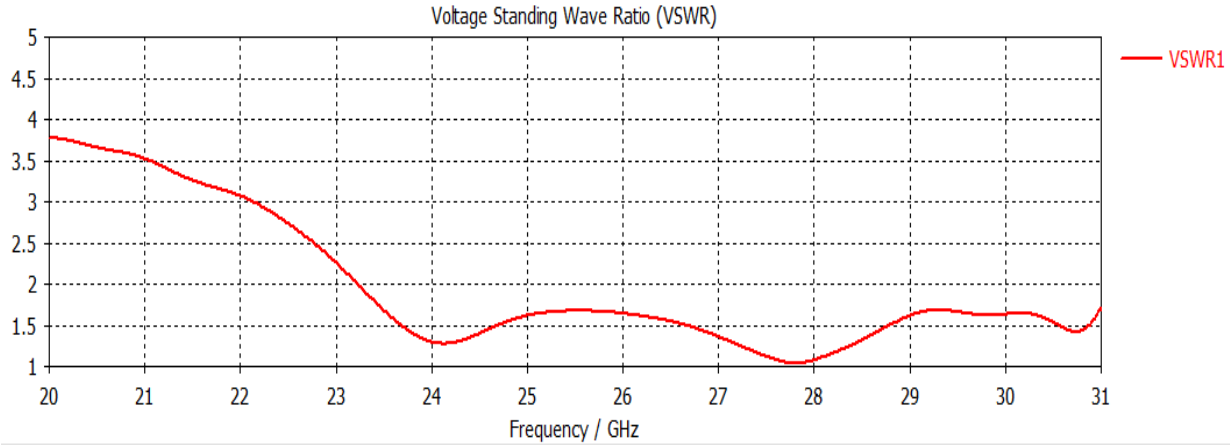


Figure 3-16 slot microstrip antenna based on photonic crystals resonant frequency VSWR

3.10.3.4 Gain

The gain curve is depicted in **Figure 3-17** below. A peak gain of 6.37dB has been achieved.

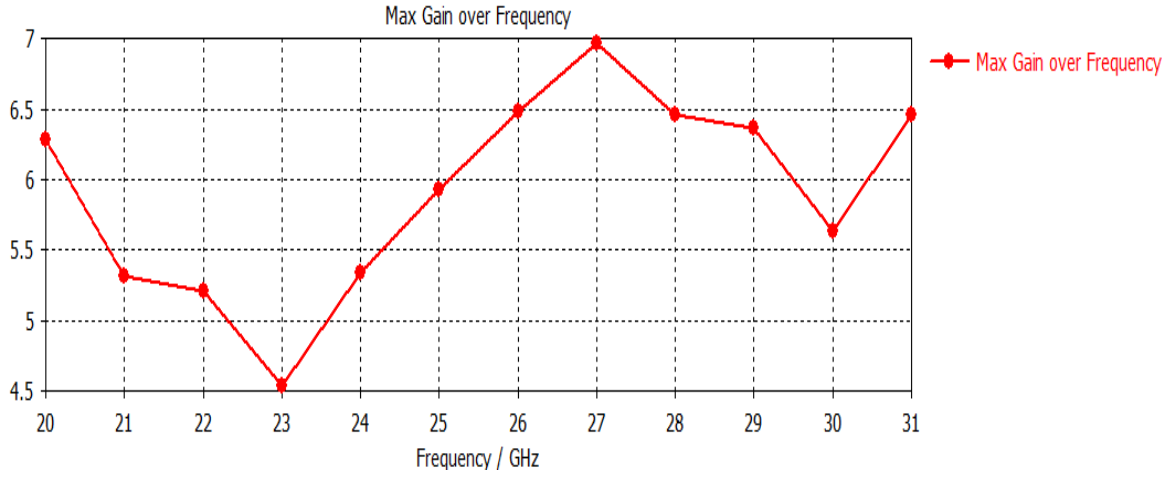


Figure 3-17 Gain achieved for the slot microstrip antenna based on photonic crystals

3.10.3.5 Directivity

To optimize the pattern of radiation of the antenna's response in a fixed direction, it is preferable to send or receive power. In the same way, the form of the radiation diagram determines the directivity. The planned antenna achieves 6.37 dB directivity at 29 GHz, as illustrated in **Figure 3-18**.

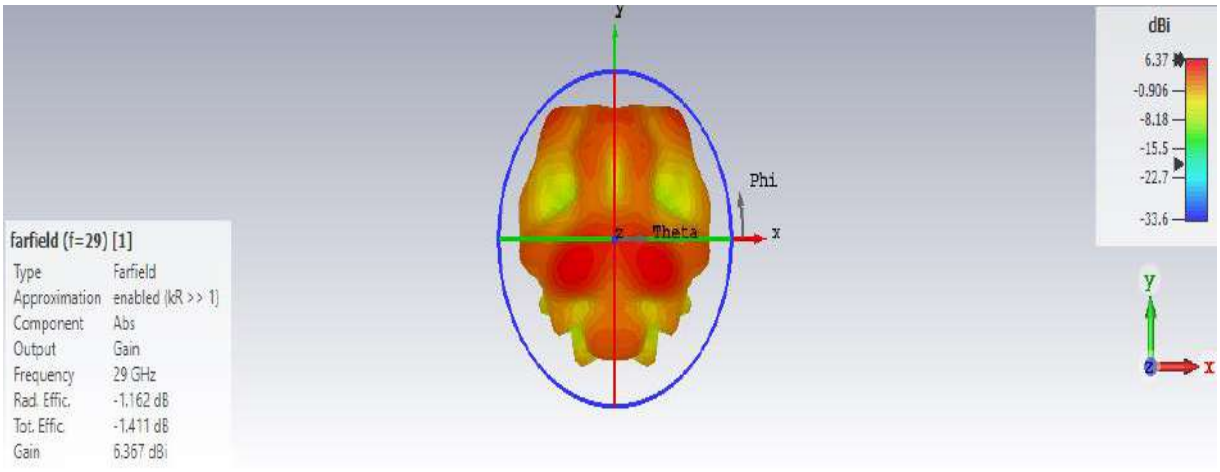


Figure 3-18 3D representation of patch antenna directivity

The simulations show a slot microstrip rectangular antenna based on photonic crystals structure, with a gain of Gr= 6.37 dB. According to **Figure 3-19**, the front-to-back ratio is also quite good.

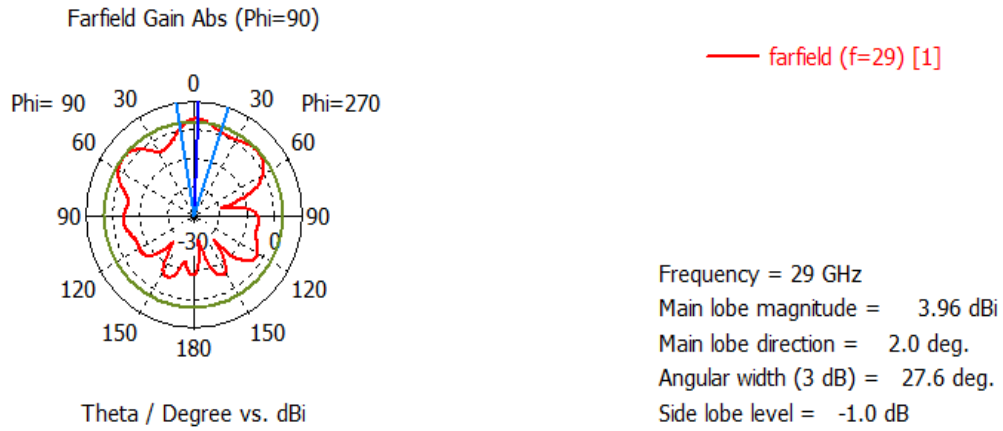


Figure 3-19 Polar diagram of the elevation angle of the slot microstrip antenna based on photonic crystals

3.10.3.6 Radiation efficiency

The radiation efficiency curve is shown in **Figure 3-20**. She represents dispersed power in the diagram below. As evidenced by the value of 94 percent at 29 GHz.

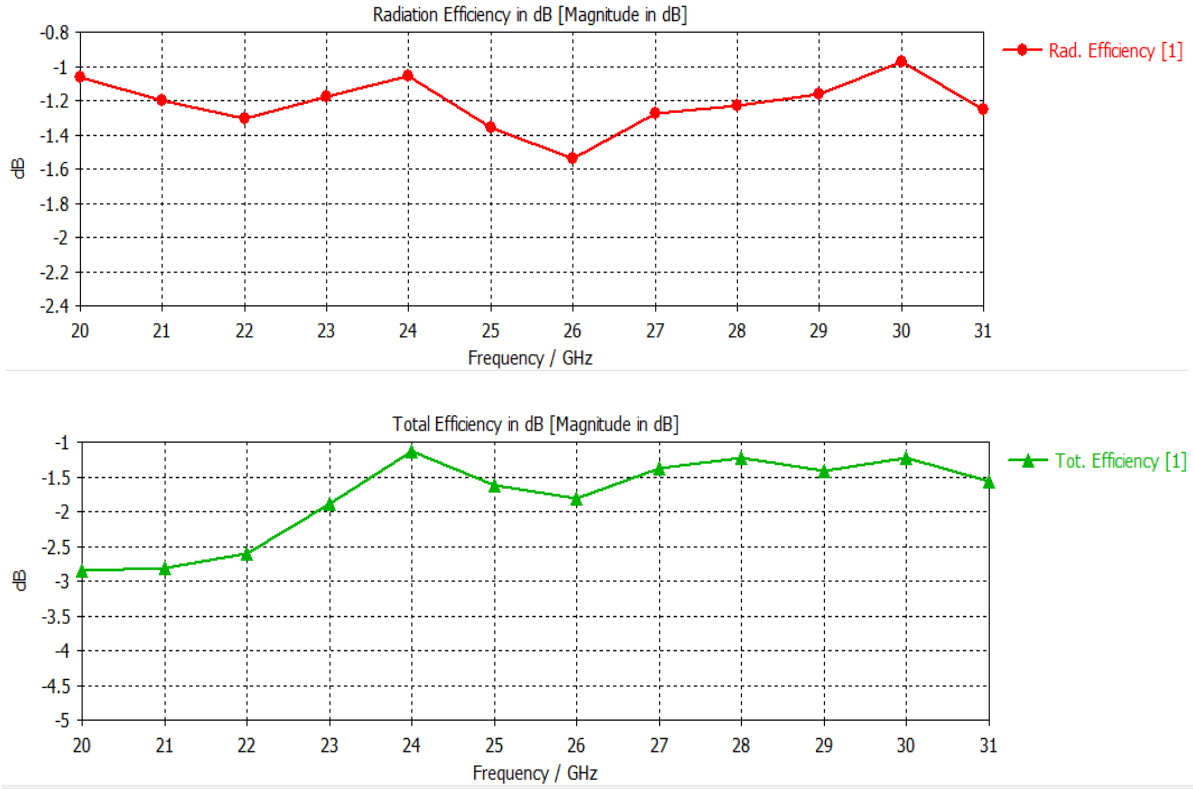


Figure 3-20 the radiation efficiency of the slot microstrip antenna based on photonic crystals

3.11 Conclusion

To increase the gain, we used photonic crystals. The first thing we did was modify the l_p, the second l_p, l_s , r_m and w_s and the third l_p, l_s , $r_m$and w_s. This modification improves the outcomes of the second and third manipulations.

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General conclusion

In this dissertation, we've covered the characteristics of antennas as well as their application areas. Among these antennas, we've focused our efforts on microstrip antennas, particularly those with photonic crystals. Photonic crystals are dielectrics or metallic materials that have been artificially strutted, with a dielectric constant that change periodically in several directions of space across a range of wavelengths and a sufficient refractive index contrast.

We used the CST STUDIO SUITE® electromagnetic modeling software to evaluate the performance of a microstrip patch antenna based on photonic crystals.

The modeling results show that the photonic crystal structure provides better performance for microstrip antennas, such as a higher gain and better directivity of sensibility and directionality.

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