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Multiband Microstrip Patch Antenna for 4G (LTE)

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A Dissertation for the Fulfillment of the Requirement of a

Master's Degree

Multiband Microstrip Patch Antenna for 4G (LTE)

Presented by:

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Favorable opinion of the Jury President

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Stamp and signature

Dedication

I dedicate this modest work:

To who told me the right way by reminding me the will always makes great women … Thanks to my Grandmothers

To every Girl who seeks to be the best and to anyone who fights for the success of his work

Acknowledgement

All praises to Almighty Allah, whose enormous blessings give us strength and make us able to complete this thesis. I would like to express gratitude to my supervisor Mr.Ameid Sofiane for his guidance, support, and encouragement. Working with him has been a true privilege and great experience for me. His guidance and advice have been a great source of inspiration throughout the thesis work.

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Theme:

Multiband Microstrip Patch Antenna for 4G (LTE)

Proposed by: Groun Mejda

Directed by: Mr.Ameid Sofiane

Summaries (English and Arabic)

This work talks about the multiband microstrip patch antenna for 4G (LTE), for this purpose we study to enhancement techniques for microstrip antenna. The main contribution of this project is proposes a multiband microstrip antenna with size reduction and bandwidth enhancement through metamaterials and rectangular Slots techniques. By means of enhancement techniques the return loss and bandwidth can be optimized with the aid of CST (Computer Simulation Technology). The results measured are reveals very good performances for the antenna and its good agreement with the simulation results.

Keywords: Microstrip, 4G, LTE, metamaterials, Slots.

يتمثل هذا العمل في دراسة الهوائي المطبوع متعدد القنوات الذي يعمل على تكنولوجيا الجيل الرابع LTE للاتصالات الخلوية اللاسلكية, ولهذا الغرض قمنا بدراسة تقنيات تحسين الهوائي المطبوع . تتمثل المساهمة الرئيسية من خلال هذا المشروع في اقتراح هوائي مطبوع متعدد القنوات مع تقليل الحجم وتعزيز عرض النطاق الترددي باستعمال الميتامواد والفتحات المستطيلة. من خلال تقنيات التحسين يمكن تعزيز خسارة العودة وعرض النطاق الترددي بمساعدة برنامج CST.
كشفت النتائج التي تم قياسها عن إمكانيات جيدة للهوائي المطبوع و عن اتفاقها الجيد مع نتائج المحاكاة.

كلمات مفتاحية : مطبوعة, الجيل الرابع, ميتامواد, فتحات, LTE.

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List of Abbreviations

3GPP: **3**rd **G**eneration **P**artnership **P**roject

CDMA: **C**ode **D**ivision **M**ultiple **A**ccess

CSRR: **C**omplementary **S**plit **R**ing **R**esonator

CST: **C**omputer **S**imulation **S**ystem

DL: **D**own**L**ink

DCS: **D**istributed **C**ontrol **S**ystem

DFT: **D**iscrete **F**ourier **T**ransform

eNodeB: **e**volved **N**ode **B**

E-UTRA: **E**volved-**U**TRAN

FDD: **F**requency **D**ivision **D**uplex

FDMA: **F**requency **D**ivision **M**ultiple **A**ccess

FFT: **F**ast **F**ourier **T**ransform

GPS: **G**lobal **P**ositioning **S**ystem

GSM: **G**lobal **S**ystem for **M**obile communications

HD: **H**alf-**D**uplex

ICI: **I**nter-**C**arrier **I**nterference

IEEE: **I**nstitute of **E**lectrical and **E**lectronics **E**ngineers

IMT: **I**nternational **M**obile **T**elecommunications

ISI: **I**nter-**S**ymbol **I**nterference

ISM: **I**ndustrial **S**cientific **M**edical

ITU: **I**nternational **T**elecommunication **U**nion

LHM: **L**eft **H**anded **M**aterial

LTE: **L**ong-**T**erm **E**volution

LTE-A: **L**ong **T**erm **E**volution **A**dvanced

MIMO: **M**ultiple-**I**nput **M**ultiple **O**utput

MPA: **M**icrostrip **P**atch **A**ntenna

MTM: **M**etamaterial

OFDM: **O**rthogonal **F**requency **D**ivision **M**ultiplexing

OFDMA: **O**rthogonal **F**requency **D**ivision **M**ultiple **A**ccess

PAPR: **P**eak to **A**verage **P**ower **R**atio

PNA: **P**rogrammable **N**etwork **A**nalyzer

QOS: **Q**uality-**O**f-Service

RFID: **R**adio-**F**requency **ID**entification

SC-FDMA: Single-Carrier Frequency Division Multiple Access

SRR: **S**plit **R**ing **R**esonator

SMA: **S**ub**M**iniature version **A**

TDD: **T**ime **D**ivision **D**uplex

TDMA: **T**ime **D**ivision **M**ultiple **A**ccess

UE: **U**ser **E**quipment

UL: **U**p**L**ink

UWB: **U**ltra **W**ide **B**and

UMTS: **U**niversal **M**obile **T**elecommunications **S**ystem

USB: **U**niversal **S**erial **B**us

VNA: **V**ector **N**etwork **A**nalyzer

VSWR: **V**oltage **S**tanding **W**ave **R**atio

WiFi: **Wi**reless **Fi**delity

WiMAX: **W**orldwide **I**nteroperability for **M**icrowave **A**ccess

WLAN: **W**ireless **L**ocal **A**rea **N**etwork

General Introduction

General Introduction

The antenna is a necessary component of each wireless communication system and provides a means of transmitting and receiving electromagnetic waves, the development of wireless technology is due to the development of antennas.

In nowadays, antennas are widely used to communicate between different parts of the globe. They are present on satellites, planes, in our telephones, at different sizes, different frequencies, and different geometries. Among different types of antennas, the microstrip patch antennas have attracted the attention of researchers over the past decades and have taken more interest than any other field of antenna research and development has revolutionized activity in the area of antenna engineering because it’s multiple aspects. It’s a source of pride that we are doing our researchers in this domain.

Mobile communication is one of the areas when the microstrip patch antenna is active, is a very spacious domain which exists in this world, a lot of evolution and a lot of new requirements and challenges. The LTE (Long Term Evolution) is a big step to a new century of technologies and smart devices with high data-rate, rapid technological developments in data transfer at very high speed. It holds a comprehensive solution for all the challenges of modern communication and compatible with major developments like the audio, video, multimedia technology and other services, using new techniques and technologies to increase the number of subscribers with best services quality.

Our study is talking about design a microstrip antenna structure that supports the LTE technology with multiband capability in order to find optimal parameters of the microstrip antenna, this problem can be expressed as an optimization problem.

Regarding the simulation tool, we have opted for the CST (Microwave Studio software) given the multitude of solvers it includes, it’s simple and flexible interface, its mesh adaptable to any structure, possibility of export its results into others computing environments like Matlab, the variety of optimization algorithms, the possibility of post-processing, parametric studies, …etc.

The project's objectives

To address the issues discussed above, we formulate a list of objectives that we identified during the development of the work plan:

- To address and improve the microstrip antenna parameters.
- To design and simulate a microstrip patch antenna for LTE technology with multiband applications.
- To miniaturize the microstrip antenna.
- To confirm the validity of design results through fabrication and measure.
- Made an applicable antenna with a lot of application.

Work and Study plan

This thesis is divided into three chapters organized as follows:

The first chapter: an introduction to the evolution of mobile communication systems, different standards, and generations, as well as the techniques of each of these generations. Then a short study and definition of the Long-Term Evolution standard, its characteristics, principle, and requirements technology, we finish the chapter with a scope of the services and benefits of LTE.

The second chapter: introduces the fundamental theories of the working context of the microstrip antennas and the concern review about performance enhancement techniques for the microstrip patch antenna using rectangular slots and metamaterials.

The third chapter: is specified for the design of our antenna and discusses the integration of metamaterials and rectangular slots in the designed antenna, and his effect for enhancements of antenna parameters, in the end, we will validate our antenna using fabricated prototype antenna is made and measured.

Finally, we present our conclusions as well as perspectives of our work.

Chapter I: Overview of LTE Technology

Chapter I
Overview of LTE
Technology

I.1 Introduction

The last decade has witnessed a remarkable development in the wireless network industry on sides, the technology used and the number of connected subscribers.

LTE was released in 2008 by 3GPP. From the moment it was launched, it has proven to be the future solution for mobile networks and defeat competing solutions such as WiMAX and UMB and all systems or later versions were only developments and additions. Moreover, long-term evolution (LTE) technology incorporates major advancements of computer networking, microelectronics, and modern communication system. We will provide this chapter as an introduction to this technology.

I.2 History of Evolution of Cellular Systems 1G, 2G, 3G and 4G

Day by day, we hear about new technologies for faster communication and better performance. But how did communications networks begin and how did they evolve? In this section, we will know how cellular communication networks were at their inception, how they evolved and what their future was.

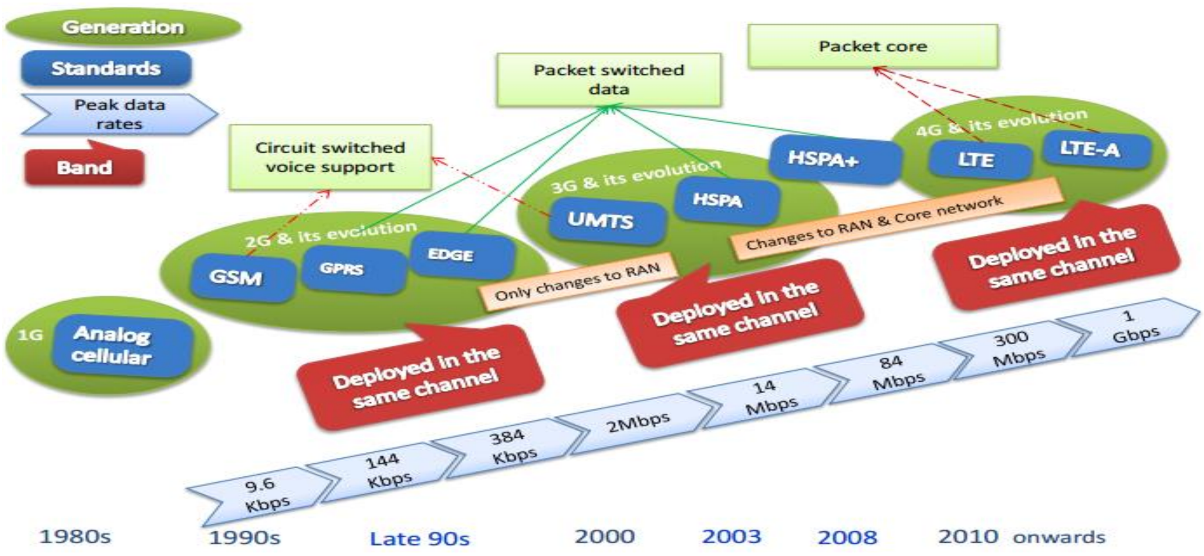


Fig.I.1: Evolution of cellular networks[1]

a. The first generation (1G) systems

Mobile communications systems were introduced for the first time in the early 1980s. The first generation (1G) systems operate with the FDMA (Frequency Division Multiplexing), analog communication techniques, which were similar to those used in conventional analog broadcasting. Individual cells were large and radio spectrum systems were not readily available, so their capacity at today's scales was very small. Mobile devices were large and expensive and were marketed almost exclusively to business users[2].

The main disadvantages of this first generation of cellular networks are the massive equipment constituting these systems, and the analog techniques have a low security, which has led to the appearance of a second generation more efficient based on new techniques, which are all digital[3].

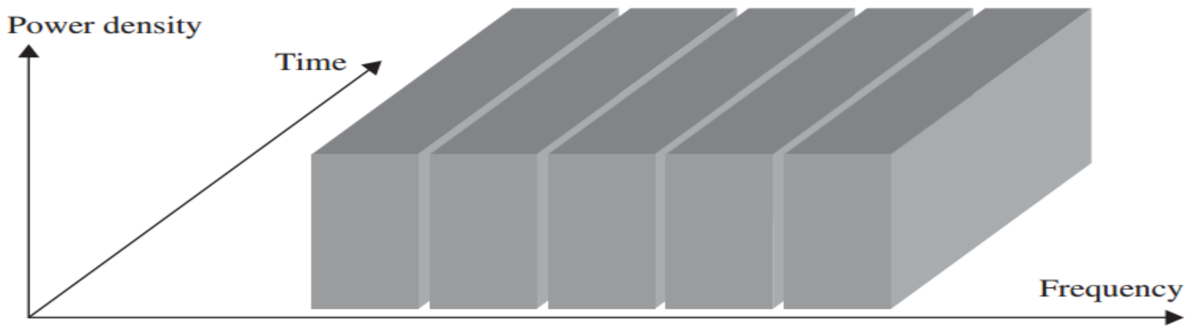


Fig.I.2: Principle of FDMA (with N=5 sub channels)[4]

b. The second generation (2G) systems

This is the most popular generation in the world of communication, which was known as GSM or global system of mobility. Which opened the door to new services such as this generation has adopted new technologies based on digital signals to be the first generation based on TDMA.

At the beginning of the 1990s, the Global System for Mobile Communications triggered an unprecedented change in the way people communicate with each other. GSM is used by over 3 billion subscribers worldwide in 2010. This has mostly been achieved by the steady improvements in all areas of telecommunication technology and the resulting steady price reductions for both infrastructure equipment and mobile devices. The third-generation (3G) systems**[5]**.

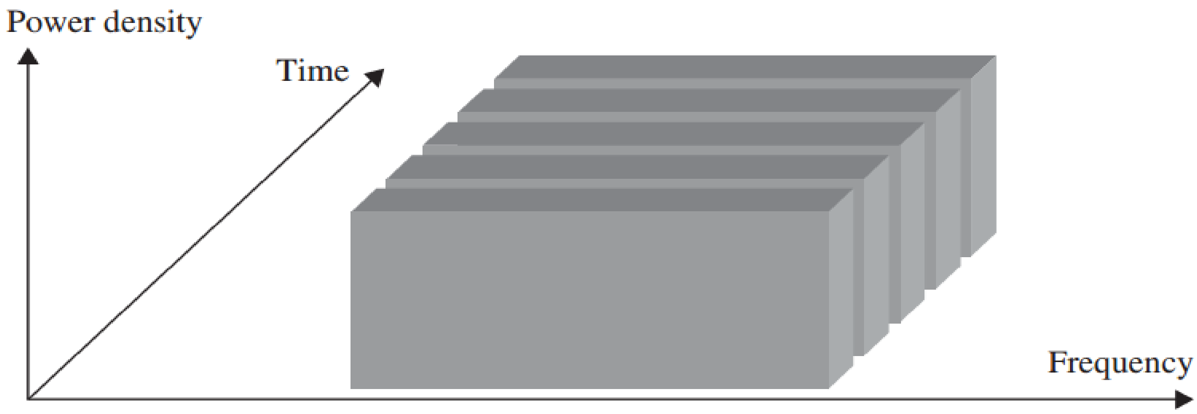


Fig.I. 3: Principle of TDMA (with five time slots)[4]

c. The third generation (3G) systems

The Third-generation systems based on CDMA use different techniques for radio transmission and reception from their second generation predecessors, which increases the peak data rates that they can handle, makes still more efficient use of the available radio spectrum, enabled faster data transmission speeds, greater network capacity and more advanced network services. In these systems, the air interface includes extra optimizations that are targeted at data applications, which increase the average rate at which a user can upload or download information, at the expense of introducing greater variability into the data rate and the arrival time[2].This generation is a revolution in the world of communications because of its applications and rapid speed of high, which enabled the use of the Internet high speed, until the fourth generation improvements that exceeded this generation.

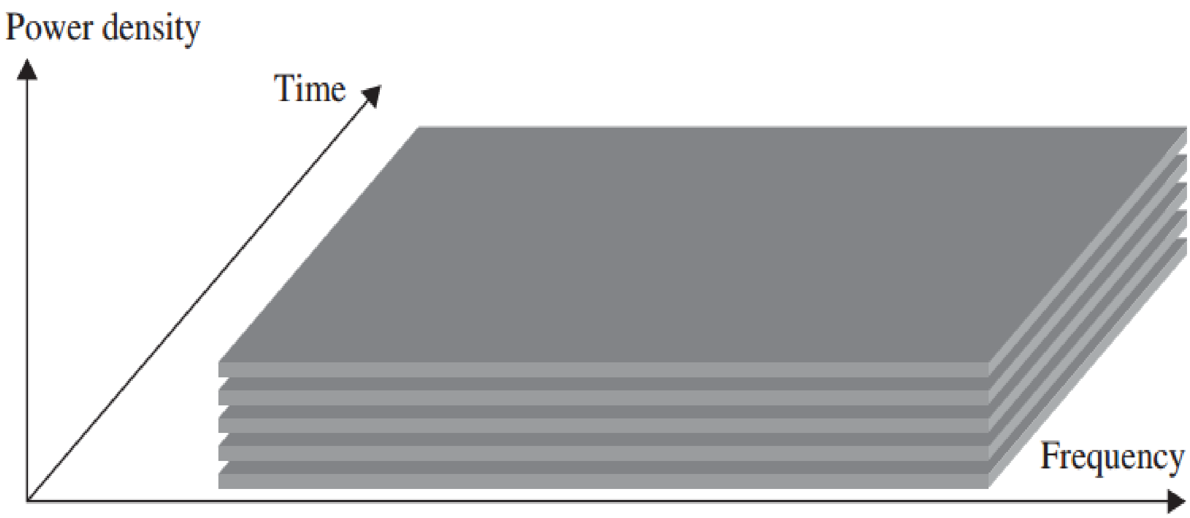


Fig.I. 4: Principle of CDMA (with five spreading codes)[4]

d. The fourth generation (4G) systems

4G is an ITU specification that is currently being developed for broadband mobile capabilities. 4G technologies would enable IP based voice, data and streaming multimedia at higher speeds and offer at least 100 Mbit/s with high mobility and up to 1Gbit/s with low mobility[2].This generation depends on standards LTE and LTE Advanced for a faster and more efficient way.

I.3 Technology Comparison

We see through the **Table. I. 1** the differences between cellular technologies in terms of access technique, system service, max data rate, modulation and carrier bandwidth, which represent cellular evolved:

G	Access Teq	System/service	Max Data rate	Modulation	Carrier BW
2G	TDMA	GSM	9.6Kbps	GMSK	200Khz
2.5G	TDMA	GPRS	171Kbps	GMSK	200Khz
2.75G	TDMA	EDGE	553Kbps	8psk	200Khz
3G	W-CDMA	UMTS	2Mbps	QPSK	5Mhz
3.5G	W-CDMA	HSDPA	14.4Mbps	16QAM	5Mhz
3.75G	W-CDMA	HSUPA	5.8Mbps	16QAM	5Mhz
3.8G	W-CDMA	HSPA+	42Mbps	64QAM	5Mhz
3.9G	OFDMA &SC-FDMA	LTE	100Mbps	64QAM	20Mhz
4G	OFDMA &SC-FDMA	LTE Advanced	1Gbps	128QAM	100Mhz

Table. I. 1: Comparison of technologies[6]

I.4 LTE Standards Evolution

LTE (Long Term Evolution) is the project related to high performance air interface for mobile telephony. LTE is the latest new technology that ensures competitive edge over existing standards: GSM, UMTS, etc. It improves user experience with full mobility. LTE minimizes the system and user-equipment complexities[7].

LTE is the successor of the third-generation technology of 3GPP, the main advantages of LTE are that it a cover more space and provides greater speed in the wireless environment; provides broadband Internet in cellular or any devices. LTE data speed is ten times faster than current 3G technologies. LTE users do not need to work at home or office for a broadband Internet experience, which is required only in the LTE coverage area[8].The multiple access schemes in LTE downlink uses Orthogonal Frequency Division Multiple Access (OFDMA) and uplink uses Single Carrier Frequency Division Multiple Access(SC-FDMA)[9].

I.5 LTE Key Technology

The following information describes the various supporting techniques that make up LTE and meet their requirement.

a. OFDM

The rapid growth of the digital telecommunications sector in recent years has led to increased demand for high speed data transmission systems.

Orthogonal Frequency Division Multiplex (OFDM) is a promising candidate for high speed data transfer in the wireless medium due to its resistance, multicarrier transmission technique, which divides the available spectrum into many subcarriers, each one being modulated by a low data rate stream, OFDM allocates user just in time domain[10].

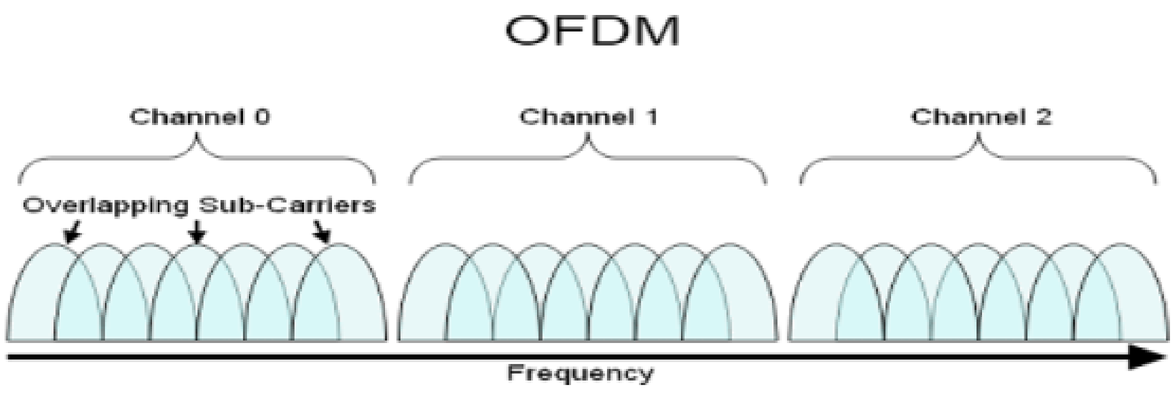


Fig.I. 5: Principle of OFDM[11]

Smart antenna technologies are also easier to support with OFDM because each subcarrier becomes f l at faded and the antenna weights can be optimized on a per-subcarrier or block of subcarriers basis. In addition, OFDM enables broadcast the services on a synchronized. This allows broadcast signals from different cells to combine over the air, thus significantly increasing the received signal power and supportable data rates for broadcast services[12].

The advantages of OFDM are [4]:

- High spectral efficiency due to nearly rectangular frequency spectrum for high numbers of sub-carriers;
- Simple digital realization by using the FFT operation;
- Low complex receivers due to the avoidance of ISI and ICI with a sufficiently long guard interval;
- Flexible spectrum adaptation can be realized, e.g. notch filtering;
- Different modulation schemes can be used on individual sub-carriers which are adapted to the transmission conditions on each sub-carrier, e.g. water filling.

The disadvantages of OFDM are [4]:

- Multi-carrier signals with high peak-to-average power ratio (PAPR) require high linear amplifiers;
- Otherwise, performance degradations occur and the out-of-band power will be enhanced.

a.1. OFDMA

In the downlink direction, LTE used orthogonal frequency division multiple access (OFDMA), is a combination of orthogonal frequency division multiplexing (OFDM) and time division multiple access (TDMA). OFDMA identifies different subscribers in the same cell by different time and subcarriers. To maximize spectrum efficiency, intra frequency networking is often used in LTE[13].

Downlink OFDMA[14]:

- High spectral efficiency;
- Robust against frequency-selectivity / multi-path interference;
- Inter-symbol interference contained within cyclic prefix;
- Supports flexible bandwidth deployment;
- Facilitates frequency-domain scheduling;
- Well suited to advanced MIMO techniques.

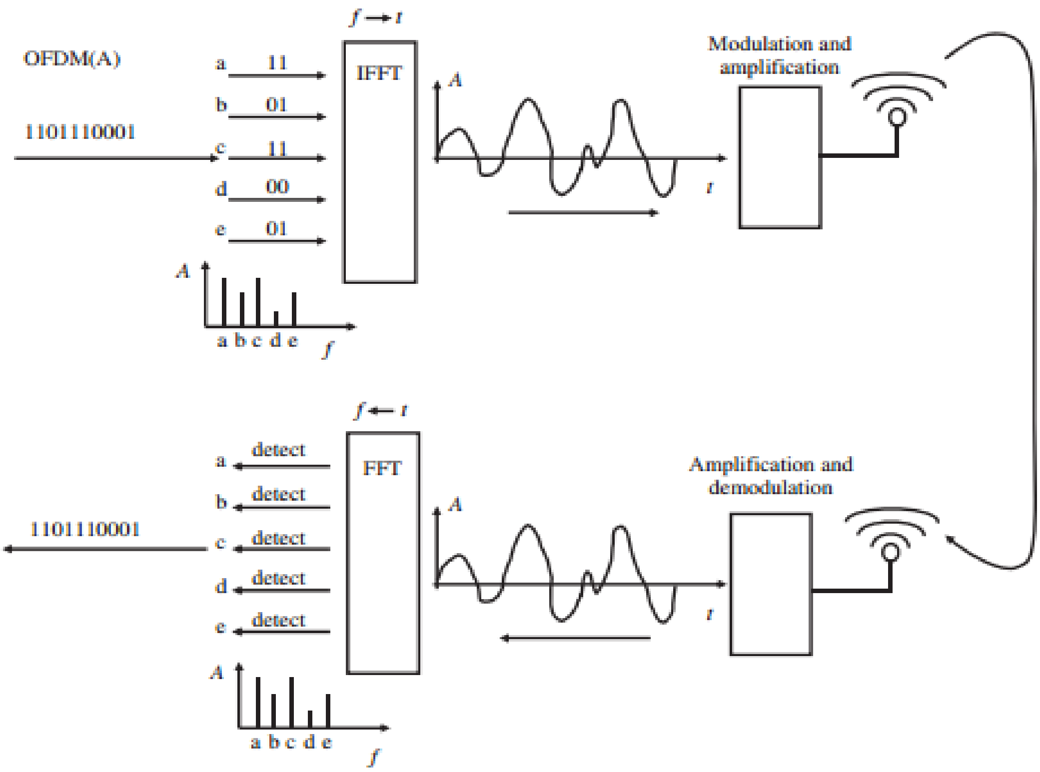


Fig.I. 6: Principle of OFDMA for downlink transmission [5]

a.2. SC-FDMA

In Uplink, a different concept is used in access technique. Although some form of OFDMA technology is still used, the implementation is called Single Carrier Frequency Multiple Access Division (SC-FDMA). Unsurprisingly, energy consumption is a key consideration for the EU. The high PAPR and the efficiency loss associated with the OFDM are major concerns. The SC-FDMA is well adapted to the requirements of LTE in Uplink[6].

Uplink SC-FDMA[14]:

• Based on OFDMA with DFT preceding;

• Common structure of transmission resources compared to downlink;

• Cyclic prefix facilitates frequency-domain equalization at eNodeB;

• Low PAPR for efficient transmitter design (mobile power saving).

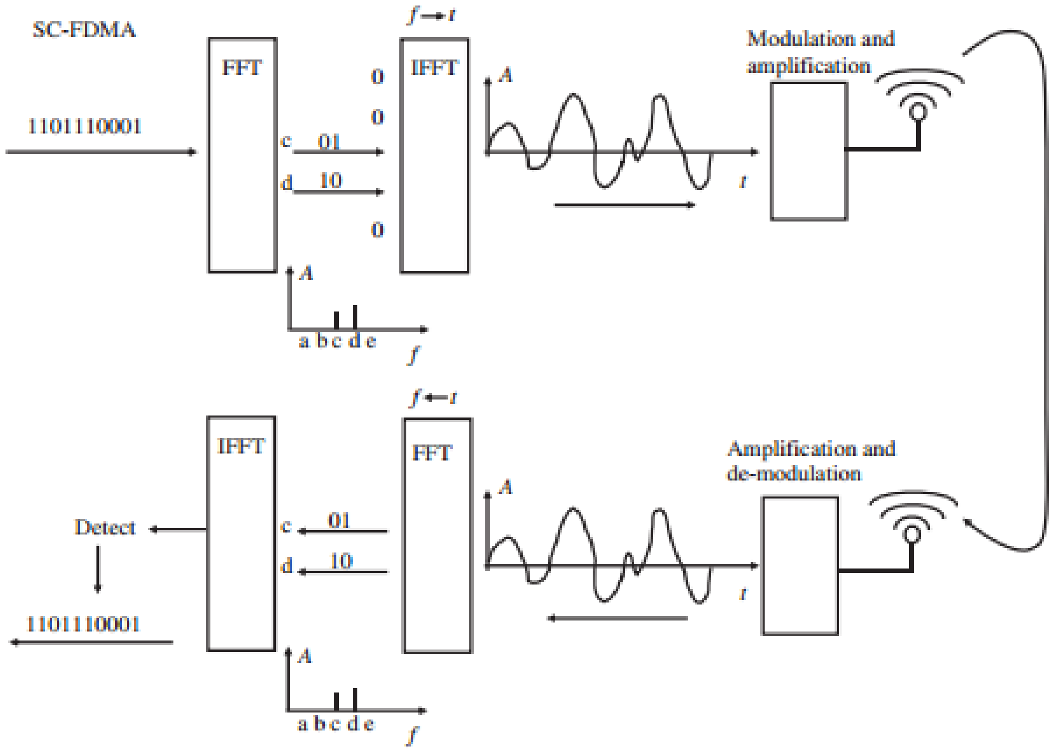


Fig.I. 7: Principle of SC-FDMA for Uplink transmission [5]

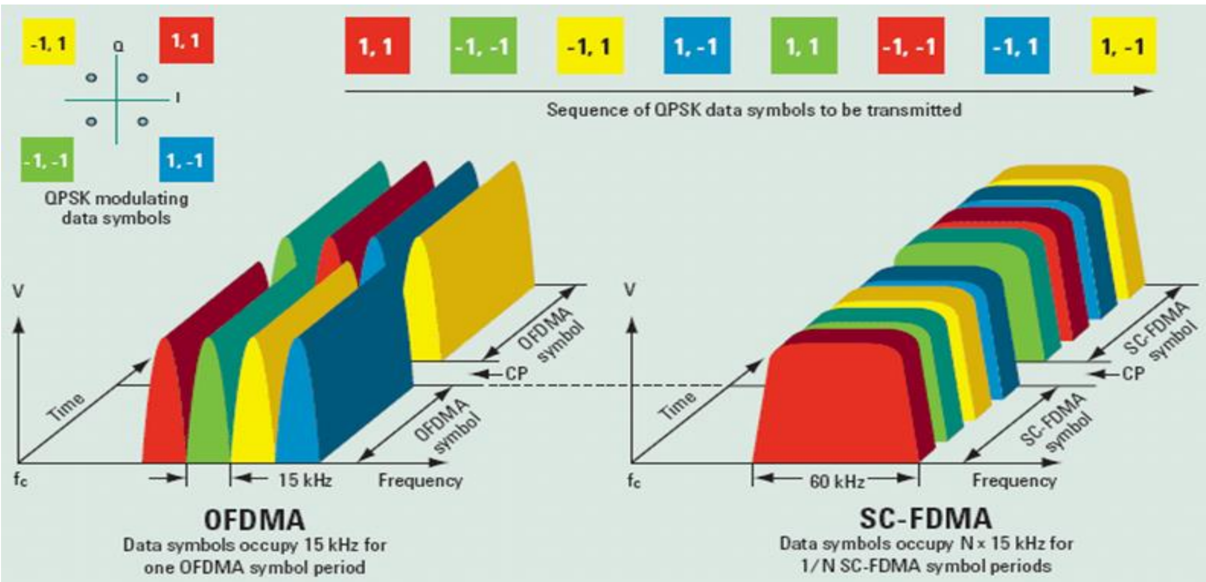


Fig.I. 8: Comparison between OFDMA and SC-FDMA[6]

- OFDMA: sending data in parallel on several sub-carriers, (high PAPR)[6].
- SC-FDMA: sending serial data on the same carrier (lower PAPR)[6].

b. MIMO

Multiple inputs and multiple outputs (MIMO), is one of the major technological breakthrough in the 1990s in the field of signal processing, it relies on the use of multiple antennas at the transmitter and the receiver, to allow transmit several independent data streams at longer range, on the same time / frequency resources using spatial multiplexing[3].

All mobile devices have to support MIMO transmission. With this advanced transmission scheme, several data streams are transmitted on the same carrier frequency from multiple antennas from the base station to multiple antennas in the mobile device.

Most LTE networks and devices in the first years of deployment will use 2 × 2 MIMO, that is, two transmit and two receive antennas. In the future, 4 × 4 MIMO might be used with category 5 UEs in case this is also supported on the network side. It will be a challenge, however, to fit four independent antennas in a small mobile device. Further, there are many frequency bands that LTE can be used in, making antenna design in mobile devices even more challenging, especially when taking the fact that devices have to support GSM and UMTS in the same or different frequency bands into account[5].

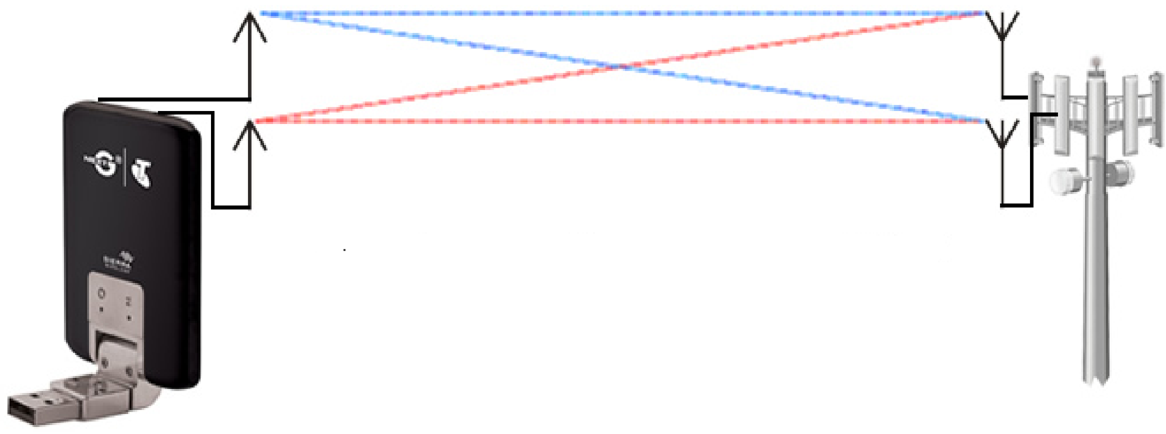


Fig.I. 9: Principle of MIMO technology (2×2)[15]

I.6 LTE frequency and bandwidth

LTE have many bands; where bands 1 to 31 are Frequency Division Duplex (FDD) and 33 to 48 and above are Time division duplex (TDD)[8].

Operating band index	Uplink(UL) Operating band Frequency range(MHz)	Downlink (DL) Operating band Frequency range (MHz)	Duplex mode
1	1920-1980	2110-2170	FDD
2	1850-1910	1930-1990	FDD
3	1710-1785	1805-1880	FDD
4	1710-1755	2110-2155	FDD
5	824-849	869-894	FDD
6	830-840	875-885	FDD
7	2500-2570	2620-2690	FDD
8	880-915	925-960	FDD
9	1749.9-1784.9	1844.9-1879.9	FDD
10	1710-1770	2110-2170	FDD
11	1427.9-1447.9	1475.9-1495.9	FDD
12	699-716	729-746	FDD
13	777-787	746-756	FDD
14	788-789	758-768	FDD
15	Reserved	Reserved	FDD
16	Reserved	Reserved	FDD
17	704-716	734-746	FDD
18	815-830	860-875	FDD
19	830-845	875-890	FDD
20	832-862	791-821	FDD
21	1447.9-1462.9	1495.9-1510.9	FDD
22	3410-3490	3510-3590	FDD
23	2000-2020	2180-2200	FDD
24	1626.5-1660.5	1525-1559	FDD
25	185-1915	1930-1995	FDD

Table.I. 2: Paired frequency bands defined for E-UTRA[16]

Operating band index	Uplink and Downlink operating band frequency range (MHz)	Duplex mode
33	1900-1920	TDD
34	2010-2025	TDD
35	1850-1910	TDD
36	1930-1990	TDD
37	1910-1930	TDD
38	2570-2620	TDD
39	1880-1920	TDD
40	2300-2400	TDD
41	2496-2690	TDD
42	3400-3600	TDD
43	3600-3800	TDD

Table.I. 3: Unipaired frequency bands defined for E-UTRA[16]

a. Comparison between FDD and TDD:

TDD means Time Division Duplex and FDD means Frequency Division Duplex. These topologies are widely used in advanced wireless communication systems such as WLAN, WiMAX(fixed/mobile) and LTE.TDD and FDD are two topologies by which critical resources time and frequency are shared among mobile subscribers or terminals. LTE uses both of these flavors to provide facility for the mobile subscribers to utilize the scares resource efficiently based on the need[17].

a.1. LTE FDD

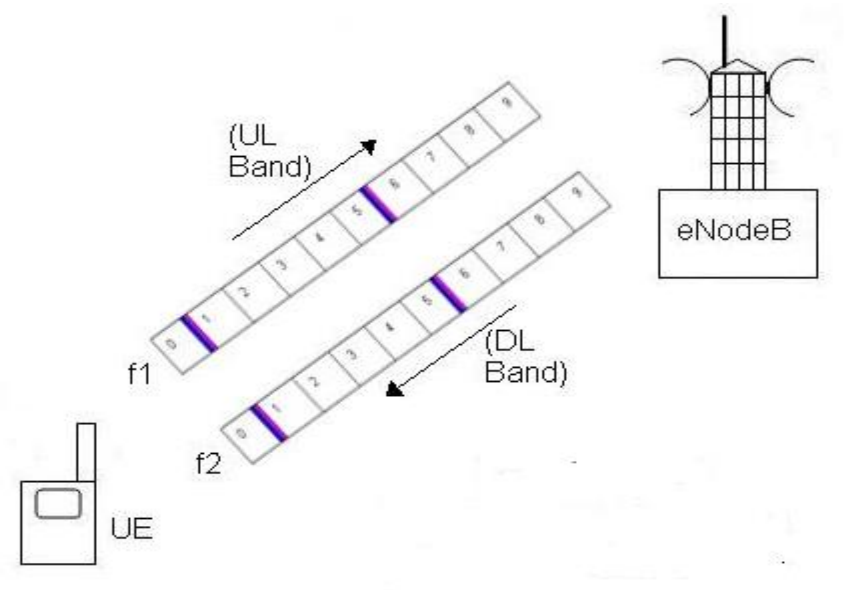


Fig.I. 10: Principle of LTE FDD[17]

The figure describes LTE FDD scenario. As shown in the figure f1 and f2 are one pair of frequencies allocated separately for both the uplink and downlink direction. That downlink always refers to transmission from LTE eNodeB to UEs and uplink refers to transmission from UEs to eNodeB. Both uplink and downlink will have 10MHz bandwidth each on which entire frame will be used.

a.2. LTE TDD

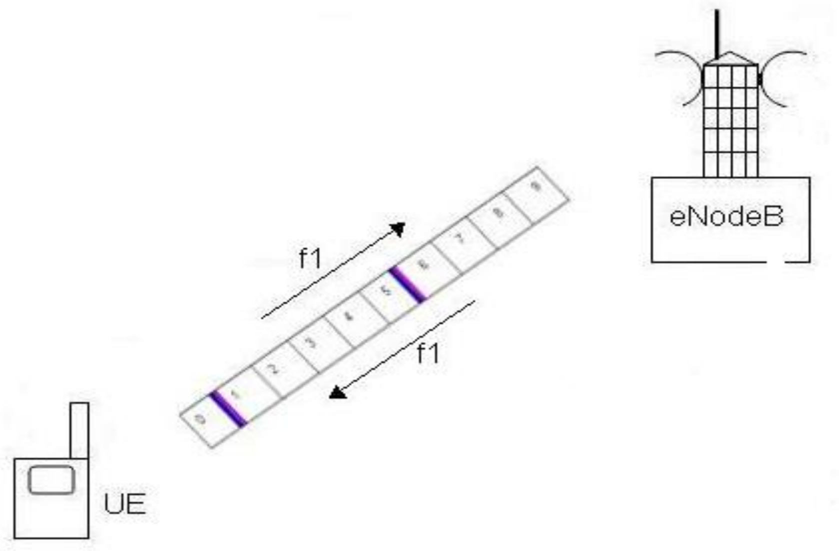


Fig.I. 11: Principle of LTE TDD[17]

The figure describes TDD LTE scenario. As shown in the figure both uplink and downlink has been allocated same frequency f1 and but both uses different time slots for mapping their information data. Entire bandwidth of 20MHz is used for both eNodeB and UEs.

I.7 Bandwidth Analysis

In this section, we define the channel bandwidth and transmission bandwidth configuration for E-UTRA carrier, through the **Table.I. 2** and **Fig.I. 12:**

1RB = 180kHz, 6RBs = 1.08MHz, 100RBs = 18MHz

Nominal Bandwidth (MHz)	**1.4**	**3**	**5**	**10**	**15**	**20**
Number of RB	6	15	25	50	75	100
Frequency Domain Real Bandwidth (MHz)	1.08	2.7	4.5	9	13.5	18

Table.I. 4: Transmission bandwidth (number of RB) in E-UTRA in channel bandwidths[18]

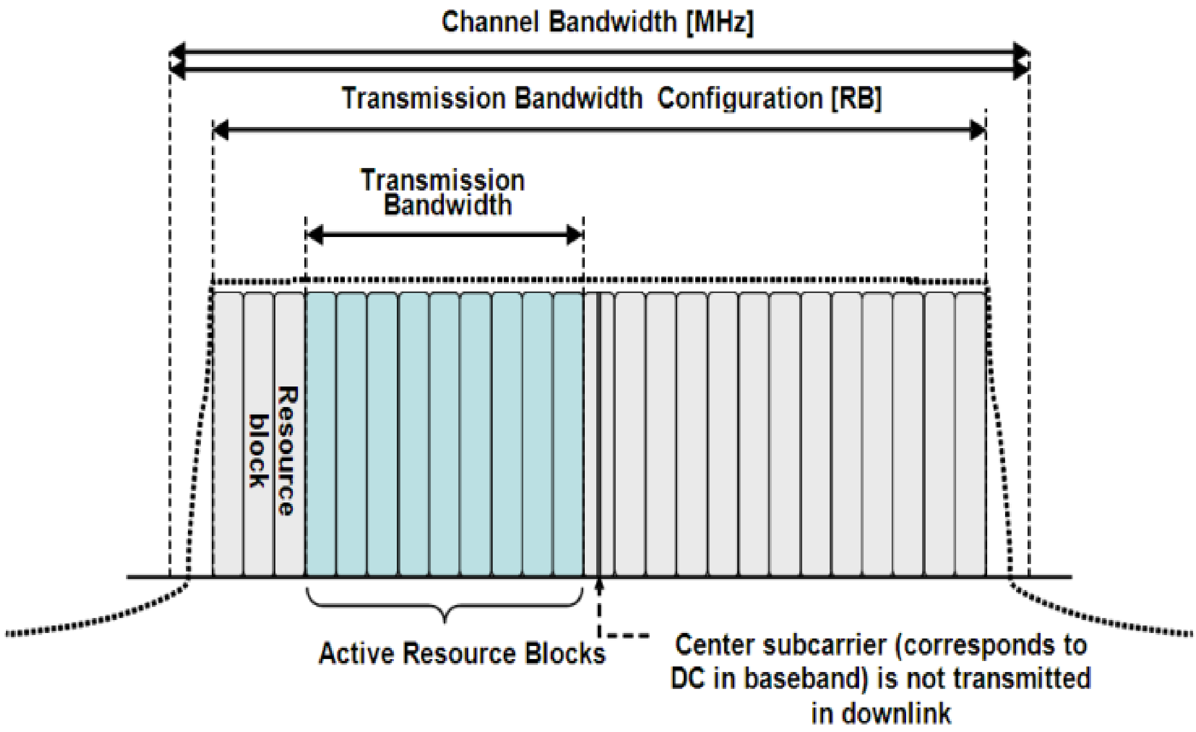


Fig.I.12: Channel bandwidth and transmission bandwidth configuration for one E-UTRA carrier[19]

I.8 LTE Services

The LTE system converts information into: audio, video, image and data (before it is only in audio) and improves user experience by high capacity, quick response, high data rate and better QOS. LTE enriches the mobile services; the table shows some of the services provided by LTE technology[18]:

Mobile office	Mobile Community	Mobile Business	Mobile Entertainment
• Mobile email • Net meeting • HD video conference	• Video sharing • Video blog • Video chat • Information	• Mobile shopping • Mobile bank • Mobile stock	• Video on demand • Online game • HD video streaming

Table.I.5 : LTE mobile services

I.9 LTE Devices Tendencies

Development faster than expected [17]:

- Current development focused on the US market;
- LTE devices types :

1. USB d’ongles
2. Mobile hotspots
3. Smart phones
4. Tablets
5. Machine-to-machine

- Leading chipsets: Samsung, Qualcomm, ST-Ericsson;
- Leading devices manufacturers: HTC, LG, Samsung.

I.10 The Benefits of LTE

The Benefits of the LTE technology are[12]:

- Provides a global ecosystem with inherent mobility.
- Offers easier access and use with greater security and privacy.
- Dramatically improves speed and latency.
- Delivers enhanced real-time video and multimedia for a better overall experience.
- Enables high-performance mobile computing.
- Supports real-time applications due to its low latency.
- Creates a platform upon which to build and deploy the products and services of today and those of tomorrow.
- Reduces cost per bit through improved spectral efficiency.

I.11 Conclusion

In this chapter, we presented our study on the long-term evolution generation of cellular mobile; we explained the principle of its work and the techniques on which it is based, the keys to its development and all the services it has been able to provide in the current technological development world.

In addition to all the techniques that have improved this long-term technology, we can't ignore the microwaves antennas that have the main role in the work of this technology and has a great influence on their characteristics, we will build our study on the microstrip antennas that support the fourth generation to be a comprehensive study integrated, will be presented that in the next chapter.

Chapter II: Overview of Microstrip Patch Antenna

Chapter Ⅱ

Overview of Microstrip Patch Antenna

II.1 Introduction

Nowadays, microstrip patch antennas are the important device in wireless communication systems. These antennas have been successfully utilized in many communication systems; it is the transitional structure between free space and a guiding device; it is used to transport electromagnetic energy from the transmitting source to the antenna or from the antenna to the receiver.

In this chapter, theoretical analysis of microstrip patch antenna; we will detail in each of its characteristics, advantages and disadvantages, feeding methods, parameters and enhancing techniques.

II.2 Basic Characteristics

The basic structure of MPA consists of a copper patch on one side of a dielectric substrate and a copper ground plane on other side and can take different shapes , as shown in **Fig.II.1.**

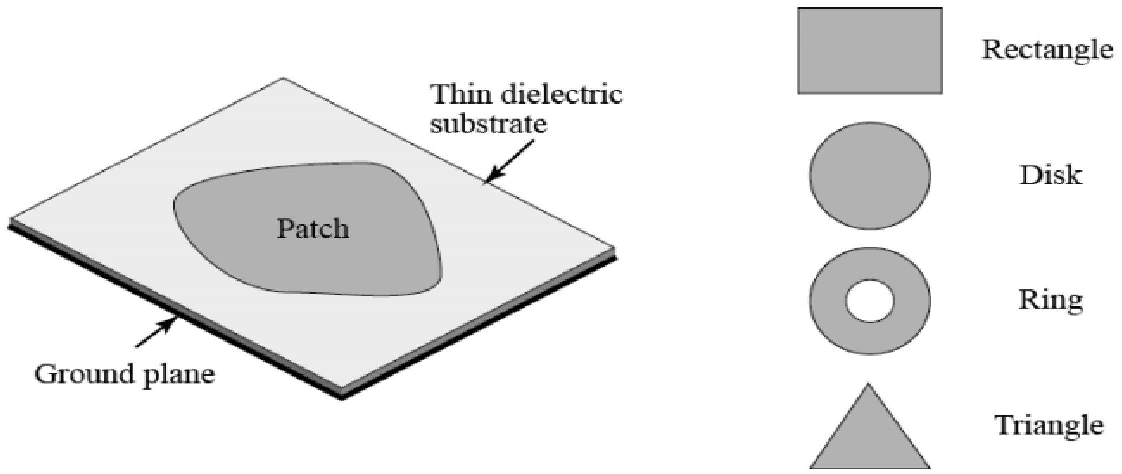


Fig.II. 1: Representative Shapes of microstrip patch elements[20]

The printed antenna is distinguished from other antennas has precise characteristics, despite its simple form and ease of fabricating. The IEEE definition of an antenna is given by the following phrase: "That part of a transmitting or receiving system that is designed to radiate or receive electromagnetic waves".

To achieve effective results, we must follow the conditions at which the antennas work[2]:

- t<< $\lambda 0$ where $\lambda 0$ is the free space wavelength.
- h << $\lambda 0$, usually $0.003\lambda 0 \leq h \leq 0.05\lambda 0$.
- Broadside radiator.
- Is accomplished by properly choosing the mode (field configuration) of excitation beneath the patch.
- The length L is usually $\lambda 0/3 < L < \lambda 0/2$.
- The strip (patch) and the ground are separated by a dielectric (substrate).
- Dielectric constants are usually in the range of $2.2 \leq \varepsilon r \leq 12$.

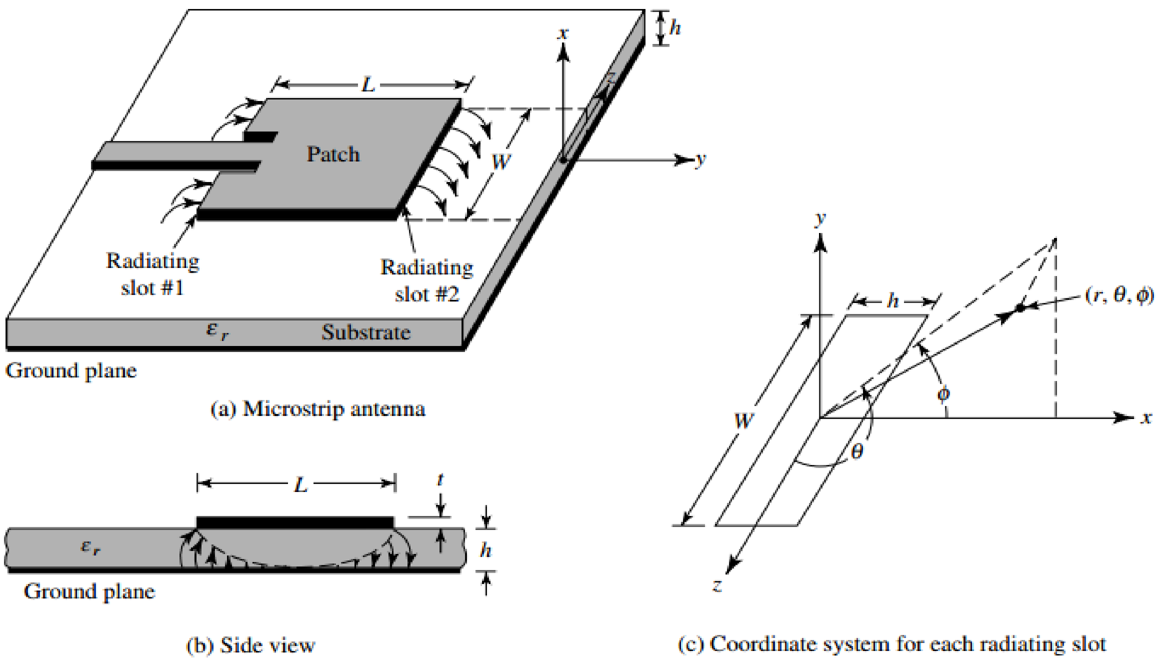


Fig.II. 2: Microstrip antenna and coordinate system [21]

II.3 Advantages and Disadvantages of MPA

The advantages of the MPA are[21]–[23]:

- Low-cost fabrication.
- Can easily conform to a curved surface of a vehicle or product.

- Antenna thickness (profile) is small.
- The considerable range of gain and pattern options (2.5 to 10.0 dBi).
- Mechanically robust when mounted on rigid surfaces.
- They are very versatile in terms of resonant frequency, polarization, pattern, and impedance.

The disadvantages of the MPA are:

- Dielectric and conductor losses can be large for thin patches, resulting in poor antenna efficiency.
- Spurious feed radiation and very narrow frequency bandwidth.
- Sensitivity to environmental factors such as temperature and humidity.

II.4 Microstrip Antenna Applications

The use of microstrip patch antenna allowed us to meet a large number of commercial needs, these include the GPS system, wireless Applications, Zigbee, Bluetooth, WiMax, WiFi applications, 802.11a,b,g, mobile satellite communication system, Radar, Missiles, marine uses, mobile Communication Base Stations and others, have created a large demand for antennas, the majority of these are rectangular patches, some of which are shown in **Fig.II.3**[22]–[24].

Fig.II. 3: microstrip antenna applications[25]

II.5 Feeding Methods

Microstrip patch antenna feeds with different mechanism feedings, the four most popular are[21], [23]:

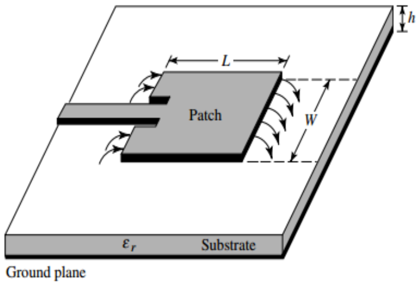
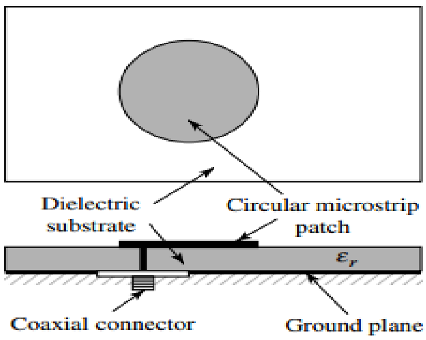
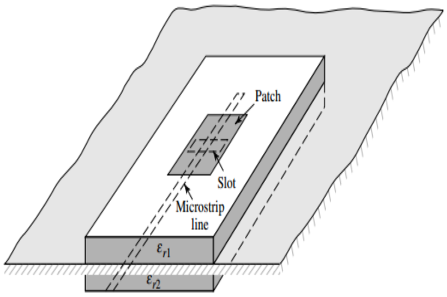
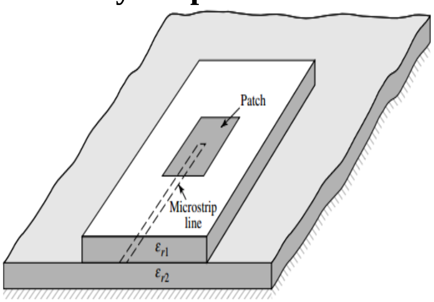
	Advantages	Disadvantages
Microstrip Line feed 	• Easy to fabricate •Simple to match by controlling Insert position • Very simple in modeling and match with characteristic impedance 50Ω or 75Ω	•Limit the bandwidth (typically 2-5%) •Not successful when using with air-gap substrate •surface waves and spurious feed radiation increase
Coaxial feed 	•Easy to fabricate and match •Low spurious radiation	•Narrow bandwidth •More difficult to model especially for think substrate (h > 0.02 λ)
Aperture-coupled feed 	•easy to model •mode rate spurious radiation	• Narrow bandwidth • The most difficult of all four to fabricate
Proximity-coupled feed 	•Easy to model •Large bandwidth (as high as 13 %) •Eliminates spurious radiation	• Fabrication is somewhat more difficult • due to overall increase in the thickness of the microstrip patch antenna

Table.II. 1: Fedding methods

II.6 Physical Models of Analysis

The most popular models are:

a. Cavity Model

The cavity model is more dependable than other models. This model provides a better way to model the radiation patterns and is closer in the physical interpretation of the antenna characteristics. The normalized fields within the dielectric can be found more accurately by treating the region as a cavity bounded by electric conductors (above and below) and by magnetic walls along the perimeter of the patch. The disadvantage of this method is complex in nature[26].

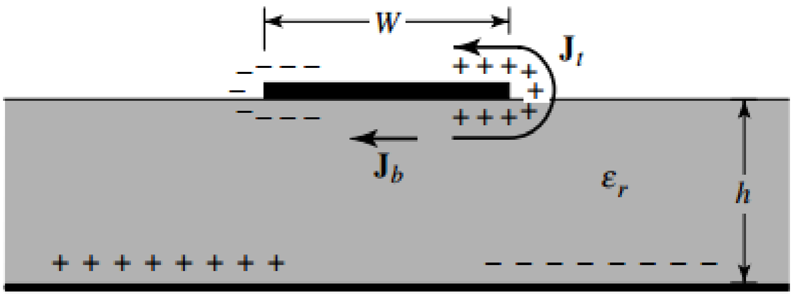


Fig.II. 4: Charge distribution and current density creation on microstrip patch[21]

b. Transmission Line Model

Basically, the transmission line model represents the microstrip antenna by two slots of width W and height h, separated by a low impedance Zc transmission line of length L , is the easiest of all but the least accurate result and lacks the versatility[26].

Because the dimensions of the patch are finite along the length and width of some electric field lines are traveling outside the substrate resulting fringing effect[21].

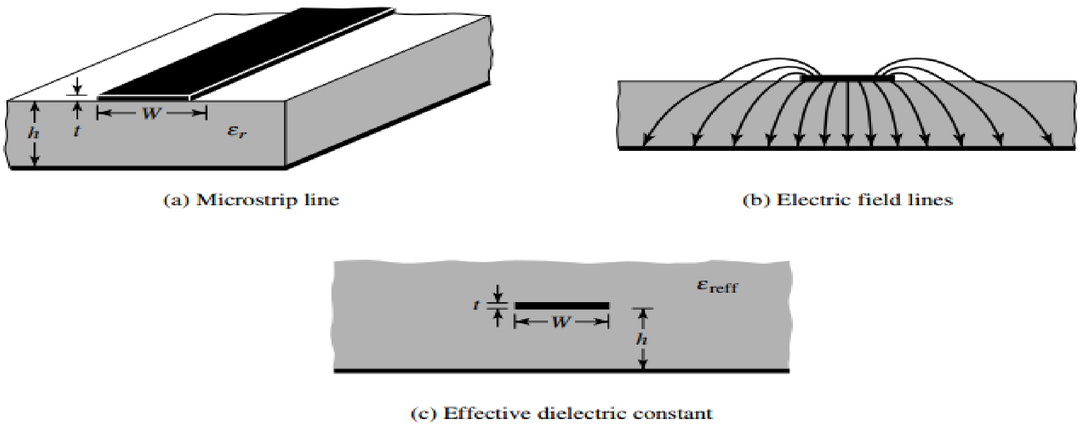


Fig.II. 5: Microstrip line and its field lines, and effective dielectric constant geometry[21]

b.1 Antenna Configuration

In this section, we will design a3D model of rectangular microstrip antenna to perform the simulation: design on FR-4 substrate material with dielectric constant of εr=4.4 and loss tan δ = 0.025, thickness h = 1.6mm and 50 Ω microstrip feed line is used for better impedance matching to the 2.45GHz resonance frequency. The dimensions parameters are presented and calculated based on analytical formulations given by [21], [27]:

1) Width of the patch :

c : Free space velocity

F_0 : Resonance frequency

ε_r : Relative permittivity

$$W = \frac{c}{2F_0\sqrt{\frac{\varepsilon_r+1}{2}}} = \frac{3\,.\,10^8}{2\ \cdot\ 2.45\ \cdot\ 10^9\ \sqrt{\frac{4.4+1}{2}}} \approx 37.26\,mm \qquad (II.1)$$

2) Effective dielectric constant is given as:

$$\varepsilon_{ref} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-0.5} = \frac{4.4+1}{2} + \frac{4.4-1}{2}\left[1+12\cdot\frac{1.6}{37.26}\right]^{-0.5} \approx 4.081 \qquad (II.2)$$

3) Length extension due to the fringing field is given as:

$$\Delta L = 0{,}412\frac{\left(\varepsilon_{ref}+0{,}3\right)\left(\frac{W}{h}+0{,}264\right)}{\left(\varepsilon_{ref}-0{,}258\right)\left(\frac{W}{h}+0{,}8\right)} = 0.412\frac{(4.081+0.3)\left(\frac{37.26}{1.6}+0.264\right)}{(4.081-0.258)\left(\frac{37.26}{1.6}+0.8\right)} \approx 738.61\,\mu m \qquad (II.3)$$

4) Effective length due to the resonance is given as:

$$L_{eff} = \frac{c}{2F_0\sqrt{\varepsilon_{ref}}} = \frac{3\cdot 10^8}{2\cdot 2.45\cdot 10^9\sqrt{4.081}} \approx 30.31mm \qquad (II.4)$$

5) Actual length of the patch is given by:

$$L = L_{eff} - 2\Delta L = 30.31mm - 2\cdot 738.61\mu m = 28.83mm \qquad (II.5)$$

6) Ground plane:

$$Wg = 6\cdot h + W = 6\cdot(1.6) + 37.26 \approx 46.86\,mm \qquad (II.6)$$

$$Lg = 6\cdot h + L = 6\cdot(1.6) + 28.83 \approx 38.43\,mm \qquad (II.7)$$

7) Feed line length is calculated using the below equation:

$$L_f = \frac{\lambda_g}{4} = \frac{59.4}{4} \approx 15.14\, mm \qquad (II.8)$$

Where λ_g is guided wave length and it is given by: $\lambda_g = \frac{\lambda}{\sqrt{\varepsilon_{ref}}} = \frac{0.12}{\sqrt{4.081}} \approx 60.58\text{mm} \quad (II.9)$

Using the impedance calculator provided by CST Microwave Studio, we can variant the width value of feed line to perform the impedance Z0 at 50Ω as seen from **Fig.II.6**. The final sizes of the microstrip patch antenna are listed on the **Table.II. 2.**

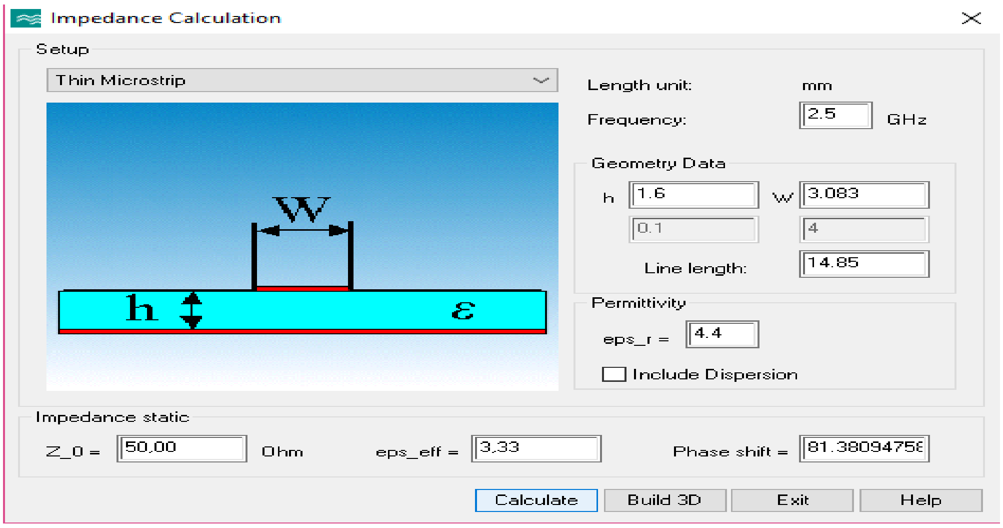


Fig.II. 6: Impedance calculation by CST microwave studio

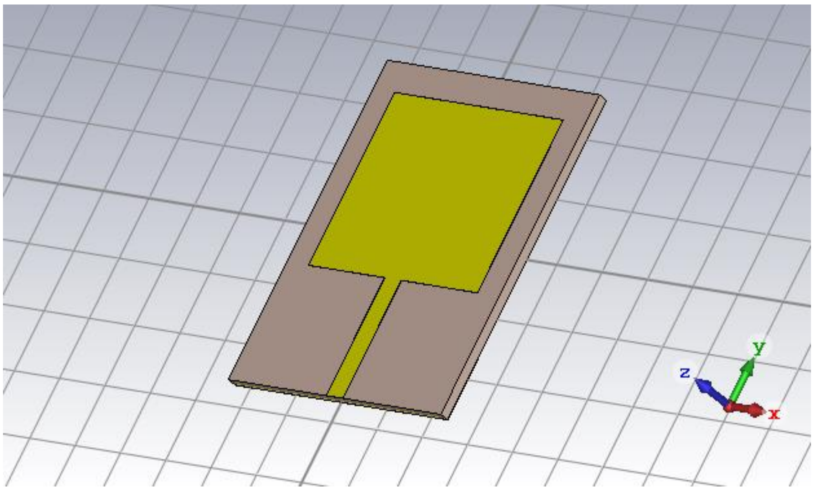


Fig.II. 7: Structure design of microstrip patch antenna using CST software

Lg	**Wg**	**L**	**W**	**Lf**	**Wf**
53.28	46.86	28.83	37.26	19.65	3

Table.II. 2: Dimensions of microstrip patch antenna (in mm)

b.2 Basic Properties of a Transmission Line Circuit

b.2.1 Input Impedance

Antenna input impedance (Za) is the impedance presented by an antenna at its terminals or the ratio of the voltage to current at its terminals. Mathematically, the input impedance is**[28]**:

$$Z_a = \frac{V_{in}}{I_{in}} = R_a + jX_a \qquad (II.10)$$

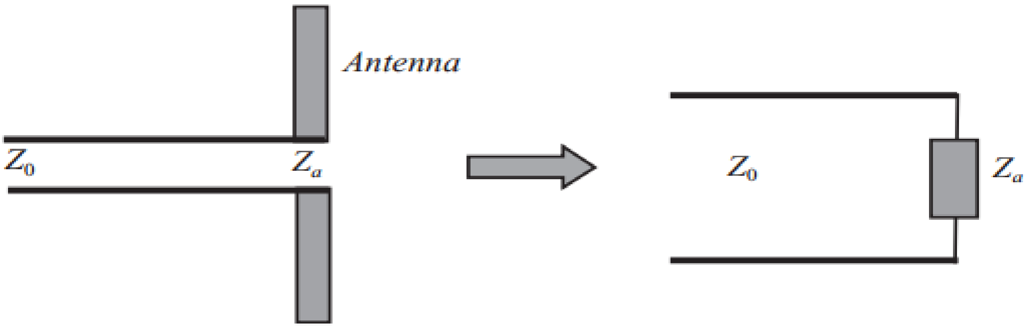


Fig.II. 8: antenna input impedance model[28]

Where Vin and Iin are the input voltage and current at the antenna input, respectively.

b.2.2 Matching and Reflection

The input impedance of patch antennas depends on their geometrical shape, dimensions, the physical properties of the materials involved, the feed type and location.To achieve the best geometry for matching. There are different methods to controlling impedance match for microstrip line with patch antenna and the most common is the Quarter-Wave Transformer.

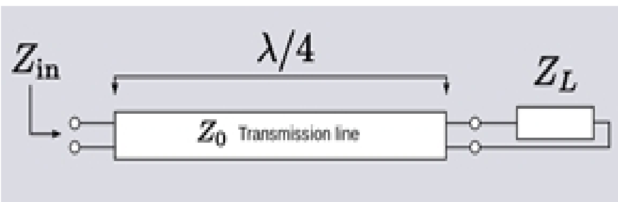


Fig.II. 9: circuit schematic of a quarter wave transformer[29]

A quarter-wave transformer is a simple impedance transformer which is commonly used in impedance matching in order to minimize the energy which is reflected when a transmission line is connected to a load. The quarter-wave transformer uses a transmission line with different characteristic impedance and with a length of one-quarter of the guided-wavelength to match a line to a load[30].

Derivation of the quarter wave transformer equation[29]:

The wavelength can be calculated based on frequency here:

$$Z_{in}(-L) = Z_0 \left[\frac{Z_L + jZ_0 \tan(\beta L)}{Z_0 + jZ_L \tan(\beta L)}\right] \qquad (II.11)$$

The input impedance of a transmission line of length L with characteristic impedance Z_0 and connected to a load with impedance Z_L:

$$Z_{in}\left(L = \frac{\lambda}{4}\right) = Z_0 \left[\frac{Z_L + jZ_0\ \tan\left(\frac{2\pi}{\lambda}\frac{\lambda}{4}\right)}{Z_0 + jZ_L \tan\left(\frac{2\pi}{\lambda}\frac{\lambda}{4}\right)}\right] \qquad (II.12)$$

When the wavelength is take to be a quarter wave (λ/4). This formula simplifies down to:

$$Z_{in}\left(L = \frac{\lambda}{4}\right) = \frac{Z_0^2}{Z_L} \qquad (II.13)$$

The Characteristic Impedance of Transmission Line is then given by:

$$Z_0 = \sqrt{Z_L Z_{in}} \qquad (II.14)$$

b.2.3 VSWR

When a traveling wave at some point is totally or partially reflected, a standing wave is created. The ratio of the absolute values of the complex voltage wave amplitude at maximum and at minimum in the transmission line is known as the voltage standing wave ratio (VSWR), and can be defined as follows[31]:

$$VSWR = \frac{1 + \Gamma}{1 - \Gamma} \qquad (II.15)$$

Where Γ is the reflection coefficient.

b.2.4 Return loss

Return loss is a measure of the effective power transfer from the power source to the antenna. It can be calculated by the following equation and is given in dB[32]:

$$RL_{dB} = -20\ log|\rho| \qquad (II.16)$$

The return loss is also stated as the S11 of the S-parameters; are a complex number but they mostly only refer to the magnitude as you want to know how much loss or gain you get, S-parameters can be either be calculated or measured a network analyzer[33].
In **Table.II.3** S-parameters are described:

S parameter	Description
S11	The input ports voltage reflection coefficient.
S12	The reverse voltage gain.
S21	The forward voltage gain.
S22	The output ports voltage reflection coefficient.

Table.II. 3: S parameters[33]

b.2.5 Radiation Pattern

The radiation pattern or antenna diagram is defined as "a mathematical function or a graphical representation of the antenna's radiation properties as a function of space coordinates". In most cases, radiation is determined in the far field area and is represented as a function of directional coordinates[21].

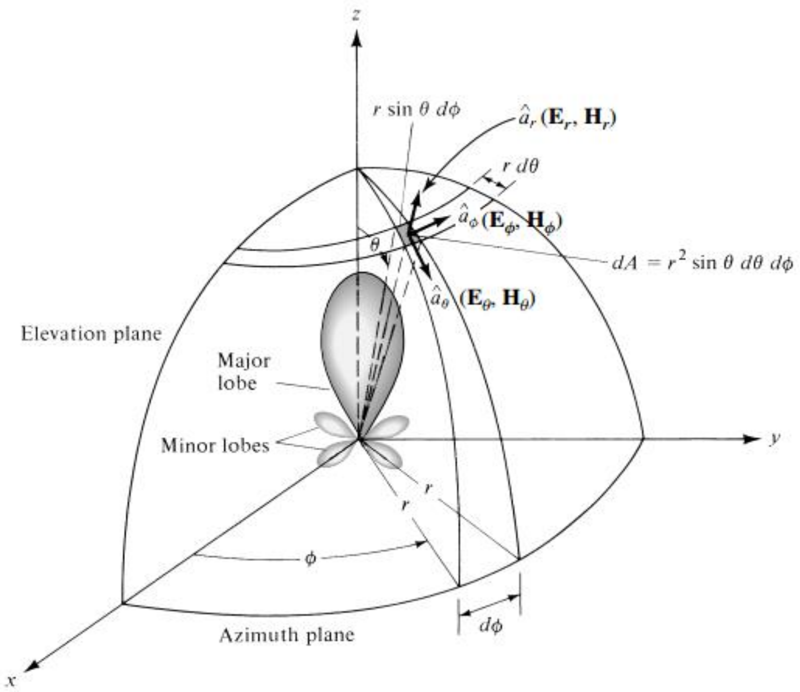


Fig.II. 10: Coordinate system for antenna analysis[21]

b.2.6 Bandwidth

Bandwidth is the parameter of the other core antenna. Bandwidth describes the frequency band that an antenna can radiate or receive power correctly. Often, the desired bandwidth is one of the specific parameters used to determine the antenna.

In the field of antennas in terrestrial applications, the bandwidth generally corresponds to the frequency range on which 90% of the incident power is transmitted, which corresponds to S11 = -10 dB, and provided that the radiation pattern, or the distribution of the radiated energy, do not change on this band[34].

b.2.7 Gain

Gain is a measure of the ability of the antenna to direct the input power into radiation in a particular direction and is measured at the peak radiation intensity. The gain of an actual antenna increases the power density in the direction of the peak radiation and gain is achieved by directing the radiation away from other parts of the radiation sphere[32].

We will note:

P (θ, φ): the average power density radiated by the antenna (W / m2).
P0: the average power density radiated (W / m2) by the isotropic antenna. The gain is then given by the following expression[34]:

$$G(\theta,\varphi) = \frac{P(\theta,\varphi)}{P_0} \qquad (II.17)$$

b.2.8 Directivity

The directivity of the antenna is the ratio of the power radiated per unit of solid angle in the direction (θ,φ) to the power that would radiate the isotropic reference source per unit of solid angle for the same total radiated power. The directivity indicates in which directions the power density is better or worse than that of the isotropic antenna, is given by the following equation[35]:

$$D(\theta,\varphi) = 4\pi\frac{P(\theta,\varphi)}{\eta P_a} \qquad (II.18)$$

Where η the performance of the antenna is the ratio between the total power that it radiates P and the Pa input power of the antenna.

II.7 Multi-Band Antennas

Many modern communication systems have to work well over multiple frequency bands[28]. The advantage of multiband antenna frequencies is evident in mobile phones. The designers of phones always need more space for nine different antennas and other elements. Among the solutions they have the use of one antenna operates in several frequencies instead of using the antenna for each frequency and this is what we call the multiband frequency which opened the way for wireless evolution. Proof of the validity of our idea we take a sample of Samsung business Galaxy S5, see the antenna diagram below:

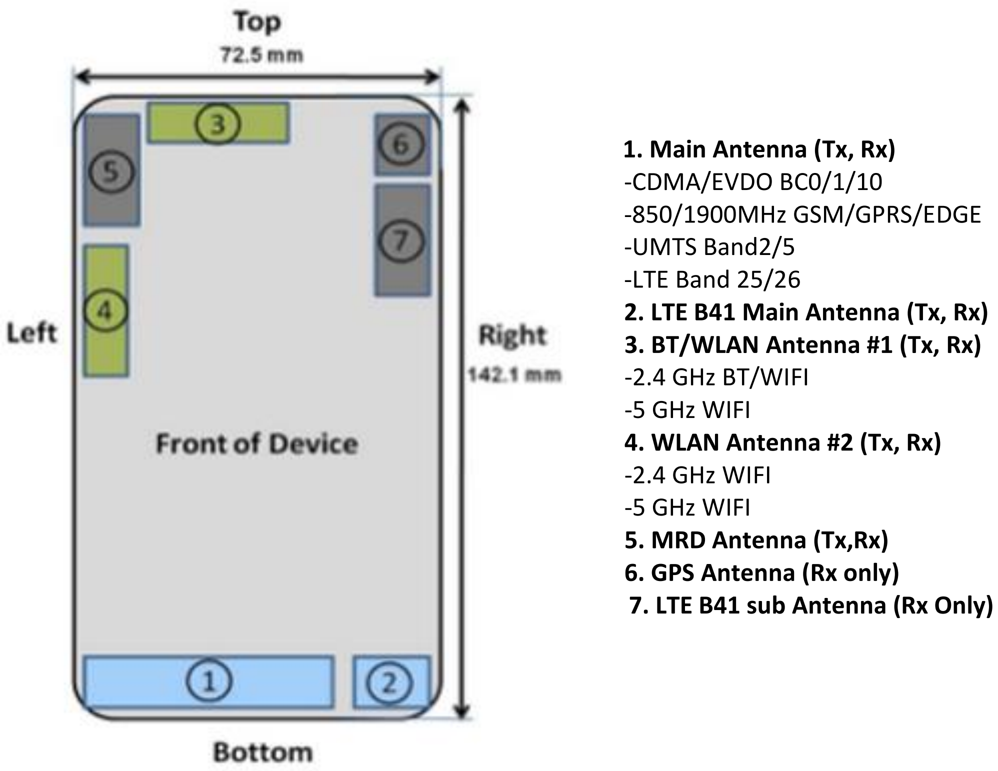


Fig.II. 11: Dut antenna location of Galaxy S5[36]

II.8 Methods for Enhancing the Parameters of MPA

This section provides an introduction on how to improve the performance of the microstrip patch antenna to reduce defects that limit its effectiveness such as low bandwidth, low gain, spurious radiation, high complexity, narrowband, large dimensions, and surface wave propagation.

There are various methods for improving the parameters of MPA like changing the surface of patch, different dielectric substrates, using multilayer structures, different feeding techniques, using array method etc. Comparative analysis of some methods is given below:

a. Enhancing using Slots

Microstrip slot antennas invented in 1938 by Alan Blumlein. Slot radiator or slot antennas are antennas that are used in the frequency range from about 300 MHz to 25 GHz. The slot behaves according to Babinet's principle as a resonant radiator. Jacques Babinet (1794-1872) was a French physicist and mathematician, formulated the theorem that similar diffraction patterns are produced by two complementary screens.This principle relates the radiated field and impedance of an aperture or slot antenna so that of the field of a dipole antenna. It can also provide the low profile, low cost, small size, easier integration with other circuits and conformability to a shaped surface[37].

By using a different shape of slots researchers found that; we can improve the efficiency of an antenna as compared to conventional microstrip patch antenna. By the use of the slot, we can enhance bandwidth, gain etc. Return loss is reducing. Axial ratio and the radiation pattern are also improved. By the use of slot microstrip antenna can be used in any application. The **Table.II.4** gives us some of the studies that have been provided in this area:

Configuration	**Remarks**
Five rectangular slots are etched on the patch	Multiband and miniature microstrip antenna for wireless communication, increase the bandwidth 89% for GSM band, 19.45% for UMTS and 36.25% for WLAN[38].
The insertion of two symmetrical U-shaped slots	Triple-band resonant modes are achievable , the antenna be effective in WLAN, LTE cellular, and WiMAX applications[39].
Two E Shapes slots placed parallel on the rectangular patch	The antenna can operate at 4.5GHz , displays a good Omni-directional radiation pattern ,good return loss and radiation pattern characteristics and used in the s, c-bands[40].
Cut three rectangular parallel slots in the proposed antenna	Improved impedance bandwidth 19.7% for the WLAN applications[41].
13 Slots are etched on the patch	0.8% Improvement in bandwidth. It is designed for GPS application to operate at 1.6 GHZ center frequency[42].

Table.II. 4: Slots configuration on patch surface

b. Enhancing using Metamaterials

Metamaterials have attracted a great amount of attention in the area of research. Christophe Caloz and Tatsuo Itoh presented in their book **"Electromagnetic metamaterials: transmission line theory and microwave applications "**, the definition of metamaterials by: ‘’Electromagnetic metamaterials (MTMs) are broadly defined as artificial effectively homogeneous electromagnetic structures with unusual properties not readily available in nature’’**[43]**.

b.1 Classification of Materials

Materials are classified based on the sign of permittivity (ε) and permeability (μ). **Table.II.5** show the classification[42]:

Permittivity	**Permeability**	**Material**
ε >0	μ>0	Double positive material
ε <0	μ>0	Epsilon negative material
ε >0	μ<0	Mu negative material
ε <0	μ<0	Double negative or Left-Handed Materials (LHMs)

Table.II. 5: Materials based on permittivity and permeability values

Out of these four types of materials LHMs are used for improving the performance of microstrip patch antenna and these LHMs are called as metamaterials.

b.2 What is a Left –Handed Metamaterials ?

Veselago’s Conclusions**[44]:**

- Simultaneous negative permittivity (-ε) and permeability (-μ).
- Reversal of Snell’s law (negative index of refraction), Doppler Effect and Cerenkov Effect.
- The electric field, Magnetic field, and wave vector of the electromagnetic wave in a LHM form a left-handed triad.
- LHMs support backward waves: antiparallel group and phase velocity.
- Artificial effectively homogenous structure: metamaterial.

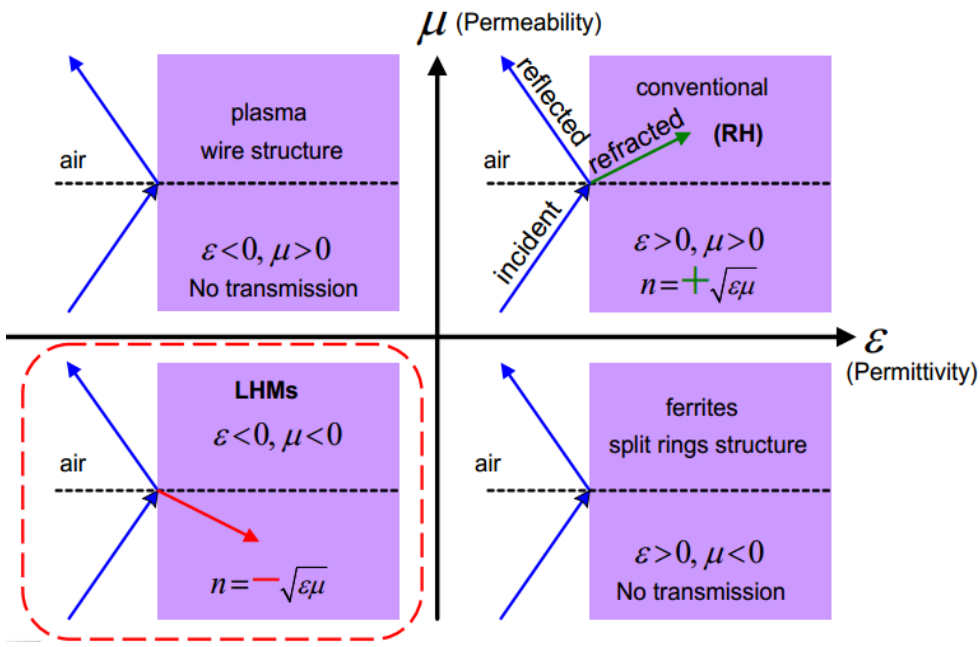


Fig.II. 12: Material classification[44]

b.3 Split Ring Resonator in Metamaterials

Metamaterial was theoretically investigated by Veselago in 1968, later Pendry; proposed an artificial thin wire medium to realize electric plasma giving negative permittivity and split ring resonators (SRR) to realize magnetic plasma; These are the elements used to fabricate metamaterials. It produces the desired magnetic response in various types of metamaterials up to 200 THz. This SRR unit cell can be transformed by an equivalent circuit using capacitor and inductor element. Show the topologies of the SRR and CSRR and their equivalent circuit models in figure [42], [45] **:**

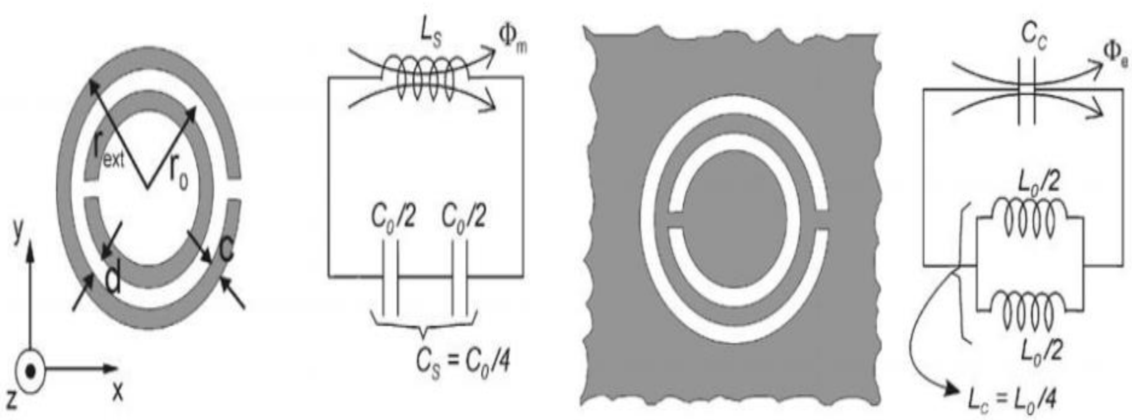


Fig.II. 13: Topologies of the SRR and CSRR and their equivalent circuit models.

b.4 Antenna Solution

Some of the solutions provided by metamaterials in the field of antennas are [46]:

- Improved radiation efficiency;
- Miniature Cavity Antennas, Miniature Network Antenna, Offset Antenna;
- Antenna compliant to integrate directly into the vehicle structure;
- Greater degree of freedom for the realization of filtering devices and electromagnetic shielding:
    - Frequency selectivity (high band rejection)
    - Spatial selectivity (very high directivity)
    - Miniaturized size
    - Low weight compared to metal structures
- Antenna design and integration into their operating platform:
    - Mass plan
    - Recovery Radiation Diagram
    - Conforming antenna to integrate into the vehicle structure.

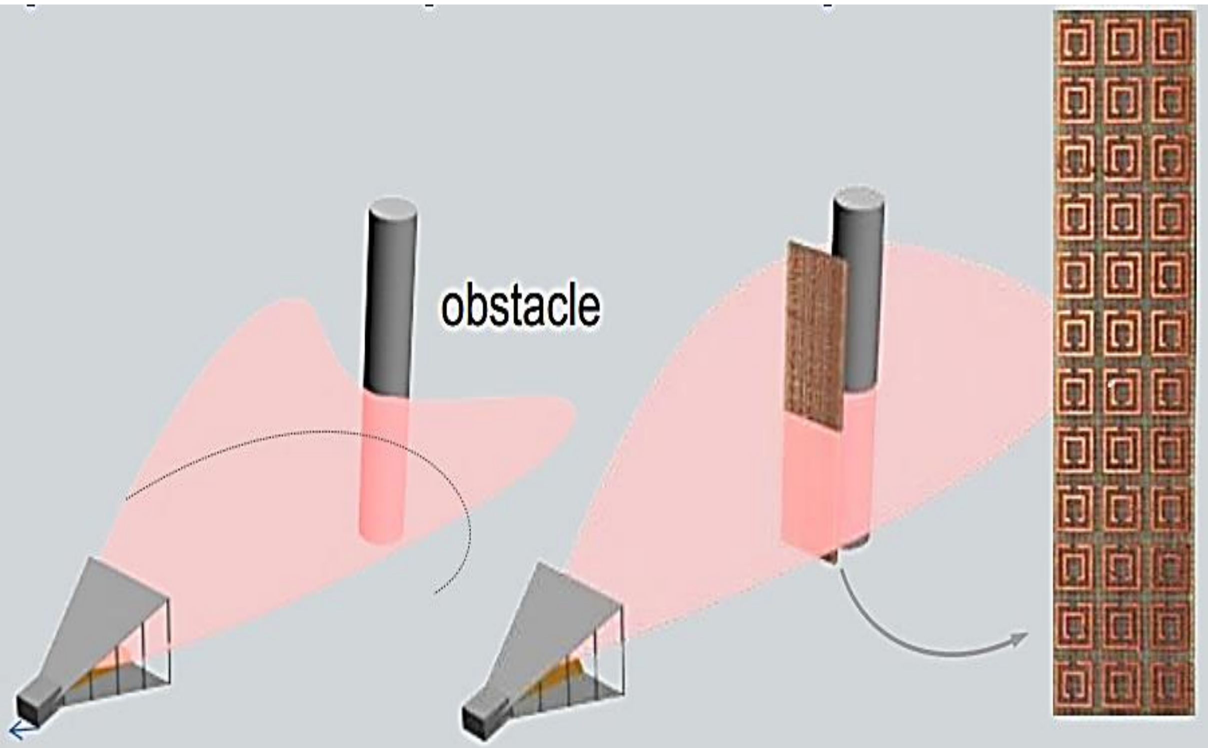


Fig.II. 14: Application to antennas[46]

The **Table.II.6** gives us some of the studies that have been provided in this area:

Configuration	**Remarks**
Symmetrical ring structure complimentary split ring resonator (CSRR)	A size reduction of 72.5%, providing lowering in resonance frequency by 26%.[47]
Microstrip Patch Antenna with EBG Structure	The bandwidth of the antenna has been increased by 39.63% and the size of the antenna reduced by 22.38%.[48]
Patch antenna (MSA) with complimentary split ring resonator (CSRR) loaded ground plane	the size reduction by 10.04% the bandwidth is also increased to 29.6% for WLAN applications.[49]
Square patch and square-loop elements (CSRR)	Provide multiple resonances with good impedance bandwidth and good candidate for GSM, DCS, IMT, WIMAX, and WIFI/WLAN communication.[50]
A complementary split ring resonator etched from the ground plane and U slot in the radiating element	Achieves a 52.43% size reduction and more than 45% bandwidth enhancement for RFID reader applications.[45]

Table.II. 6: Metamaterials configuration on ground plane

II.9 Conclusion

In this second chapter, we present the generalities of the microstrip antennas, we have calculated the dimensions of the antenna that we would simulate and apply the optimization techniques discussed in this chapter.

We investigated the further technical improvement of the performance of the microstrip antenna using slots and metamaterials techniques, which proved effective in solving problems of this sensitive antenna with the secret of its simplicity, its supernatural characteristics and its ability to improve the parameters of microstrip patch antenna. However, research on these techniques is still ongoing and of interest to all researchers, and there are many problems to be solved regarding the defects of this antenna.

Chapter III: Design, Simulation and Measurement Results

Chapter III
Design, Simulation and Measurement Results

III.1 Introduction

In this chapter, we will give a design, simulation, and measurement of microstrip patch antenna. This project involves studying the effect of improvement techniques on antenna characteristics (the coefficient of reflection, the resonance frequency, and the bandwidth). The simulation is realized by applying computer simulation technology (CST) software.

The first Step is the design and the simulation of a basic antenna with the size given in chapter II, the structure consists of a rectangular patch antenna fed by microstrip line feed a 50 Ω for impedance matching.

In the second step, we will introduce the miniaturization technique to decrease the size of our microstrip patch antenna for good results and better performance at the resonance frequency 2.45 GHz.

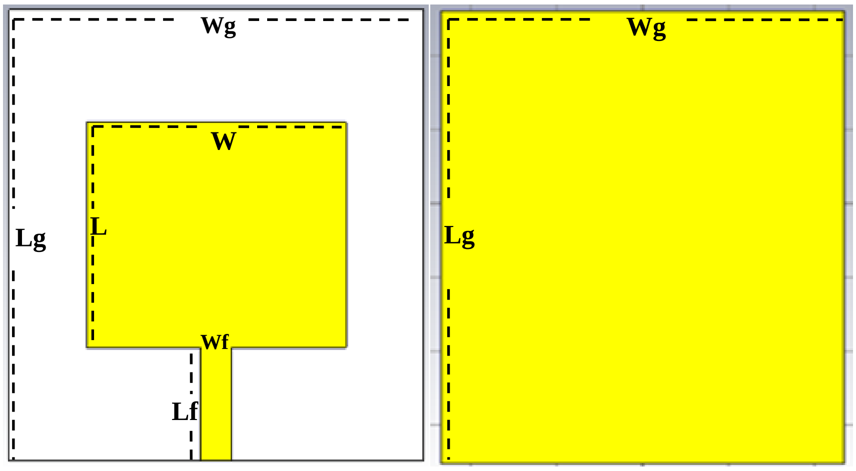
The final step, we will take the miniaturized patch antenna and we insert 5 rectangular slots on the radiating patch to perform the multiple bands, and with this insertion, we will show the appearance of the new resonance frequency.

After these 3 steps of the performance, we will finish our design by the fabrication in the private enterprise “Almitech” and the measurement of our performed microstrip patch antenna using Network Analyzer “Agilent PNA” at “CDTA- Centre de Développement des Technologies Avancées”, and make a comparison between simulation and measurement results.

Step.1. Design and simulation

a. Basic antenna

We will build our work on the dimensions of a simple rectangular patch on a grounded substrate were obtained from the formulas **(II.1-9**) in **chapter II**. We consider a simple line-feed rectangular patch at 2.45 GHz.



a) Top view b) Back view

Fig.III. 1: Top view and back view of microstrip patch antenna

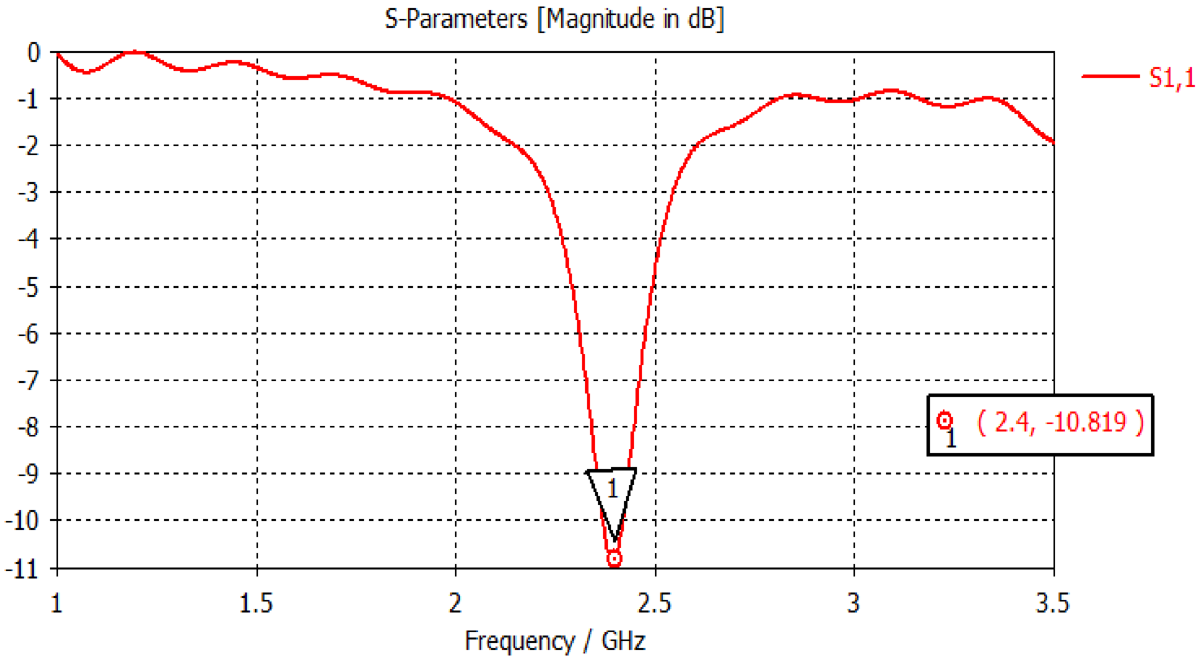
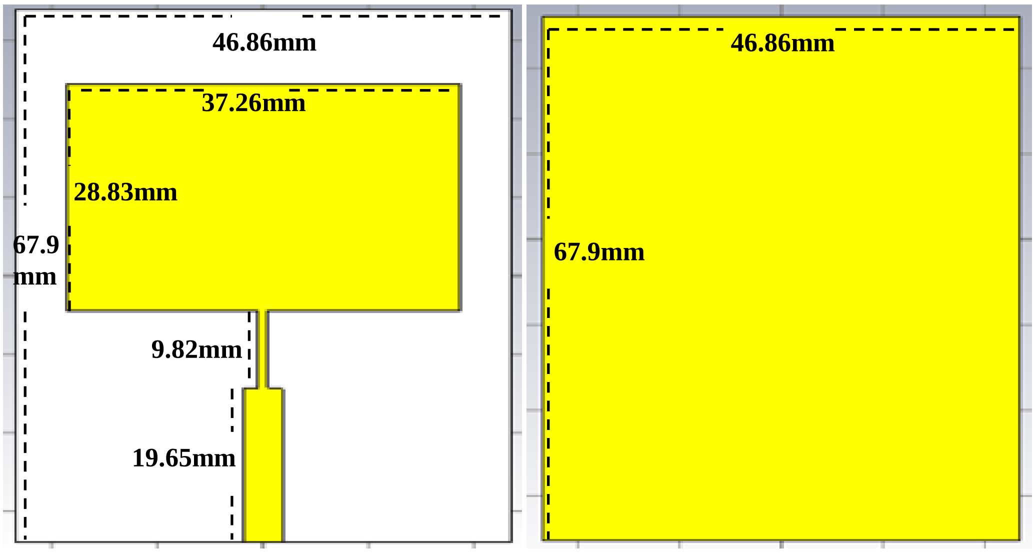


Fig.III. 2: Return loss of microstrip patch antenna

By looking at the previous results in**Fig.III.2**, the antenna gives us a return loss of-10.81dB at 2.4 GHz, which is not very optimal because their matching. By determining the result of the first design, we need to change our design to match the resistance of the antenna with a load resistance of 50 Ω. By doing some research, we ended up using Quarter-Wave Transformer; adding another feeding line between the patch and the original feed line with a width of 3.083/4 = 0.77 mm.

Lg	Wg	L	W	Lf	wf	eLf	ewf
67.9	46.86	28.83	37.26	19.65	3.083	9.82	0.77

Table.III. 1: Dimensions of basic antenna



a) Top view b) Back view

Fig.III.3: Top view and back view of basic antenna

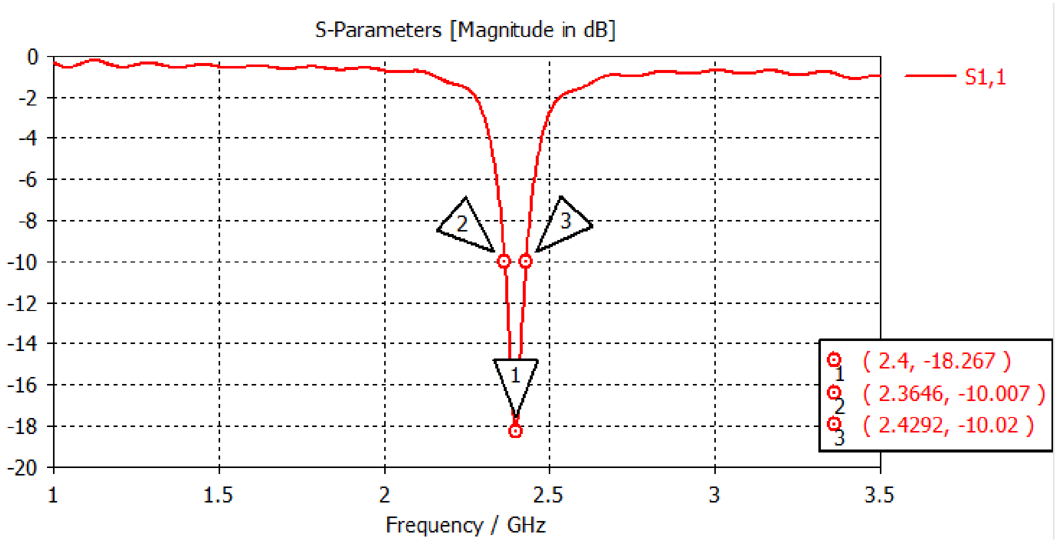
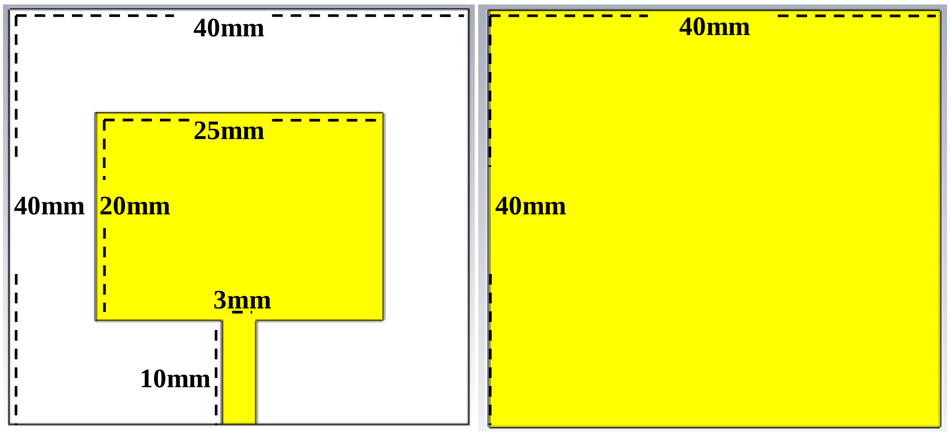


Fig.III. 4: Return loss vs frequency

After obtaining the new design,**Fig.III.4** shows the return loss, the antenna gives a narrower bandwidth 64 MHz at resonant frequency 2.4 GHz with better results, S11 equal (-18.26 dB). Despite improved results, the size of the antenna has increased and this is not helpful, so in the next step we will work for miniaturization the antenna and improve performance at the same time.

Step.2. Miniaturization



a) Top view b) Back view

Fig.III. 5: Top view and back view of antenna after miniaturization

We suggest new values for the dimensions of our antenna not subject to any calculations, and smaller than the base antenna. We will work to give good results and better performance at the required frequency of 2.45 GHz.

Lg	Wg	L	W	Lf	Wf
40	40	20	25	10	3

Table.III. 2: New dimensions of patch antenna miniaturization

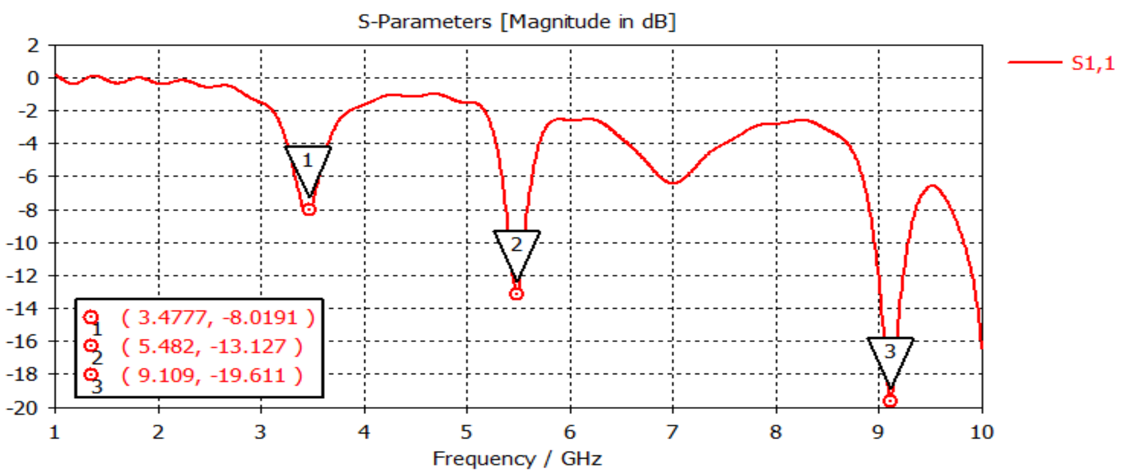


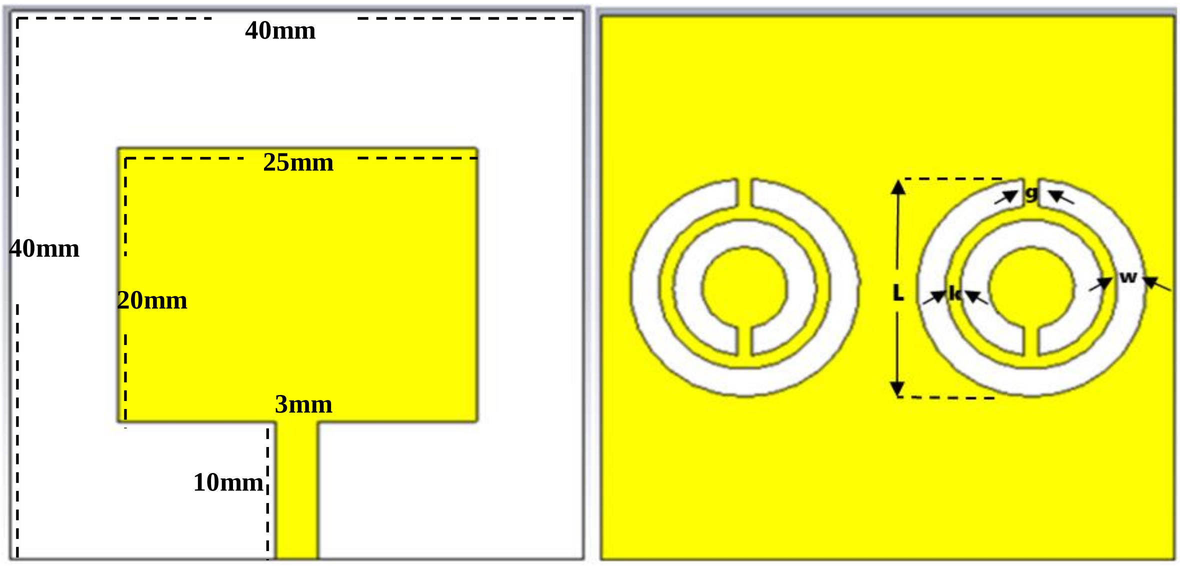
Fig.III. 6: Simulated return loss of patch antenna miniaturization

We have emulated the antenna with its new miniaturized values, that before any change in its form to thus be able to compare the results before and after the use of the Enhancing techniques which we will approach in the next steps.

The antenna miniaturization is simulated with a frequency range of 1-10 GHz because we aim to multiband resonant frequency, this antenna shows resonance at 3.47 GHz, 5.48 GHz and 9.1 GHz with the return loss of -8.01 dB, -13.12 dB and -19,61 dB respectively. After miniaturization, we lost the frequency which we seek (2.45 GHz).

a. Patch antenna miniaturization using CSRR

The size reduction using CSRR in the ground of the patch antenna, the structure is formed by two concentric rings with splits at its opposite on the inner and outer rings. Patch antenna with CSRR loading for resonance frequency at 2.45 GHz has been designed and is shown in**Fig.III.7.**



a) Top view b) Back view

Fig.III. 7: Patch antenna with symmetrical CSRR

Parameters	Values (mm)
W	1
g	2
K	1
L	8

Table.III. 3: Dimensions of CSRR (in mm)

a.1.1. Simulation results of patch antenna using CSRR

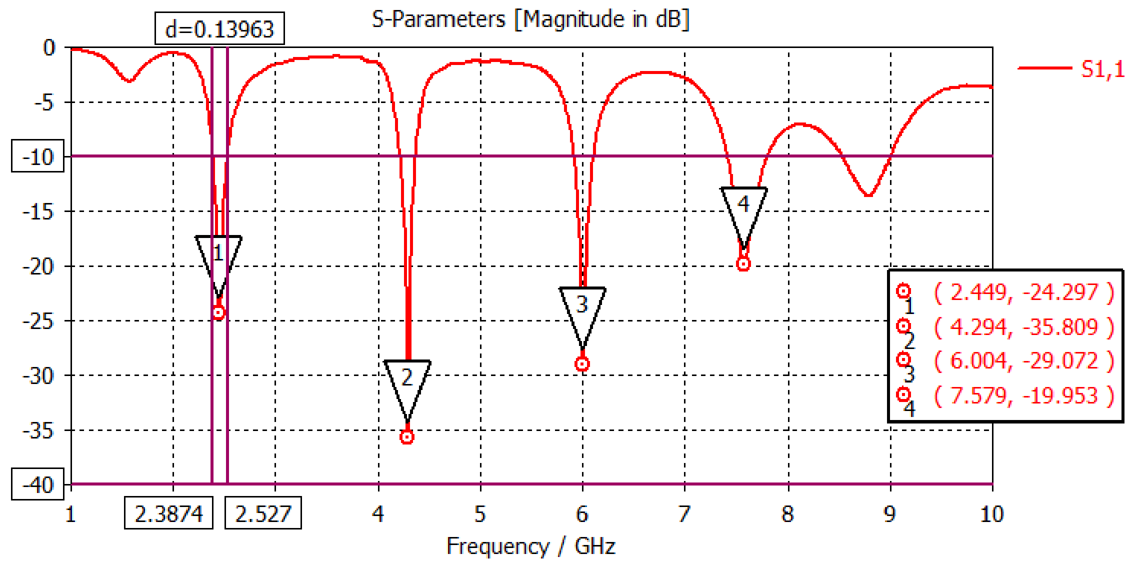


Fig.III. 8: Simulation return loss for patch antenna with symmetrical CSRR

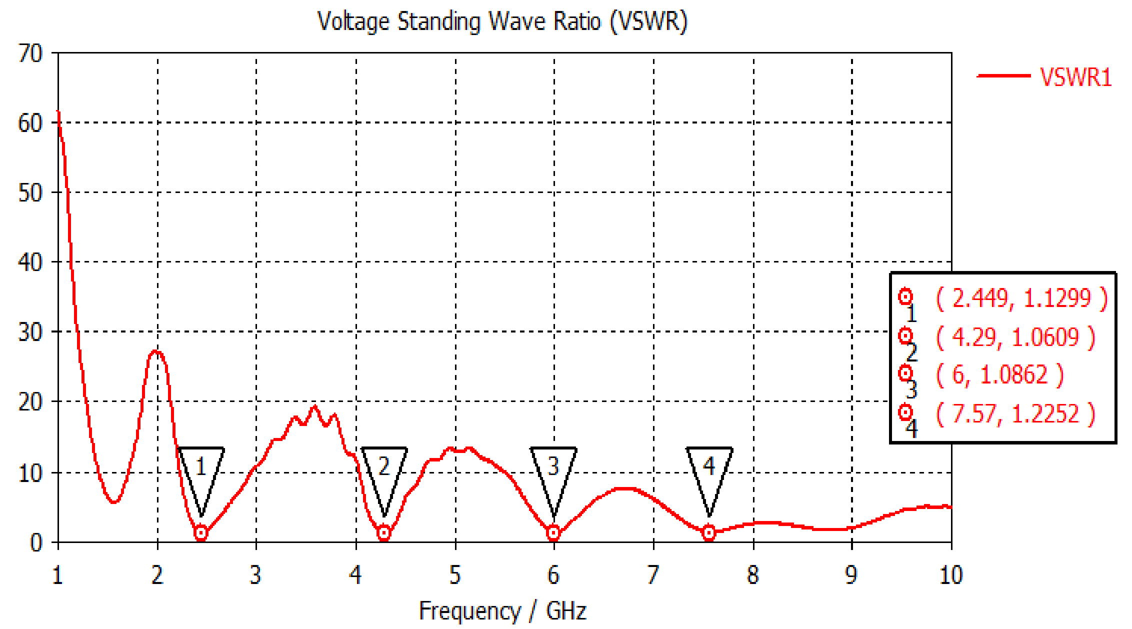
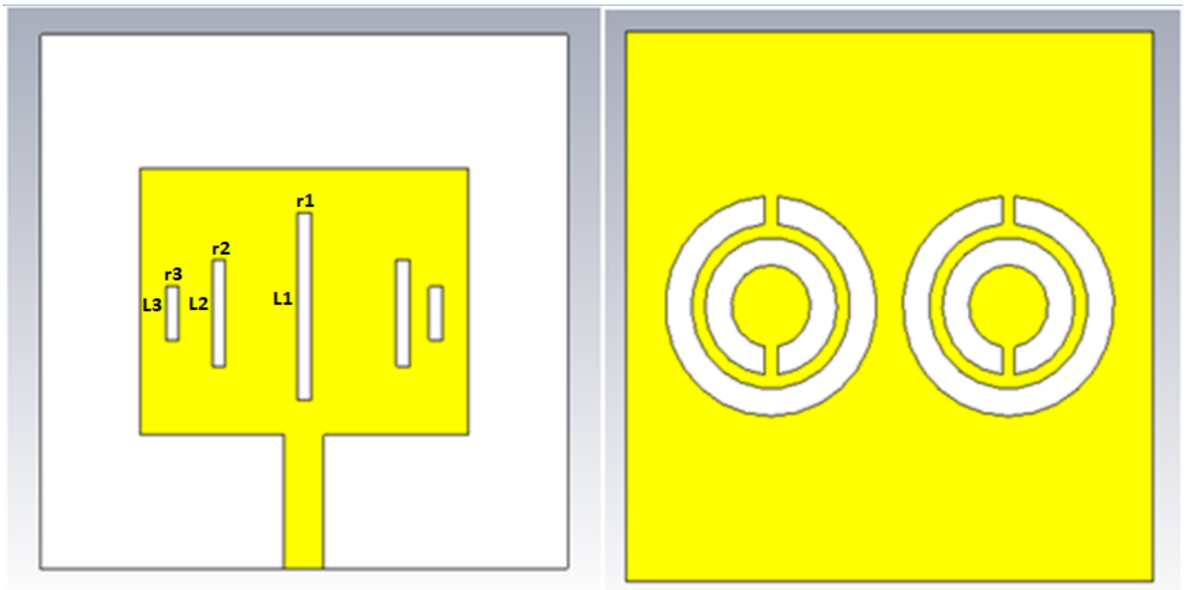


Fig.III. 9: The simulated VSWR of patch antenna with CSRR

The simulation results of the antenna in **Fig.III.8**, **Fig.III.9** show recovery the required frequency 2.45GHz in addition to enhancement the bandwidth at the same frequency 2.45 GHz to 139 MHz to allow the creation multiband frequencies with better results S11 and all virtue to metamaterials technique; CSRR Specifically. The VSWR of the antenna at operating frequencies is equal to 1, indicating that the antenna exhibits good impedance matching at those frequencies.

Step.3. Rectangular Slots in small antenna

In this step, we designed multiple slots in the small antenna with different values and different positions on the radiating patch to see the effect of the slots in creating a new resonance frequency of the antenna and get multiple technologies.



a) Top view b) Back view

Fig.III. 10: Patch antenna with rectangular slots and CSRR

Parameters	Values (mm)
r1	1
L1	14
r2	1
L2	8
r3	1
L3	4

Table.III. 4: Dimensions of cut rectangular slots (in mm)

a.1. Simulation results of final Design

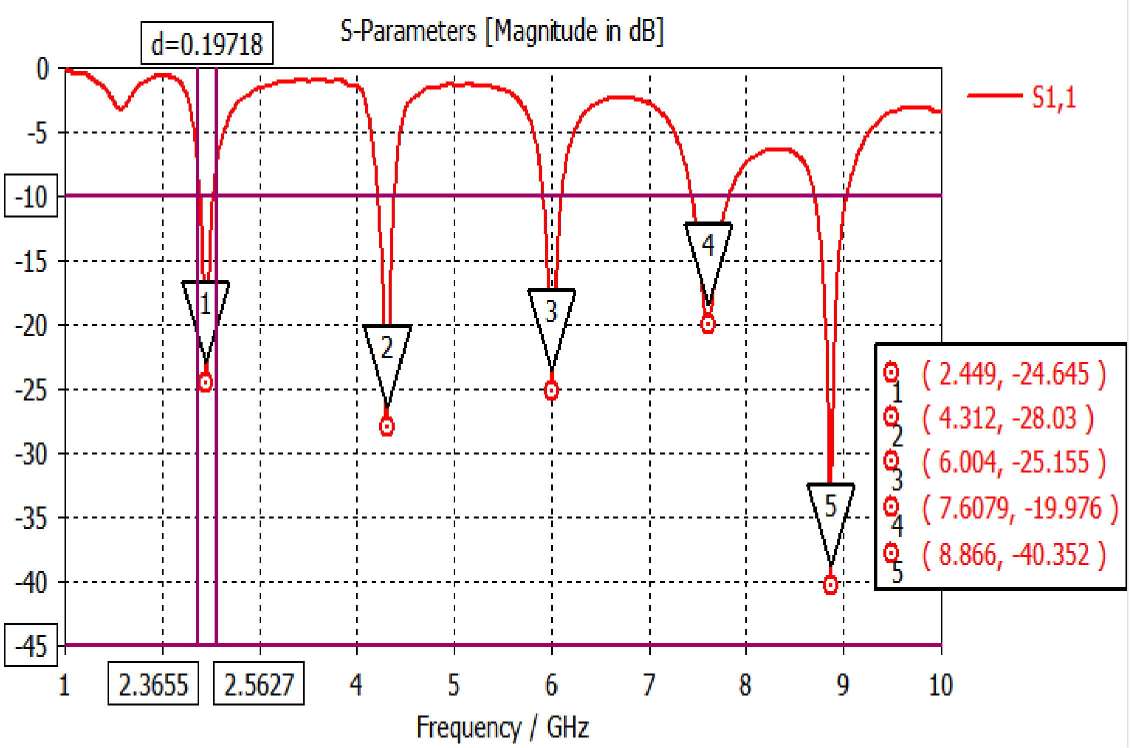


Fig.III. 11: Simulated return loss of patch antenna with rectangular slots and symmetrical CSRR

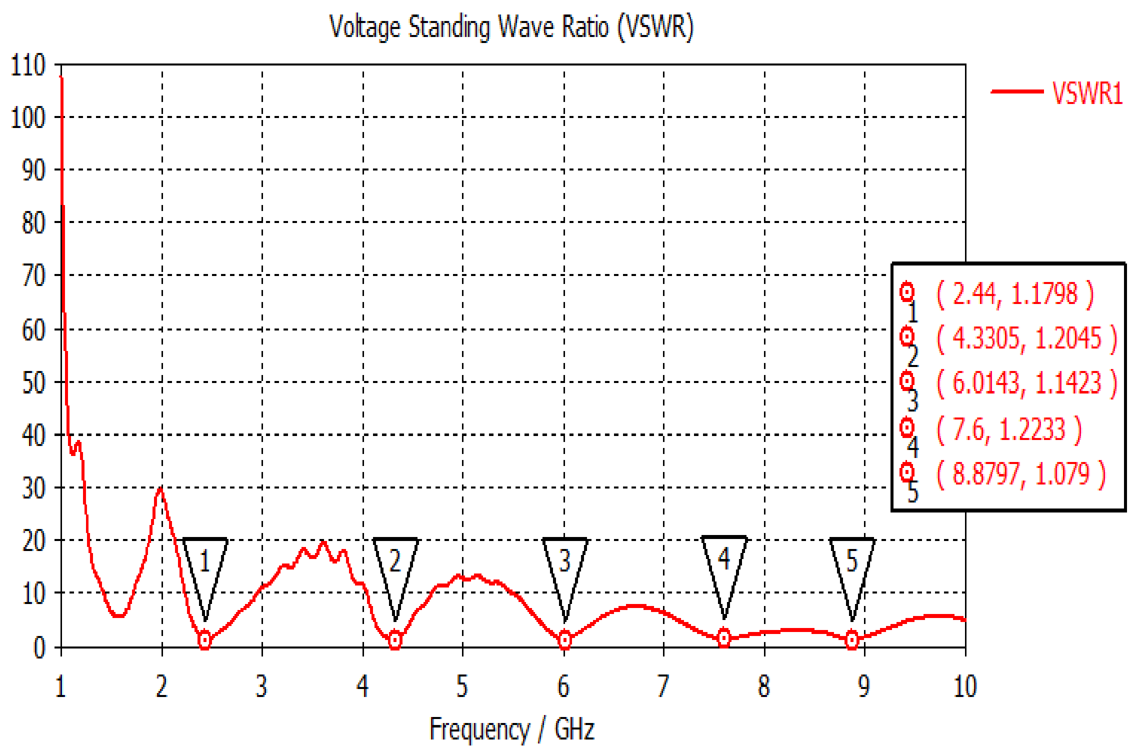


Fig.III. 12: Simulated VSWR of patch antenna with rectangular slots and symmetrical CSRR

The simulation results of the antenna draws our maintaining the required frequency in addition to enhancement the bandwidth at the same frequency 2.45 GHz to 197 MHz and getting a new resonance frequency with good adaptation after inserting the rectangular slots and enhancing the bandwidth with values up to MHz. The return loss S11 less than -10dB shows five bandwidths in Antenna 3 the selected antenna (2.36-2.56 GHz), (4.21 - 4.38 GHz), (5.91 - 6.1 GHz), (7.44 - 7.82) and (9.7 - 9.03) respectively, with good impedance matching at those frequencies.

For our objective, we find that by this improvement based on microstrip antenna, we were able to be in the following LTE areas; band 7 [2500MHz-2570MHz] (R_x only), band 40 [2300MHz-2400MHz] (R_x,T_x), an increment to a host of other technologies which increases the performance of this antenna.

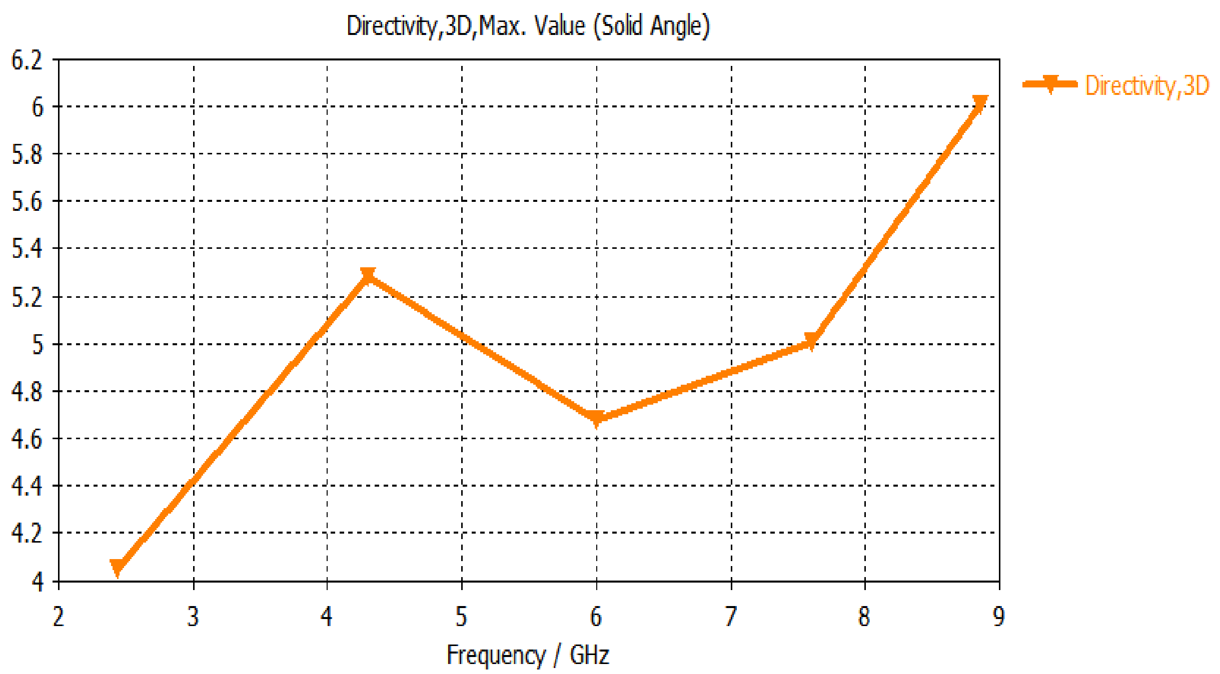
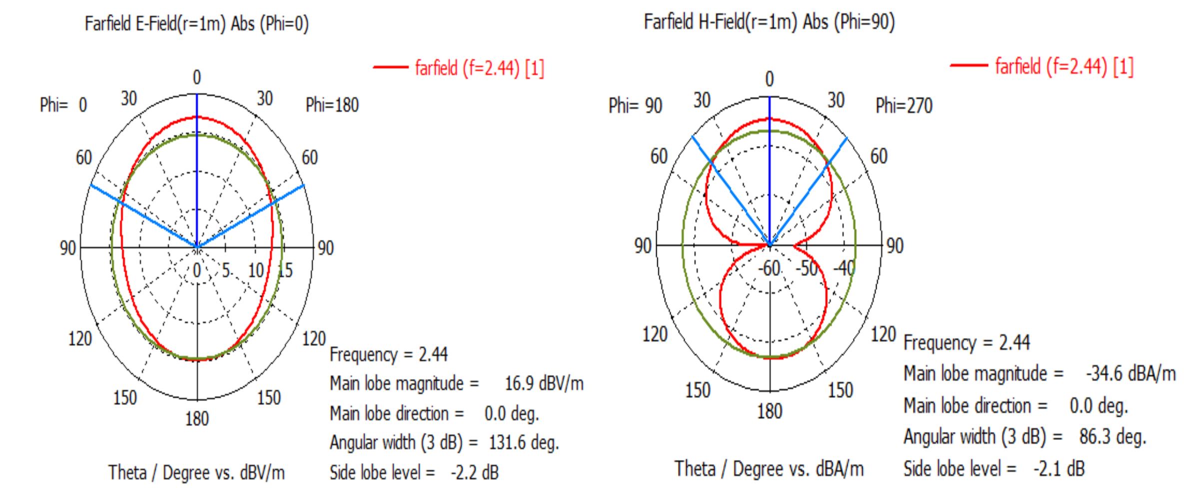
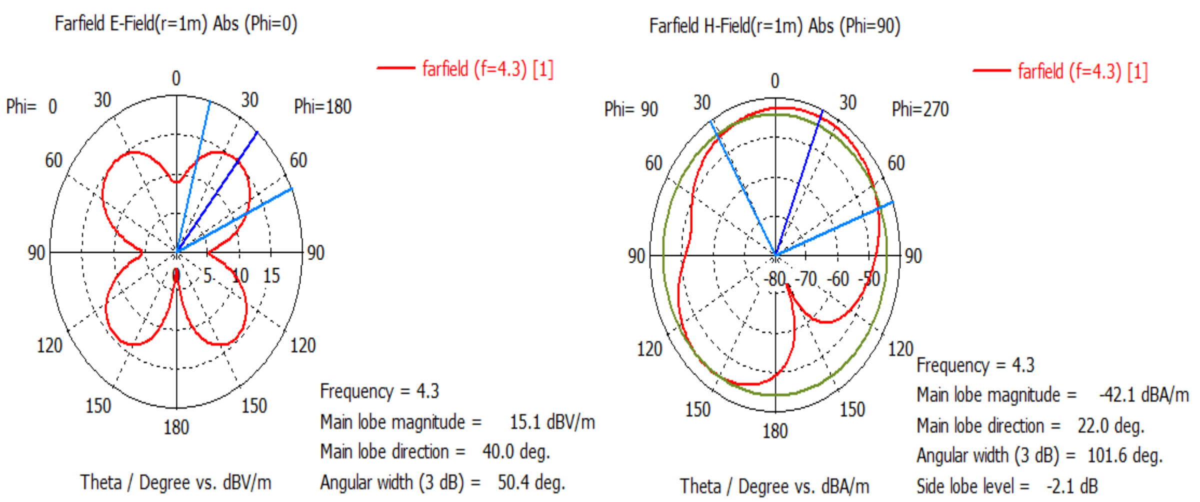


Fig.III. 13: Simulated directivity of patch antenna with slots and CSRR

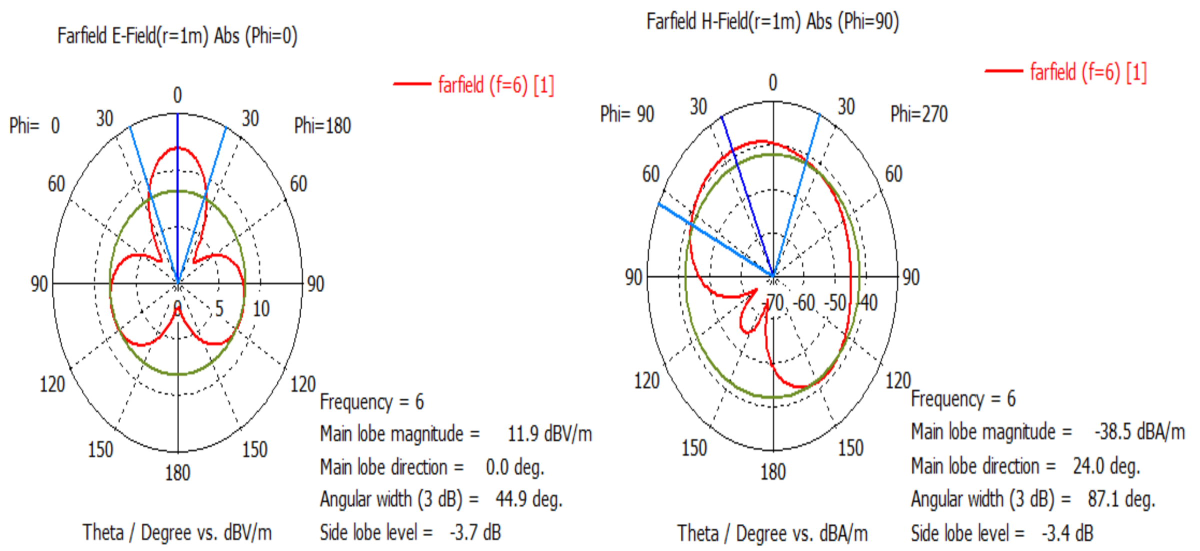
The antennas simulated in this work are directive; the maximum directivity reached is of the order 6 dB.


Farfield E-Field(r=1m) Abs (Phi=0)
farfield (f=2.44) [1]
Phi= 0
Phi=180
Frequency = 2.44
Main lobe magnitude = 16.9 dBV/m
Main lobe direction = 0.0 deg.
Angular width (3 dB) = 131.6 deg.
Side lobe level = -2.2 dB
Theta / Degree vs. dBV/m
Farfield H-Field(r=1m) Abs (Phi=90)
farfield (f=2.44) [1]
Phi= 90
Phi=270
Frequency = 2.44
Main lobe magnitude = -34.6 dBA/m
Main lobe direction = 0.0 deg.
Angular width (3 dB) = 86.3 deg.
Side lobe level = -2.1 dB
Theta / Degree vs. dBA/m

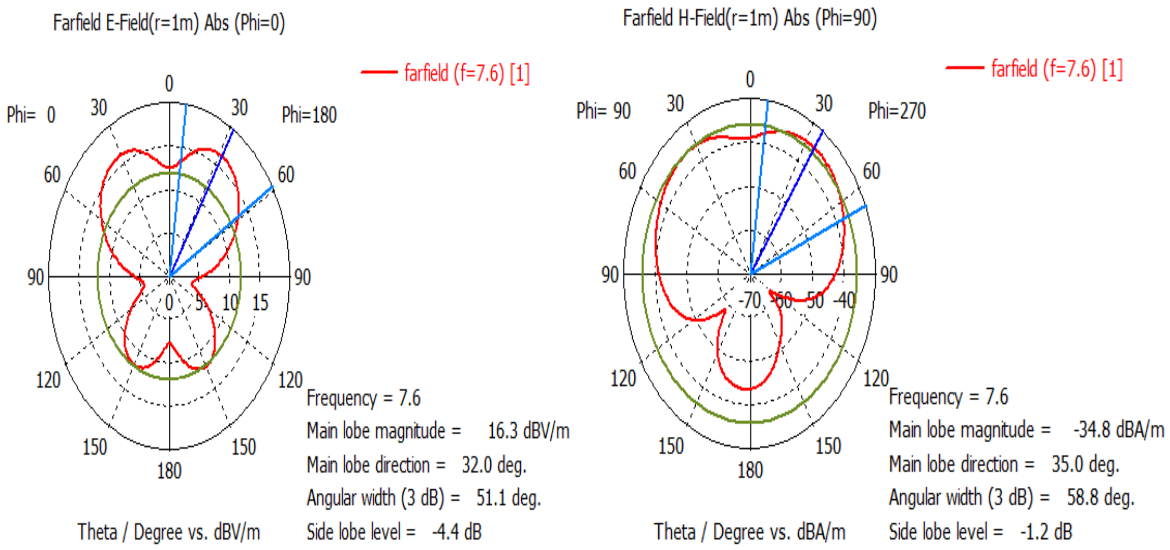
a)


Farfield E-Field(r=1m) Abs (Phi=0)
farfield (f=4.3) [1]
Phi= 0
Phi=180
Frequency = 4.3
Main lobe magnitude = 15.1 dBV/m
Main lobe direction = 40.0 deg.
Angular width (3 dB) = 50.4 deg.
Theta / Degree vs. dBV/m
Farfield H-Field(r=1m) Abs (Phi=90)
farfield (f=4.3) [1]
Phi= 90
Phi=270
Frequency = 4.3
Main lobe magnitude = -42.1 dBA/m
Main lobe direction = 22.0 deg.
Angular width (3 dB) = 101.6 deg.
Side lobe level = -2.1 dB
Theta / Degree vs. dBA/m

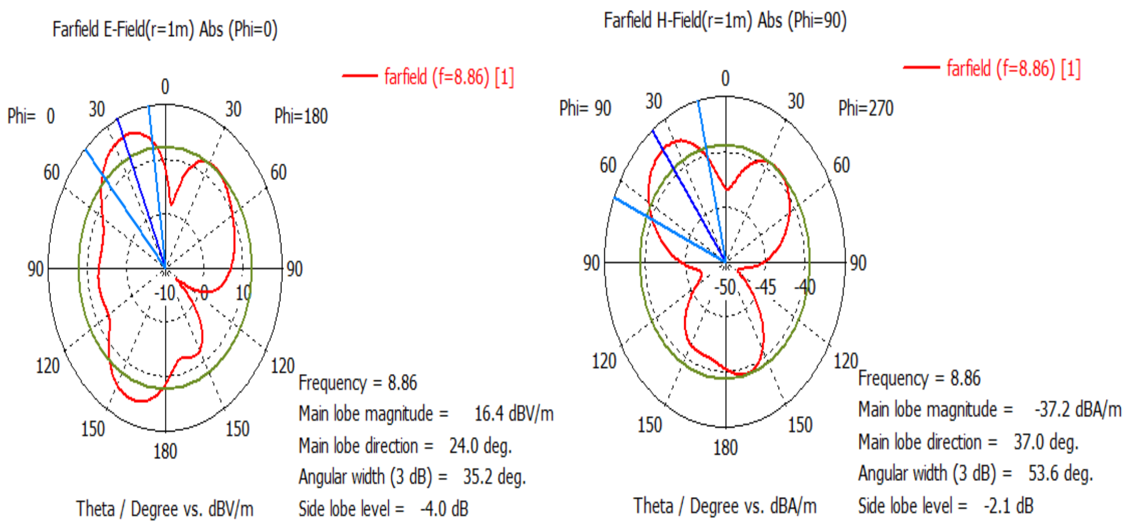
b)


Farfield E-Field(r=1m) Abs (Phi=0)
farfield (f=6) [1]
Phi= 0
Phi=180
Frequency = 6
Main lobe magnitude = 11.9 dBV/m
Main lobe direction = 0.0 deg.
Angular width (3 dB) = 44.9 deg.
Side lobe level = -3.7 dB
Theta / Degree vs. dBV/m
Farfield H-Field(r=1m) Abs (Phi=90)
farfield (f=6) [1]
Phi= 90
Phi=270
Frequency = 6
Main lobe magnitude = -38.5 dBA/m
Main lobe direction = 24.0 deg.
Angular width (3 dB) = 87.1 deg.
Side lobe level = -3.4 dB
Theta / Degree vs. dBA/m

c)



d)



e)

Fig.III. 14: Radiation pattern in the xz and yz plane for the proposed multiband patch antenna: a) 2.45 GHz, b) 4.31 GHz, c) 6 GHz, d) 7.6 GHz and e) 8.86 GHz

We can build a precise analysis of our antenna and the impact of the techniques used on its structure through the radiation pattern of an antenna which makes it possible to visualize the lobes in two or three dimensions, in the horizontal plane (phi = 0 °) or in the vertical plane (phi = 90 °) including the most important lobe.

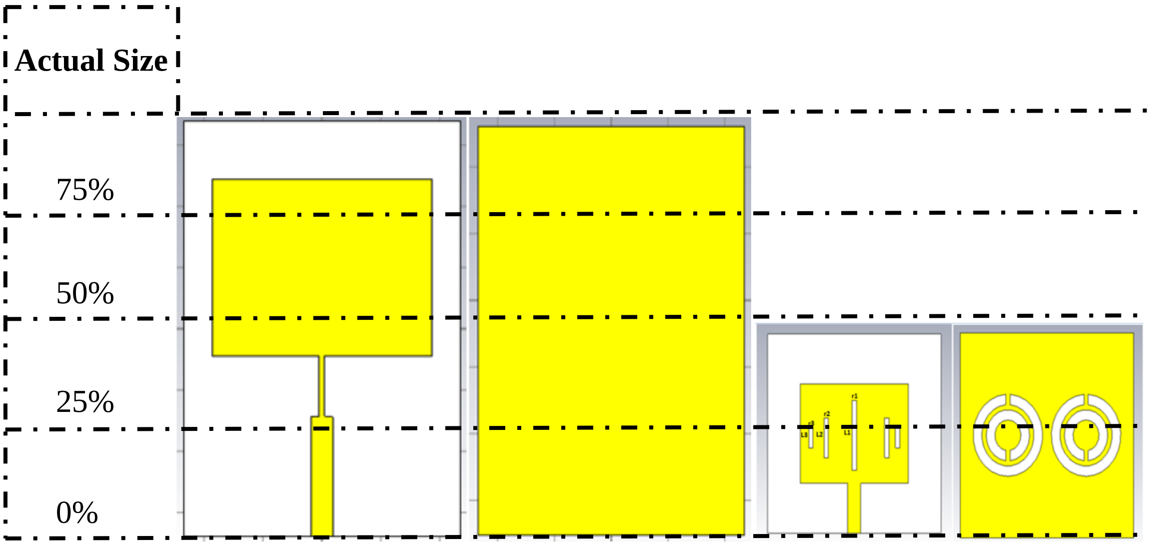


Fig.III. 15: Size reduction and comparison

Geometry	**Size (mm2)**	**Resonant Frequency**	**Return LossS11 dB**	**VSWR**	**Band width (MHz) in -10db**
Basic antenna	46.86×67.9	2.4 GHz	-18.26	1.24	64
Antenna 1 miniaturization	40×40	3.45 GHz 5.48 GHz 9.10 GHz	-7.88 -13.73 -17.70	2.35 1.52 1.29	/ 139 298
Antenna 2 with CSRR	40×40	2.45 GHz 4.29 GHz 6.00 GHz 7.58 GHz	-24.29 -35.6 -29.06 -19.75	1.14 1.05 1.07 1.22	139 154 187 386
Antenna 3 with Slots and CSRR	40×40	2.45 GHz 4.31 GHz 6.00 GHz 7.60 GHz 8.86 GHz	-24.64 -28.03 -25.15 -19.97 -40.35	1.17 1.11 1.14 1.22 1.01	197 170 190 384 333

Table.III. 5: Total comparison

III.2 Fabrication and Measurement Result

a. Printed Circuit Board Material

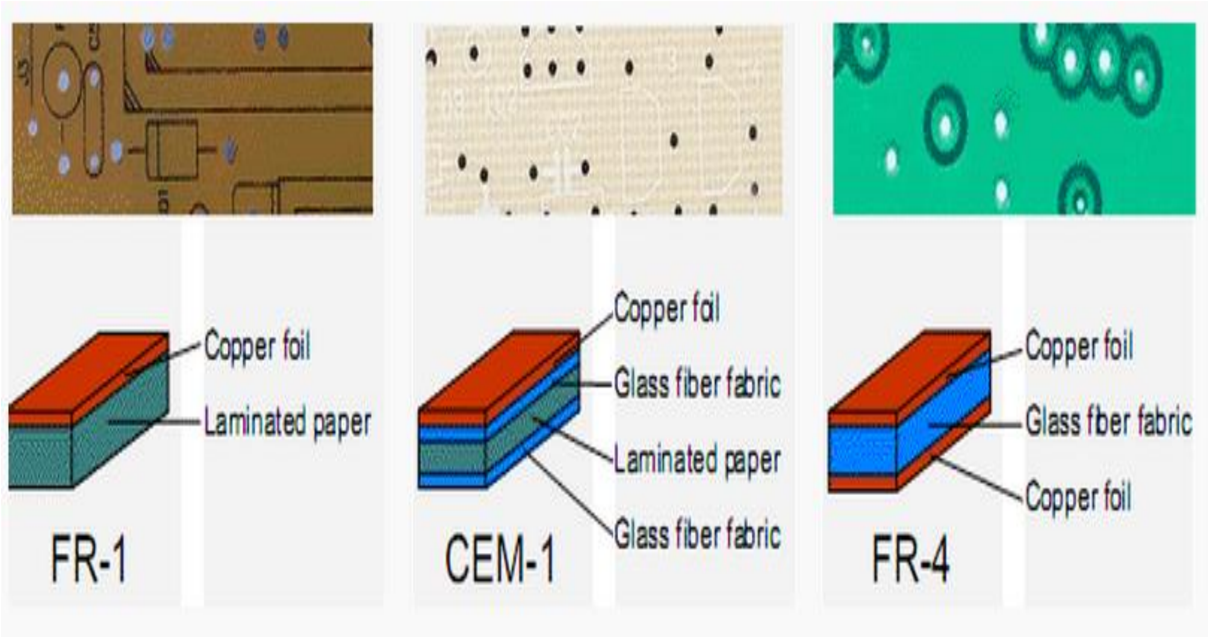


Fig.III. 16: Printed circuit board structure

Printed circuit board structure[51]:

FR1: copper foil + laminated paper

CEM1: copper foil + glass fiber fabric + laminated paper + glass fiber fabric

FR4 (single layer): copper foil + glass fiber fabric

FR4 (double layer): copper foil + glass fiber fabric + copper foil

The material of Printed Circuit Board (PCB) used in mydesign is FR4double layers utilize as substratewhere "FR" means Flame Retardant, and Type "4" indicateswoven glass reinforced epoxy resin,the thickness of the FR4 substrate is 1.6mm.

2 layer PCB board is suitable for a variety of electronic products and electronic equipment, It has excellent electrical properties[52].

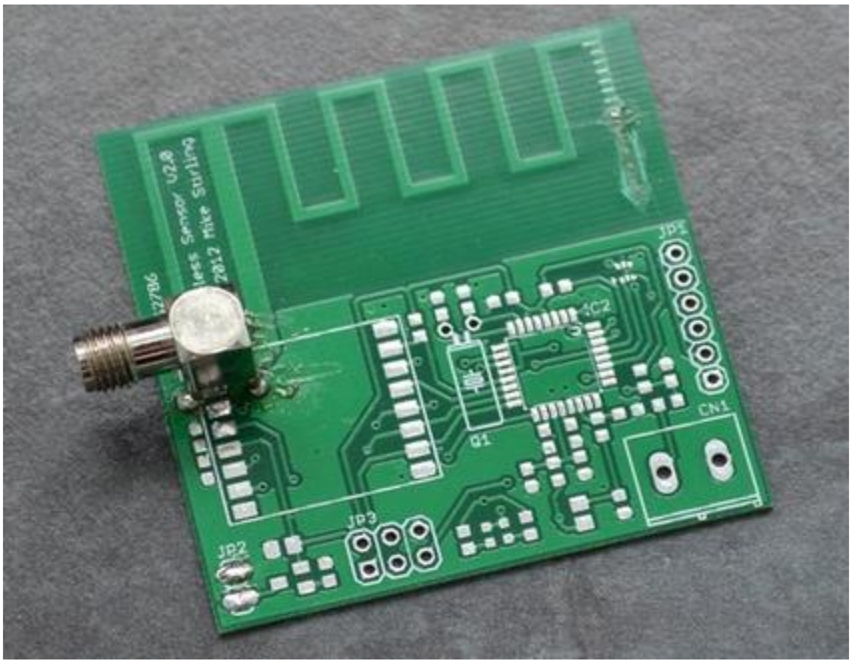


Fig.III. 17: Printed circuit board structure double layer[53]

a.1. MPA Fabrication:

The fabricated of the final design are shown in **Fig.18**. The simulations are performed in CST software and the reflection coefficients of the proposed antenna are measured using anAgilentNetwork Analyzer (N5224B). An SMA connector is carefully coupled with ground and feed structures to obtain measurements.

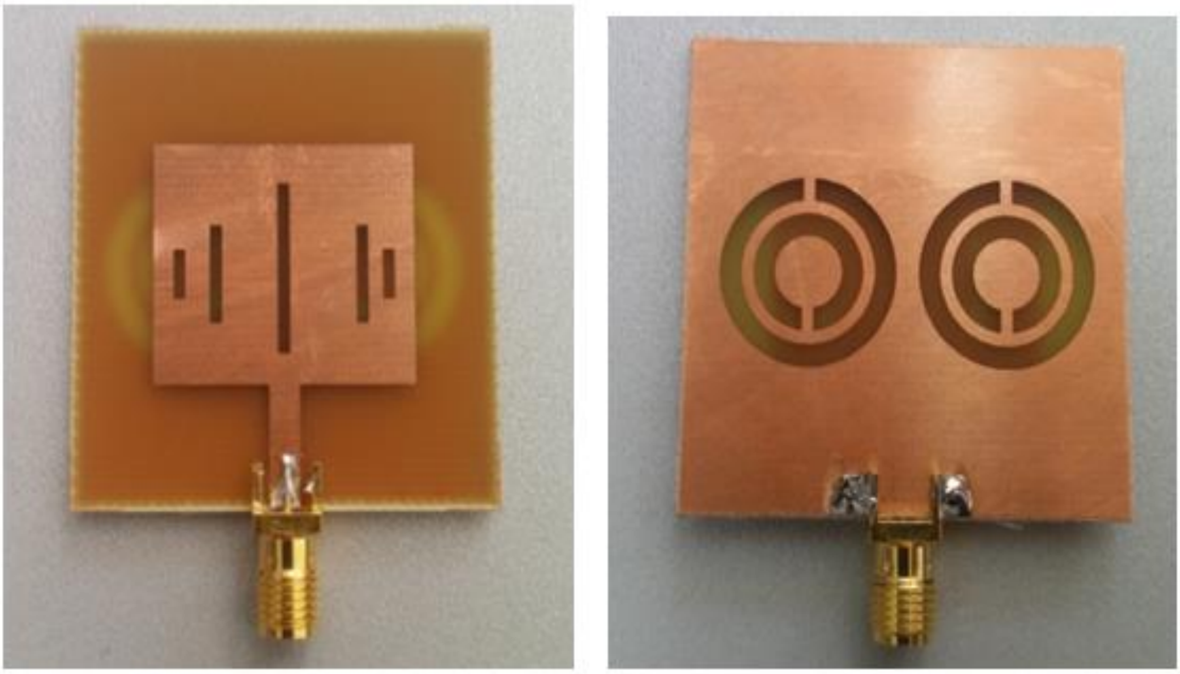


Fig.III. 18: Top view and back view of fabricated design structure of MPA

b. MPA Measurement

The network analyzer is a widely used measuring device in the field of hyper frequencies (frequency range between 1 and 100 GHz) in our case works between 1 GH and 45 GHz. It measures the S parameters of multipoles, whether it is active or passive. The measurement procedure with the network analyzer is carried out in two steps;the first calibration of the measuring bench after that one can make thedifferent measures.

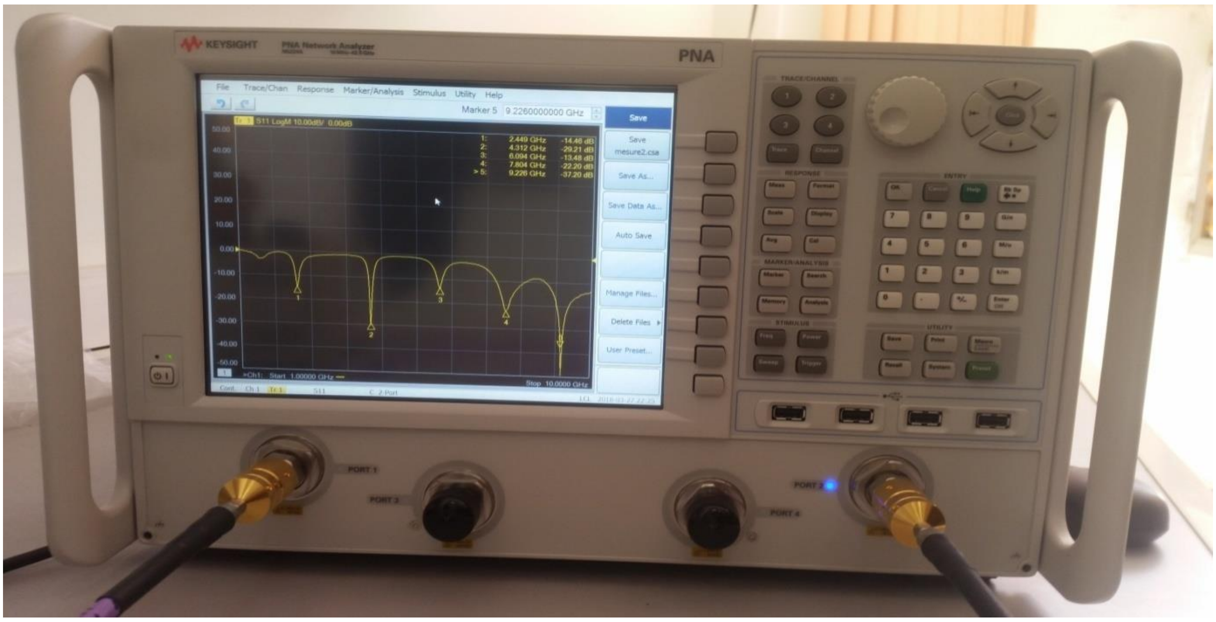


Fig.III. 19: PNA network analyser

b.1. Calibration of PNA

The Agilent 8719ES network analyzers have errors that can be corrected for each case. These errors are due to components used in systems that are not perfect and are therefore sources of losses. In order to be able to correct these errors, one must go through a calibration procedure. By default, the analyzer is calibrated at its ports for its output power, so to make measurements of the dipoles, you need cables. We must therefore compensate for the effect of the cables (attenuation and phasing), so we speak of the chain. The calibration is thus used to determine the systematic errors of the measuring system (analyzer, cable, transition). Calibration is performed by placing known charges in the VNA and making measurements by replacing the quadruples with these charges, called a calibration kit N4691B Electronic, 300 kHz to 26.5 GHz, 3.5 mm, 2-port:

Fig.III. 20: Electronic calibration module

1. The cables are connected to the inputs of the analyzer.

2. Select the measurement frequency band.

3. Set the number of points using the (sweep) button.

4. One chooses from the menu (cal) the calibration (Full port) that is to say in reflection and in transmission.

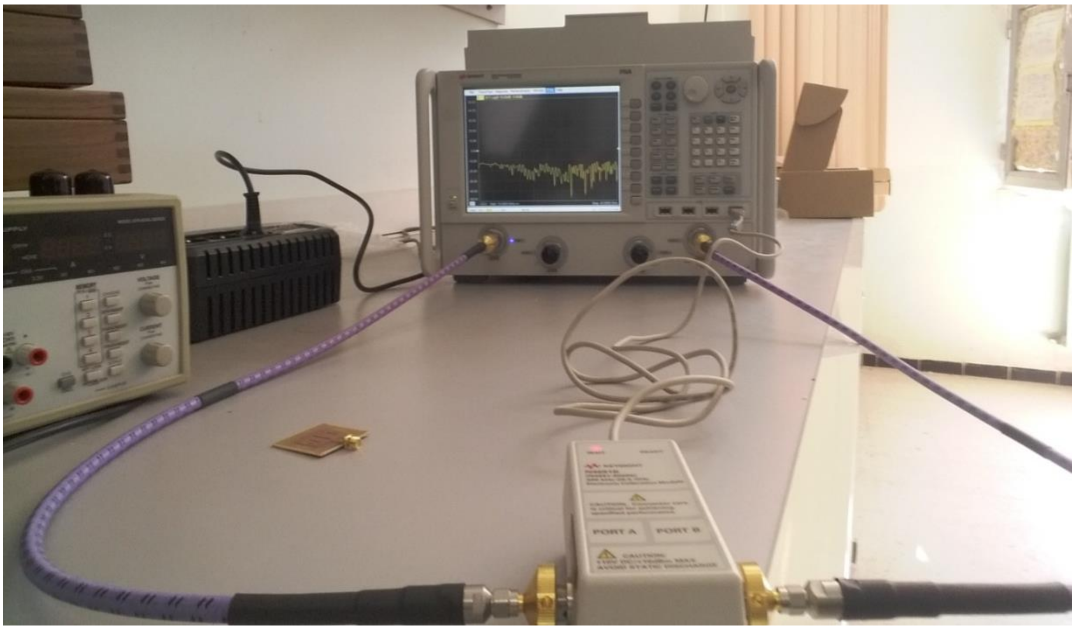


Fig.III.21: PNA calibration

b.2. MPA connect with PNA

The fabricated antenna is connected with PNA by SMA connector in port S11 for measured the reflection loss; measurements are taken for frequencies in the range of 1 GHz to 10 GHz.

The SMA connector of the antenna is connected with the cable 1 to measure S11 as shown in figure

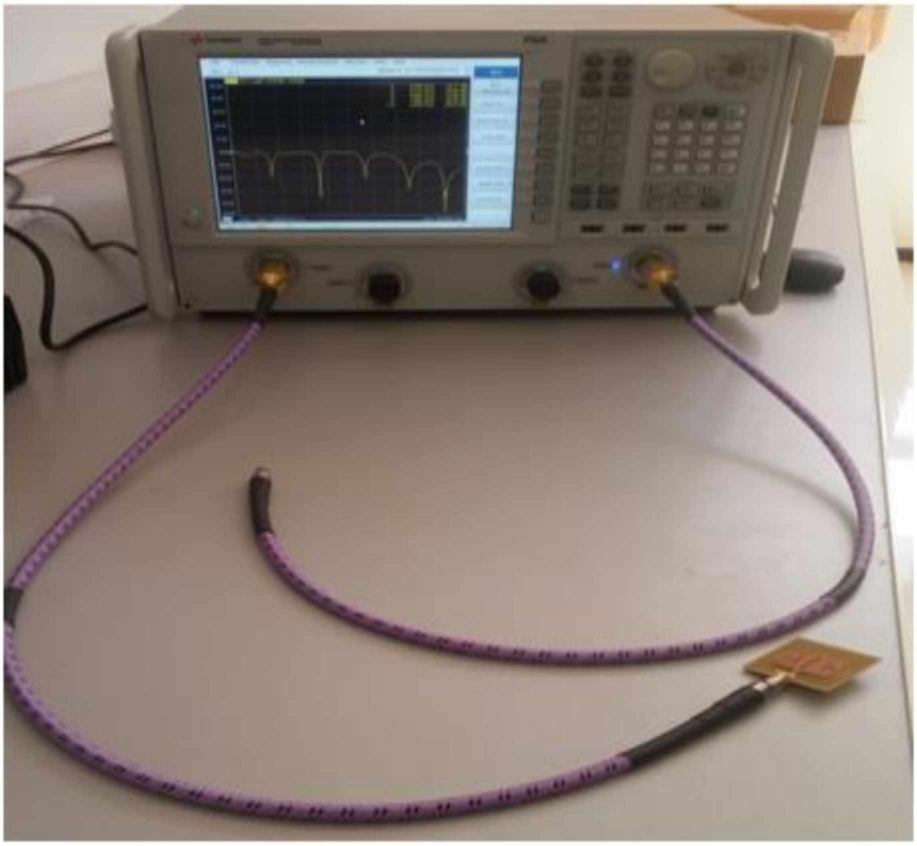


Fig.III. 22: Microstrip antenna connect the PNA

c. Reflection Loss of Fabrication

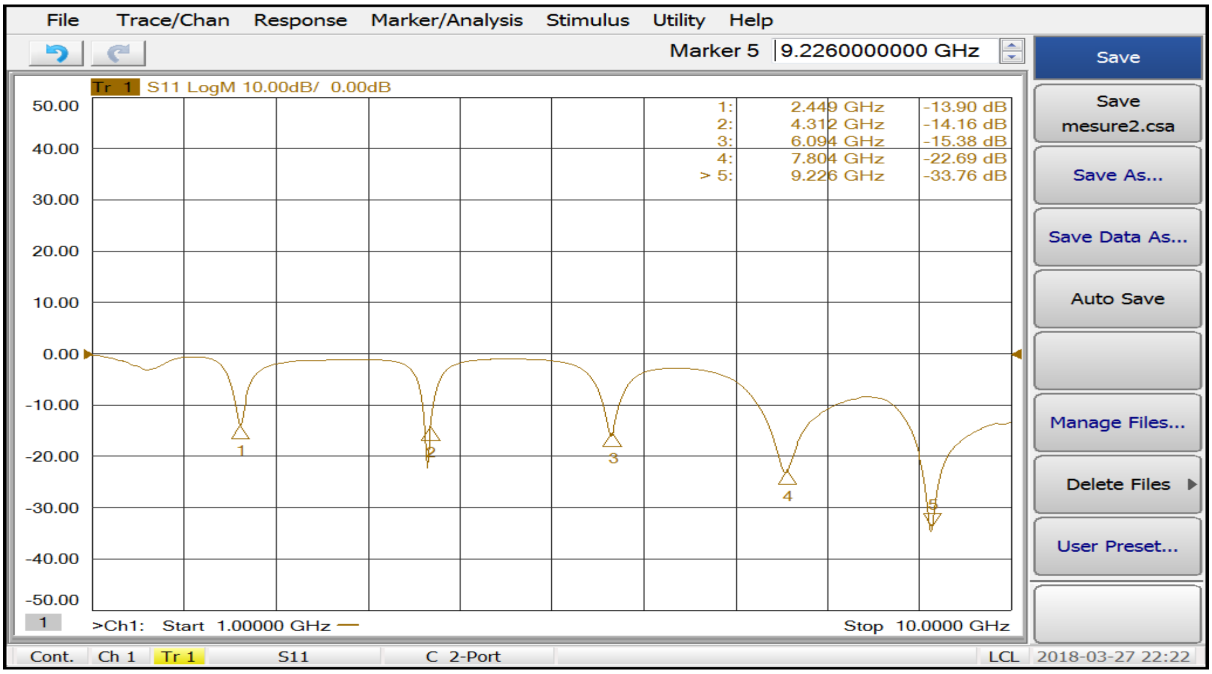


Fig.III. 23: S11 Measurement

This antenna shows resonance at five multiple bands resonating at 2.44 GHz, 4.31 GHz, 6.09 GHz, 7.8 GHz and 9.22 GHz with a return loss of -13.9dB, -14.16dB, -15.38dB, -22.69dB and -33.76dB respectively.

Parameters	**Measured MPA Results**				
Resonant Frequency(f_0GHz)	2.44 GHz	4.31 GHz	6.09 GHz	7.8 GHz	9.22 GHz
Reflection loss (S11 dB)	-13.9dB	-14.16dB	-15.38dB	-22.69dB	-33.76 dB

Table.III. 6: Result of S11 measurement

III.3 Comparison of Simulated and Measured Results

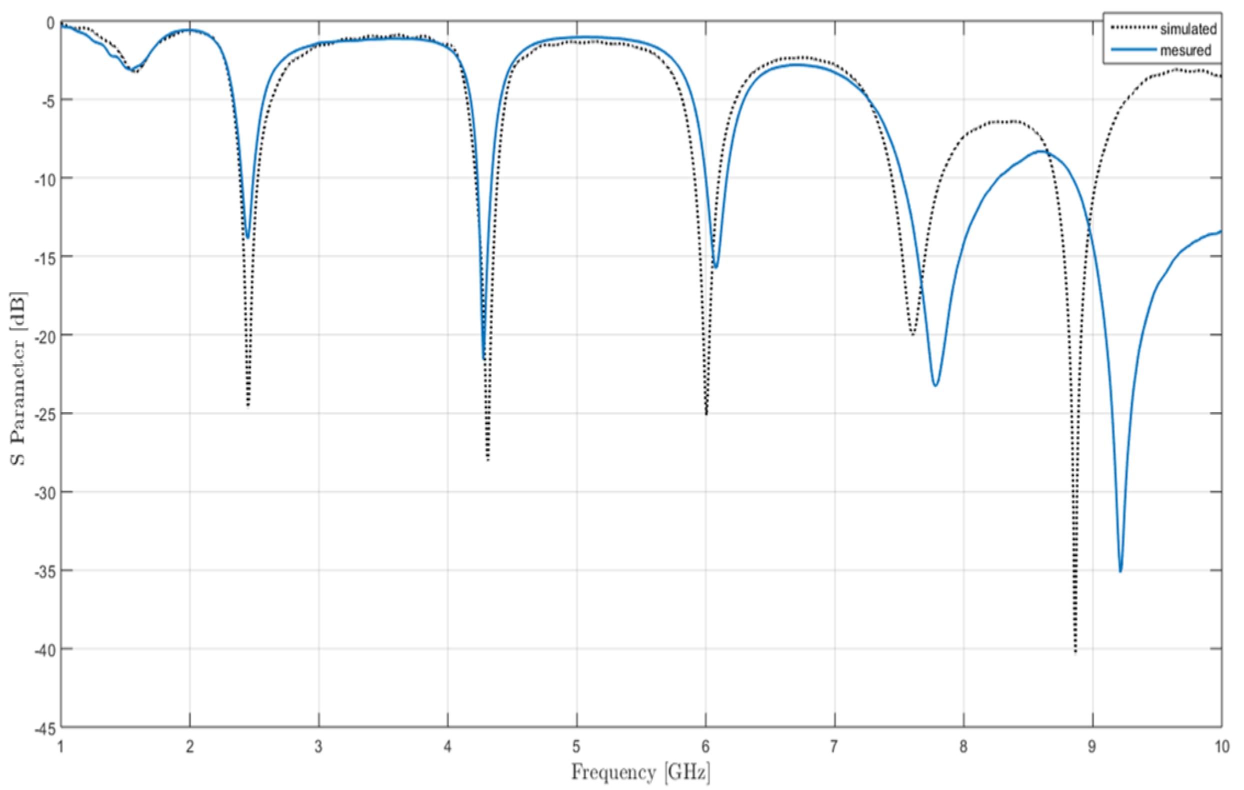


Fig.III. 24: S11 Simulated and measured result plotted using Matlab

Parameters	simulated					Measured				
Resonant Frequency (F_0GHz)	2.45	4.3	6	7.6	8.8	2.44	4.3	6	7.8	9.2
Reflection loss(S11 dB)	-24.6	-28	-25.1	-19.9	-40.3	-13.9	-21	-15.3	-22.6	-33.7

Table.III. 7: Comparison between simulated and measured results

The measured S11 shows good agreement with the simulation results; this is for clear compatibility between frequencies and in -10 dB return loss.

III.4 Comparison of proposed antenna performance with other compact antennas

The **Table.III.8** present a comparison of the proposed antenna with bibliography regarding antenna size, resonance frequency, and antenna purpose. As we can see from the same table that the proposed antenna is smaller in terms of size and suitable for five-band applications.

Published literature versus proposed work	Antenna Size (mm)	material	Resonance frequency (GHz)	Antenna purpose
Ref [54]	82 × 94	FR-4	2.4	One-Band
Ref[55]	59.5 × 75	FR-4	1.56/2.45/3.53	Tri-Band
Ref[56]	40 × 40	FR-4	2.4/5.5/6.9/9	Four-Band
Proposed work	40 × 40	FR-4	2.4/4.3/6/7.8/9.2	Five-Band

Table.III. 8: Comparison of proposed antenna performance with other compact antennas

III.5 Conclusion

In this project, we have validated a novel multi-band and miniature microstrip antenna for wireless communication. For this antenna, we did reduce the patch size by 50.28% and increase the bandwidth, that by utilizing various techniques. The designed microstrip antenna is optimized to cover the LTE for future mobile communication systems, the ISM band used by systems BLUETOOTH and WIFI, applications in RADAR, UWB, mobile communications, satellite communications and microwave frequencies with a good performance. The proposed antenna is very compact, very easy to fabricate, and is fed by a 50Ω microstrip line which makes it very attractive for current and future cellular phones applications.

General Conclusion and Future Scope

General Conclusion and Future Scope

This work is motivated by the diversity of applications of metamaterials which determine a promising research theme in the development of antennas and microwave circuits.

In this thesis, we studied an optimization of microstrip antennas. This problem is essentially about miniaturization, relies on the improvement of the antenna parameter for LTE technology, that is why we first studied the LTE technologist, its principle, and frequency band where it works, then we applied the antenna enhancement principle that we proposed we finally introduced our application.

We designed the microstrip antenna based on artificial transmission lines, after simulation and realization, this step paid off because it allowed us to improve the performance of the microstrip antenna. Among these performances, we find a total reduction in the size of the antenna of 50.28% while maintaining good performance in terms of adaptation, obtaining 4 frequency domains in addition to the LTE and an improvement in bandwidth

The Future Scope of our work are:

We suggest as an antenna work the following:

- Improve bandwidth in the 2.45 GHz frequency to win others LTE bands.
- It would have been desirable to use a better substrate than the FR4, because the latter has a lot of losses, so as a perspective, we suggest working with a more adapted substrate to the dielectric constant and the dimensions.
- Use others enhancements techniques to improve others antenna parameters such as gain.
- Minimize more the antenna sizes while maintaining its characteristics.

To conclude, this study is the initial phase of a longer-term project with the ultimate goal of improving antenna performance. Significant work remains to be done in order to achieve finalization for application in real marketable systems. However, this work has established a solid foundation for future work and despite the problems, we have encountered during the realization of this project, we consider that the work has been done and corresponds to the specifications required and we have reached some of our objectives what which we have created it.

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Appendice A

Appendice A

A: Spectrum bands of FCC (Federal communications commission)

A.1 Microwave Letter Band Designations

Band	Frequency range (GHz)	Applications
L	1 to 2	Satellite, navigation (GPS, etc.), cellular phones
S	2 to 4	Satellite,(Wi-Fi, Bluetooth, etc),cellular phones
C	4 to 8	Satellite, microwave relay, Wi-Fi, DSRC
X	8 to 12	Radar
Ku	12 to 18	Satellite TV, Police radar
K	18 to 26.5	Microwave backhaul
Ka	26.5 to 40	Microwave backhaul, 5G cellular
Q	30 to 50	Microwave backhaul, 5G cellular
U	40 to 60	Experimental, radar
V	50 to 75	New WLAN, 802.11ad/WiGig
E	60 to 90	Microwave backhaul
W	75 to 110	Automotive radar
F	90 to 40	Experimental, radar
D	110 to 170	Experimental, radar

A.2 Satellite Frequency Band

Frequency band	Frequency range (GHz)	General application
L band	1-2	Mobile satellite service (MSS)
S band	2-4	MSS, NASA, deep space research
C band	4-8	Fixed satellite service (FSS)
X band	8-12	FSS military, terrestrial earth exploration, meteorological satellites
Ku Band	12-18	FSS, broadcast satellite service (BSS)
K band	18-27	BSS,FSS
Ka Band	27-40	FSS

A.3 Most Popular Short Range Wireless Interfaces

Interface	Standard	Frequency range
802.15.4	IEEE	868,902-928MHz 2.4-2.835 GHZ
Bluetooth	Bluetooth SG	2.4-2.4835 GHz
Digital Enhanced cordless Telecommunications	ETSI	1880-1930 MHZ
Near Field communication	ISO, IES, ECMA, GSMA	13.56 MHz
Ultra wide band (UWB)	IEEE, WIMedia, Alliance	3.1-10.6 GHz
Wi-Fi (802.11)	IEEE	2.4-2.4835 GHz,5.725-5.875GHz,60GHz
Wireless HART	Hart comm, Foundation, IEEE	2.4-2.4835 GHz
ZigBee	IEEE, ZigBee Alliance	868,902-928MHz, 2.4-2.4835 GHz
Z-Wave	Z-Wave Alliance	908.42 MHz

Appendice B

Appendice B

B: Simulation with CST

B.1 General description

For simulations, we use CST's Microwave-Studio Software. This one uses the FIT Finite Integer Method; this method consists of spatially Maxwell's equations in their full form.

B.2 Simulation of the metamaterial cell CSRR

The first step is to model our elementary structure to simulate.

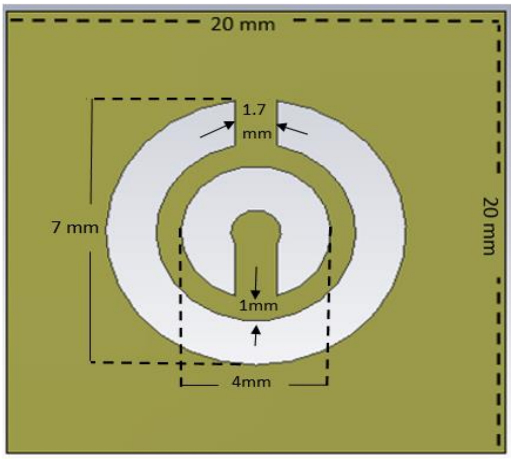

Fig.B. 1: Simullation of Cell CSRR

Once the structure is modeled with its dimensions, in the list (simulation) we choose the band of frequency as it is shown in the **Figure B.2**:

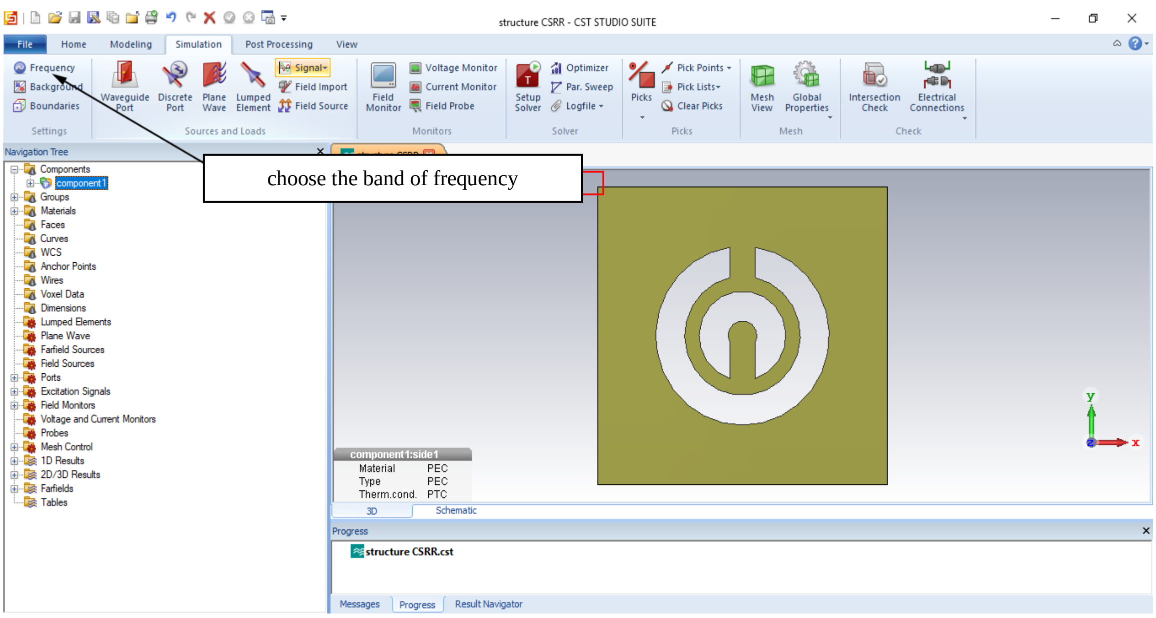

Fig.B. 2: Choose the band of frequency

Then we choose the boundary conditions for the polarization of the E and H fields in the "Boundaries" menu of the same "Simulation" list and set the conditions as it is shown in the **Figure B.3**:

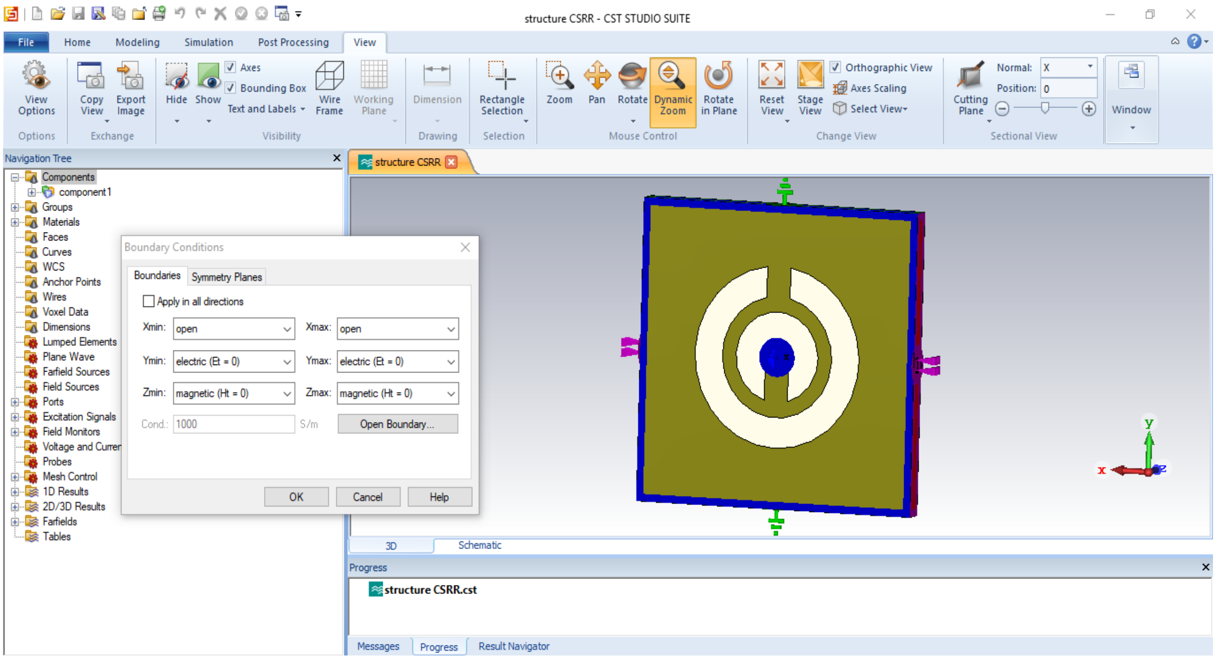

Fig.B. 3: The configuration of the boundary conditions

Now we have to add ports, in this simulation the ports to use are from type "Waveguide port" which is in the same list "Simulation", we choose the direction X then we have two ports to add one in the positive direction and the other it the negative direction, **figure B.4** illustrates this step:

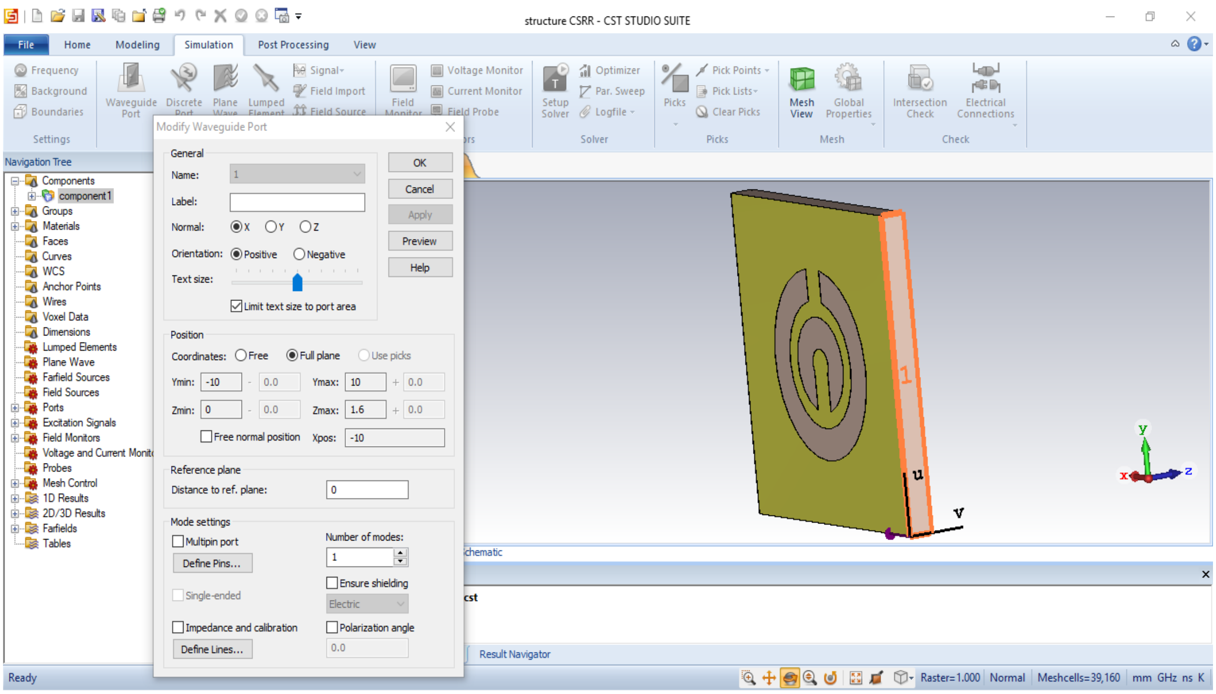

Fig.B. 4: Add port 1

In the next step, we will choose the solver and it depends on the size of the structure to simulate, in our case we chose the "Time domain solver".

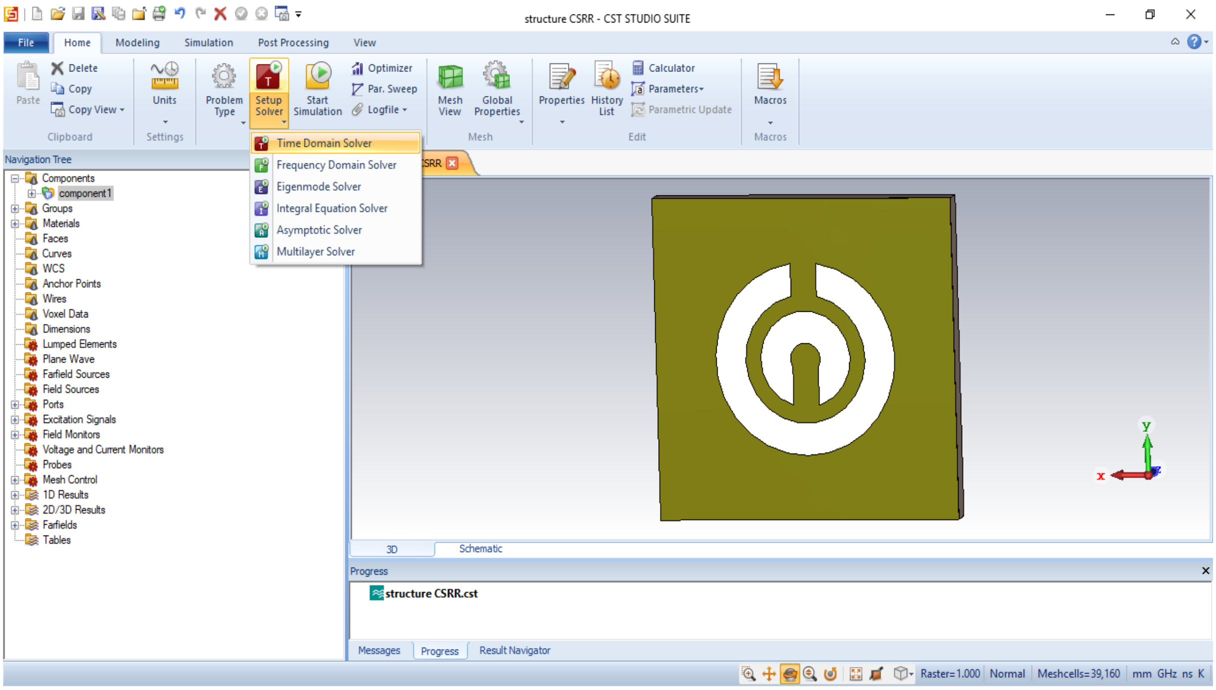

Fig.B. 5: The choice of the solver

B.3 Result of simulation

Once the simulation is complete, we get the result:

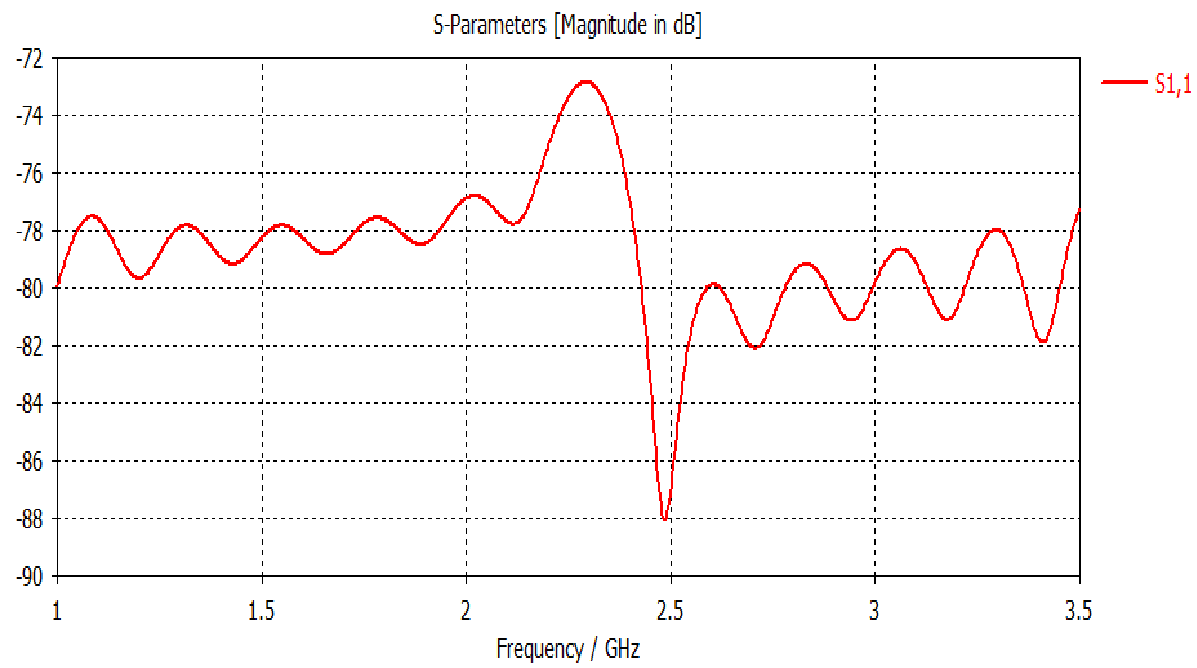

Fig.B. 6: S parameter Result