
بسم الله الرحمن الرحيم

Dedicate

This thesis is dedicated to:

;

My great parents, who never stop giving of themselves in countless ways,

My beloved ancle and anties

To my dear sisters;

To all my family, the symbol of love and giving,

My friends who encourage and support me,

Zianeamel

Dedicate

This thesis is dedicated to:

Mom and Dad who always pic me up on time and encouraged me to go on

Every adventure, specially this one;

My great parents, who never stop giving of themselves in countless ways,

My beloved brother and sisters

My supportive husband ;

My dear friends

Kamari Fatima

Acknowledgment

In the Name of Allah, the Most Merciful, the Most Compassionate all praise be to Allah, the Lord of the worlds; and prayers and peace be upon Mohamed His servant and messenger.

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Finally, we would like express my gratitude to all the people who helped me by providing their valuable assistance and time

Abstract

In this work, a design of directive wideband, low profile, bowtie antenna operating in the C band is proposed. To achieve this purpose, we propose to use AMC reflectors.
The CST MWS software is used for designing and simulations .The obtained results show that the proposed antenna operates in the 4.08 - 6.4 GHz and show a quasi-stable realized gain in broadside direction with a maximum enhancement realized gain of 8.8 dBi compared to antenna without AMC.

Résume

Dans ce travail, on propose de concevoir une antenne sous forme de papillon directive, large bande et à faible épaisseur fonctionnant dans la bande C. Pour atteindre cet objectif, on introduit des réflecteurs à Conducteurs Magnétiques Artificiels (AMC).
Le logiciel CST Microwave Studio est utilisé pour la conception et les simulations. Les résultats obtenus montrent que l'antenne proposée fonctionne dans la bande 4,08 - 6,4 GHz et présente dans la direction broadside un gain réalisé quasi stable et une amélioration maximale de 8,8 dBi par rapport à une antenne sans AMC.

ملخص

فيهذهالمذكرةتماقتراحهوائيربطةمعبالونمدمج، الغرضمنهذاالعملهوتصميمهيكلالهوائيالمقترحمع كسطح عاكس للهوائي استخدام سطح AMC.لتحسين كسب الهوائي و للحصولعلىنطاقواسع, بأصغر حجم ممكن
تمت عملية التصميم و المحاكات باستعمال برنامج CST MWS 2017 النتائج المتحصل عليها توضح ان مكسب الهوائي تم .تعزيز هواستقرار هعلىطولعرضنطاقالتشغيل.

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Abbreviations

AMC : artificial magnetic conductors

AS: Authorized Service

BALUN: Balanced to Unbalanced

BDS: BeiDou Navigation Satellite System

BOC : Binary Offset Carrier

BOC : Binary Offset Carrier

BPSK :Binary Phase-Shift Keying

BSS: Broadcast Satellite Services

CDMA: Code Division Multiple Access

CPW : coplanar waveguide

CST : Computer Simulation Technology

CS : Commercial Service

DARS : Digital Audio Radio Services

DBS: Direct Broadcast Service

DNG: Double negative

DTH: Direct to Home Internet Services

EBG: Electromagnetic band gap

EU :Europe

EIRP :Effective Isotropic Radiated Power

FDMA: Frequency Division Multiple Access

FM: Frequency Modulation

FIT: Finite Integral Technique

FSS : Fixed Satellite Services

HPA: High Power Amplifier

IF :Intermidiate Frequency

GNSS: Global Navigation Satellite System

GLONASS: Global'nayaNavigatsionnayaSputnikovayaSistema

GPS: Global Positioning Service

GEO: Geostationary Earth Orbit

GLONASS: GLObal'nayaNAvigatsionnayaSputnikkovayaSistema

LH: Left-handed

LNA : Low Noise Amplifier

MEO: Medium Earth Orbits

MPA: microstrip patch antenna

NRI: Negative refractive index

OS :OpenService

PEC : perfect electric conductor

PPS :Precise Positioning Service

PRS: Public Regulated Service

PNT: Positioning, Navigation and Timing

PMC: perfect magnetic conductor

PSK : Phase Shift Keying

RF: Radio Frequency

RFID: Radio Frequency Identification

RHCP: have right hand circularly polarized

SPS: Standard Positioning Service

TE : Transverse Electric

TM: Transverse Magnetic

TMBOC : Time Multiplexed Binary Offset Carrier

UHF: Ultra High Frequency

UWB: Ultra-wideband radio

VHF: Very High Frequency

Introduction

High-speed data transmission, linked to the ever-increasing demand for mobile devices, has generated great interest for microstrip antennas, which areantennas most used in compact commercial designs. The main advantages of these antennas are the low weight; low volume and thickness, low cost, simplicity of manufacture. However, this type of elements has limitations, including narrow bandwidth, low gain and the ability to resonate with a single frequency.

An antenna with radiating elements, commonly called "patch antenna", is a micro-ribbon line of particular shape. It is important in relation to communications devices (the transmitter and receiver), and in other words is the designer for transporting and emitting electromagnetic waves. It is also used in systems such as radiocommunications, communications networks, satellites and detection systems and civil aviation and radars.

The rapid development of telecommunications systems has made it possible to create and innovate several technologies. On the one hand, there is a trend toward miniaturization of mobile device related components. On the other hand, there is a growing demand for fast data transfer which in turn requires broadband and / or multiband components. These two constraintscontradictory needs to be overcome with inexpensive and high performance solutions.

One of the solutions proposed to meet these needs is the exploitation of the new class of materials known as "meta materials"or Electromagnetic Band Gap "EBG.

EBG are artificial composite materials whose internal structure is often periodic and can exhibit great advantages over conventional solutions like antennas with metallic reflectors. A reflector made up of perfect electrical conductor (PEC) needs to be placed at a distance of $\lambda/4$, λ being the wavelength at the central frequency of operation, in order to avoid the destructive interference between the incident and reflected electric fields in the broadside direction. This leads to a thick antenna profile. Metamaterials like AMC can be used instead to reduce the thickness of the antenna. Metamaterials are artificially engineered materials that exhibit exotic properties not found in natural materials. These properties originate from their structure and not from their composition.

The objective of this work is to design low profile wideband antenna with metamaterials. These structures can be used in order to improve antennas by reducing their thickness and making them unidirectional rather than bidirectional. Thus, designing unidirectional antennas is required on many platforms (satellite, aircrafts, Unmanned Aerial Vehicle…) in order to obtain outward radiation and preserve the interior of any electromagnetic pollution. Furthermore, for integration and mechanical constraints, antennas have to be low profile.

The first chapter is about Global navigation and communication satellite system with brief overview on antennas for space applications..

The second chapter reviews principal's properties and applications of EBG in antennas. Also we developed a state of the art on wideband antennas using an artificial magnetic conductor.

The objective of the third chapter is to design a directive wideband, low profile bowtie antenna by using AMC reflectors which operates in the C band.

Finally, a conclusion and perspectives of this work are presented.

CHAPTER I

Satellite System for navigation and communication

Chapter I: Satellite System For navigation and communication

I.1 introduction

Satellite-based technologies are the enabling tools for a wide range of civil, military and scientific applications, like communications, navigation and timing, remote sensing, meteorology, reconnaissance, search and rescue, space exploration and astronomy. In order to formulate a clear view on our research topic we focused on global navigation satellite system and communication satellite system.

I.2 Global Navigation Satellite Systems

Global navigation satellite system (GNSS) is a general term describing any satellite constellation that provides positioning, navigation, and timing (PNT) services on a global or regional basis, GNSS is used for many types of applications, coveringthe mass market, professional and safety-criticalapplications as well as a whole range of scientific applications,There are thereforeliterally hundreds of applications of GNSS, from theeveryday to the exotic, as shown in Figure 1.

While GPS is the most prevalent GNSS, other nations are fielding, or have fielded, their own systems to provide complementary, independent PNT capability .In this regard, theEuropean nations are developing the Galileo system, the Russians are modernizing theirGLONASS system while the Chinese are launching a new Compass system. All of these systemsform GNSS with desirable positional capability suitable for mining operations and civilengineering tasks. These GNSS desirable capabilities are(1):

-Global: This enables their use anywhere on earth**.**

-All weather: This feature makes GNSS useful during cloudy and rainy periods.

-Able to provide 24-hour coverage: This enables both day and night observation and can thus enable, e.g., rescue mission in mine operations to be undertaken at any time.

-Cheaper: Compared to other terrestrial surveying observation techniques such as leveling and traversing, GNSS are economical due to the fact that as an operation, few operators are needed to operate the receivers and process data. Less time is therefore required to undertake.

Figure 1: Examples of everyday GNSS applications (1)

I.2.1Current global navigation satellite system

Currently, there are four global navigation satellite systems in operation, GPS (US), GLONASS (Russia), BeiDou (China), and Galileo (EU) they commonly consist of three components(2):

_ **The space segment** comprises a constellation of satellites orbiting above the Earth's surface that transmit ranging signals on at least two frequencies in the microwave part of the radio spectrum.

_ **The control segment** is responsible for maintaining the health of the system bymonitoring the broadcast signals and computing and uploading to the satellites required navigation data. It consists of a group of globally (or locally)-dispersed monitoring stations, ground antennasfor communicating with the satellites, and a master control station with a backup facility at a different location.

_ **The user segment**consists of GNSS receiving equipment both civil and military. This includes receivers on the ground, at sea, in the air, and even in space.

For an overview summary see table I.1

System	GPS	GLONASS	BeiDou	Galileo
Orbit	MOE	MOE	MEO IGSO	MEO
Nominal Number of satellite	24	24	27,3,5	30
Constellation	6 planes 56° inclination	Walker(24/3/1) 64.8°inclination	Walker(24/3/1), 55°inclination	Walker (24/3/1), 56° inclination
Service	SPS, PPS	SPS, PPS	OS,AS, WADS,SMS	OS,CS, PRS
Initial service	Dec 1993	Sep 1993	Dec 2012	2016/2017 planned
origin	USA	Russia	China	Europe
coverage	Global	Global	Global	Global
Frequency (MHz)	L1 1575.42 L2 1227.60 L5 1176.45	L1 1602.00 L2 1246.00 L3 1202.025	B1 1561.098 B2 1207.14 B3 1268.52	E1 1575.42 E5a 1176.45 E5b 1207.14 E61278.7

Table 1: An overview of the global satellite-based navigation systems.

I.2.2 GNSS signals

Each satellite system has specific signal characteristic, but each system attempts to be compatible with others in order to prevent interferences and attenuation between the signals.

a) GPS:

The GPS system is used by more than one trillion of users and transmits 4 civilian signals(3) :

- L1C/A at 1575.42 MHz it is called the legacy signal and broadcast by all the satellites ,it use BPSK(1) modulation

– L2C at 1227.6 it isthe second civilian-use signal withBPSK modulation

– L5 at 1176.45 MHz for aviation safety of life signal using BPSK(10)

– L1C at 1575.42 for international signal using TMBOC(6.1.1/11) modulation

alsothe GPS satellites transmit signals for the military use.

b) BeiDou Navigation Satellite System (BDS):

The BeiDou Navigation Satellite System（BDS）is a new family member in the Global Navigation Satellite System(GNSS). It increases the usability and availability of Positioning, Navigation and Timing (PNT) around China in AsiaPacific area, and the global users can also profit from the constellation for high accuracy(4). The satellites transmit two levels of service, an open service and an authorized service primarily for the Chinese government and military using three frequencybands. The bands and the central frequencies for the satellites now in use, the BeiDou-2 satellites, are B1 at 1561.098MHz, B2 at 1207.14MHz, and B3 at 1268:52MHz.

c) **Galileo:**

Galileo is the European Union's Global Satellite Navigation System (GNSS). Sometimes called the ’European GPS‘, Galileo provides accurate positioning and timing information. Galileo is a programme under civilian control and its data can be used for a broad range of

applications. It is autonomous but also interoperable with existing satellite navigation systems.

Galileo satellites transmit three levels of service in three frequency bands using CDMA(2). The Open Service (OS) and the Public Regulated Service (PRS) are transmitted in the E1 frequency band centered on 1575.46MHz (the same as the GPS L1 frequency) and the PRN ranging codes are modulated onto the carrier using binary offset carrier (BOC) techniques with each satellite, like GPS, assigned separate codes. The Commercial Service (CS) signal and the PRS are transmitted in the E6 frequency band centered on 1278.75MHz using binary phase-shift keying (BPSK) and BOC modulation, respectively. Data and data-less (pilot) signals are transmitted in the E5 frequency band centered on 1191.795MHz using BOC modulation. Data and pilot signals are also available on E1 and E6. The signals are separated into an E5a and an E5b component and either can be tracked separately or together. The various signals also contain navigation messages supplying the necessary information for acquiring Galileo signals and for determining receiver positions and time.

d) GLONASS:

The former Soviet Union developed the *Global'nayaNavigatsionnayaSputnikovayaSistema*or GLONASS, GLONASS uses frequency division multiple access (FDMA) for its signals.Originally, the system transmitted the signals within two bands:Ll, 1602−1615.5MHz, and L2, 1246−1256.5MHz, at frequencies spaced by 0.5625MHz at L1 and by 0.4375MHz at L2. GLONASS-K satellites include, for the first time, code division multiple access (CDMA) signals accompanying the legacy FDMA signals.GLONASS-K1 as well as the latest GLONASS-M satellites transmit a CDMA signal on a new L3 frequency (1202.025MHz).(2)

I.2.3 Measuring principle

Position is calculated by accurately measuring the distance of a receiver from the satellite by determining the delay in the radio signal transmitted by the satellite. This delay is measured by matching and comparing the received signals by an equivalent receive generated signal more precise measurements use phase instead of timing measurements(5). The starting point is the basic principle of physique that relate the travel time t, distance travelled d and speed of light c, namely:

Distance (d)= speed(c) x time (t)

If time can be accurately measured and the speed c is known, then it is possible to obtain the distance d this basic expression forms the foundation of GPS satellite positioning GPS receiver situated on a ground or on a space accurately measure the time t taken by the signal travel from the satellite to the receiver.

Knowing the speed of light ($3x10^8$m/s), the distance from the satellite to the receiver known as (pseudorangers) can be measured since the GPS satellite orbit at about 20,000km above the earth it takes around 0.07s for the signal to travel from the satellite to the receiver

The satellite generate a binary code (C/A and P) that are sent to the receiver witch generate identical binary codes, the receiver generated code are then compared to those received from the satellite, witch lag behind those generated by the receiver, by comparing the two signal (from the satellite and the receiver), the receivers are able to compute the travel time of the signal.

A binary code generated by the satellite takes the form of +1/ -1 in order to measure the time travelled by the signal accurately, the receiver and satellite clocks must be synchronized and error free, the clocks normally have errors that are propagated to the measured ranges.

The measuring principle valid for all the other GNSS systems, they only differ in design, signal structure and coordinate systems.

I.3.Satellite Communication Systems

In satellite communication (Figure 2), satellites are used to relay signals betweenground stations. The signal is received from one ground station and re-transmits to one or more receiving ground stations elsewhere with the help of satellite. In this process, signal from ground station is first sent towards the satellite, then amplifies the signal and sends it back to the other ground station. As the signal is transferred through space, this kind of communi- cation is also known as space communication.(6)

Communications satellites are commonplace in modern society. Applications include television broadcast, mobile telephone networks and data transmission. The convention is to subdivide the satellites by their communications mission.

Each mission is characterized by the service that it provides, the number of users it can support and the geographic area over which the service is provided. Additional features include the connectivity that it offers to its users, the spectrum that it is allocated, the power

levels that are used, the scheme by which multiple users can share the satellite resource and the ability of the satellite to be reconfigured.

The major mission categories are Fixed Satellite Services (FSS), Broadcast Satellite Services (BSS), Digital Audio Radio Services (DARS), Direct to Home Internet Services (DTH) and Mobile Communications Services (Mobile). Sometimes BSS systems are referred to as Direct Broadcast Service (DBS) systems.

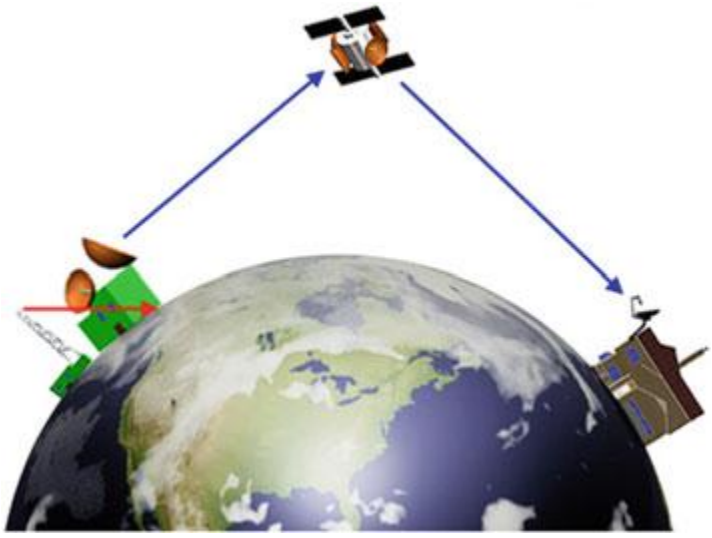

Figure 2 Satellite communication(6)

I.3.1 Satellite Communications Spectrum

The three most commonly used satellite frequency band are the C-, Ku- and Ka-bands The C-band is the oldest allocation and uses around 6 GHz for transmission (uplink) and between 3.7 and 4.2 GHz for reception (downlink).

Ku-band is the most prevalent transmission format for satellite TV in Europe and uses around 14 GHz for uplink and between 10.9 and 12.75 GHz for the downlink.

Ka-band uses around 30 GHz up- and between 18 and 20 GHz downlink frequency. The highest frequency band typically gives access to the broader bandwidths,but is also more vulnerable to signal degradation due to ‘rain fade(6)’.

There are other frequency bands available in satellite communication like VHF, UHF, L, and S for an overview (table 2).

Band	Frequency		Bandwidth	Application
VHF	<200 MHz			messaging
UHF	200 MHz – 1 GHz			Messaging, positioning, voice and fax
L	2/1 GHz			Mobile satellite services(MSS)
S	4/2.5 GHz			Fixed satellite services (FSS)
	Frequency(GHz)			
	uplink	downlink		
C	5.9-6.4	3.7-4.2	500 MHz	Fixed point to point ground station
X	7.9-8.4	7.25-7.75	500 MHz	Mobile ,radio relay ,military only
Ku	14-14.5	11.7-12.2	500 MHz	Broadcast, fixed point services not military
Ka	27.5-31	17.7-21.2	3.5 GHz	

Table 2: Satellite bandwidth and applications.

1.3.2 Elements of Satellite Communications System

The two major elements of the satellite communications system are: the space segment and the ground segment with earth stations, communication links, user terminals and interfaces and network control center. The earth stations are most often connected to the end users terminal through the terrestrial network or in case of small station connected to the end user terminal directly. The function of the earth station is to transmit a signal to the satellite and receive a signal from the satellite(7).

The block diagram of satellite communication system is shown in Figures 3 and 4.

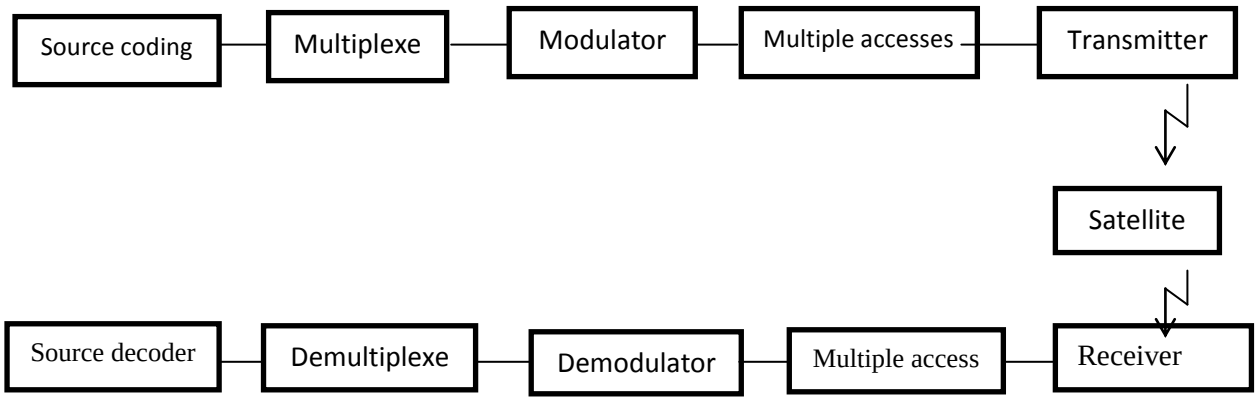

Figure 3: Signal processing elements in satellite communications.

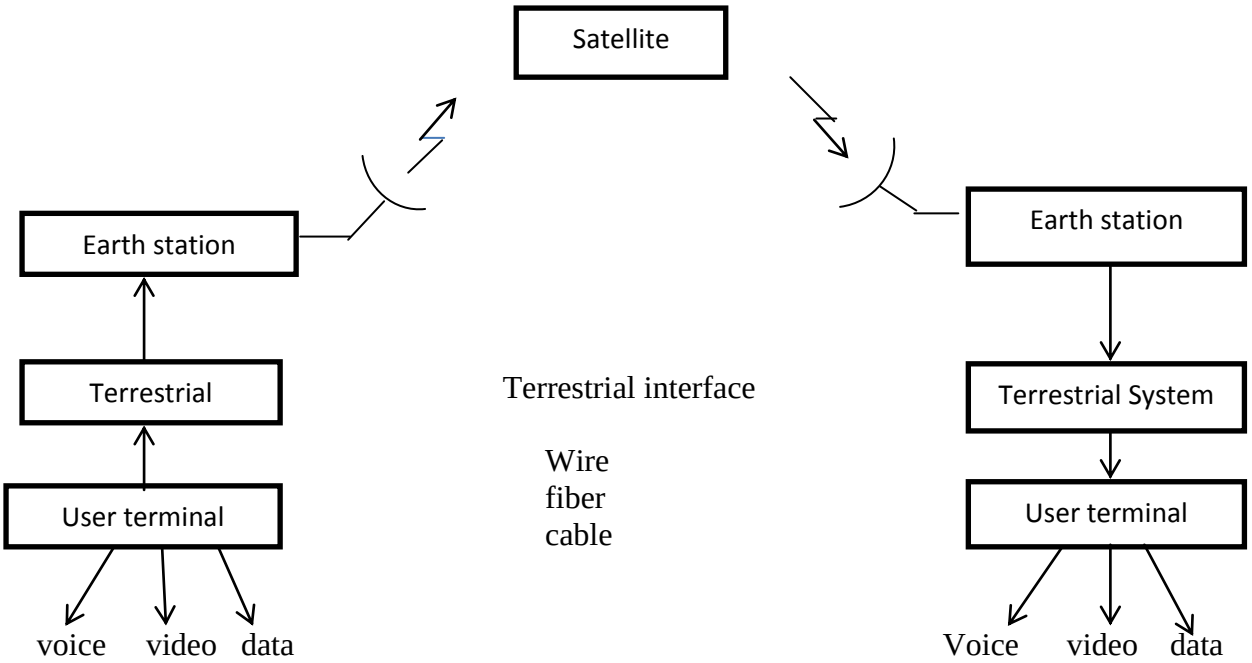

Figure 4: Element of satellite communication system.

a) Space Segment:

The space segment comprises of satellite and the equipment on board of the satellite. The satellite consists of the payload and the subsystems. The payload consists of the receiving and transmitting antennas and all the electronic equipment which holds the transmission of the carriers(6). Communication satellites are complex and expensive to acquire and launch. The Placement of a satellite into the orbit and operating it for 12 or more years involves a great deal. Placement in orbit is accomplished by contracting with a spacecraft manufacturer and launch agency andallowing them about three years to design, construct, and launch the satellite. The mass and volume of the electric power supply of a satellite poses one of the most restricting problems. In some applications such as television broadcasting or mobileand personal communications, the required electric power is over 10 kW which results in large weight and volume for communications satellites. Therefore,lightweight material is used for optimal design to support the load, withstand vibration and to keep the size and weight of the satellite small. Large temperature cycles are opted for the structure of the satellite. Once the satellite is placed in the proper orbit, it becomes the responsibility of a satellite operator to control the satellite for the duration of its mission. It is fairly complex task and involves both sophisticated ground-based facilities as well ashighly trained technical personnel.

Satellite Payload:

The payload in most commercial communication satellites consists of two distinct parts the transponder and the antennas.

a) Transponder:

There are two basic types of satellite transponders: repeater or bent pipe and processingor regenerative. In the repeater type, communication transponder captures the signals from earth, merely amplifies and frequency shifts the signals, whereas, in processing transponder, the RF carrier is demodulated to baseband signal and process the signals and later re-modulated the baseband signal in addition to frequency translation and amplification(6).

-Analog communication systems are entirelyrepeater type.

-Digital communication system may use any type. Figure 5 a, bshows the schematic diagrams of repeater type and regenerative type transponders respectively.

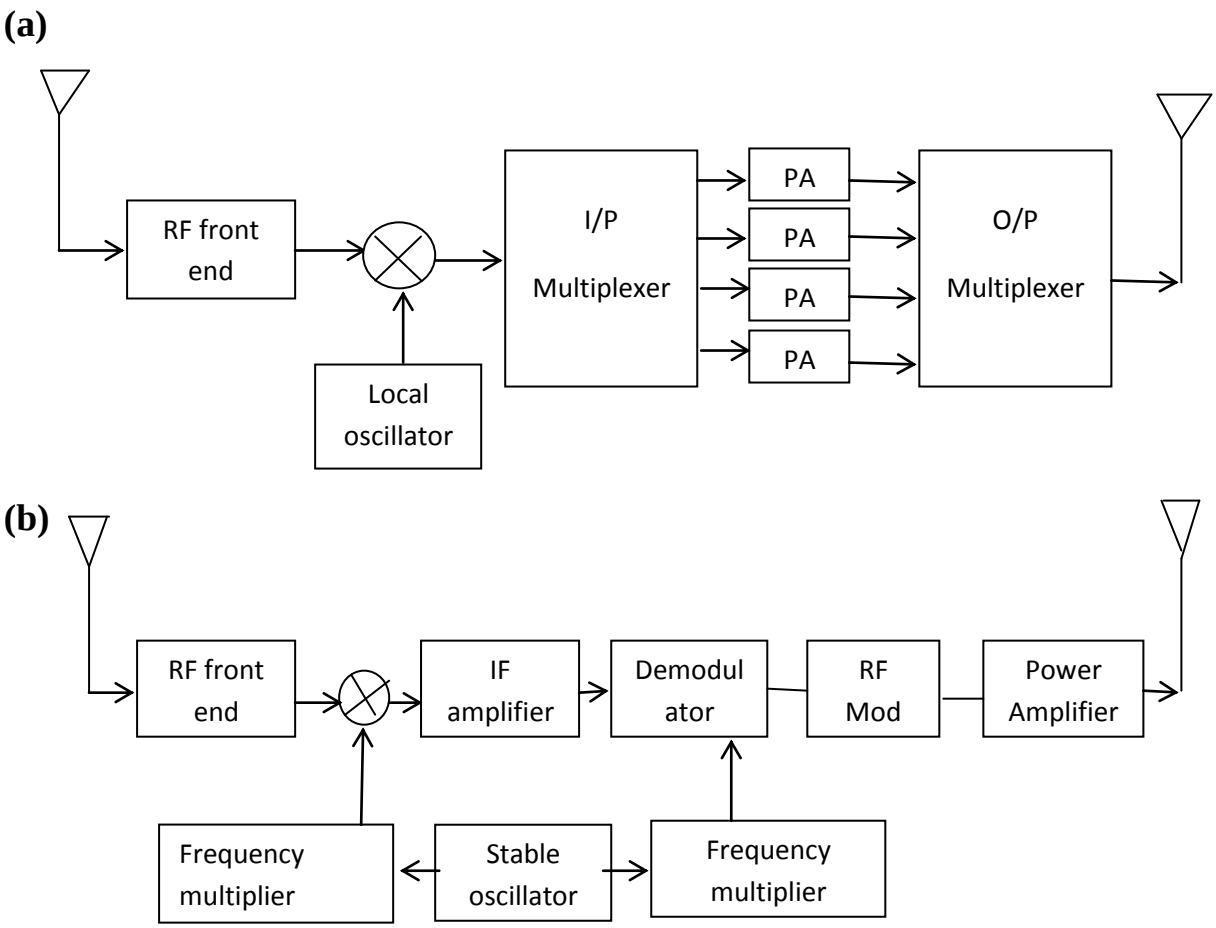

Figure 5: Repeater transponder. b Regenerative transponder

b)Satellite antennas:

The Satellite station receives and retransmits the signals using satellite antennaswhich maintain the link between the ground segment and the communicationstransponder. The size and shape of the satellite antennas depend on the specificcoverage requirements of the system. Satellite antennas generate small multiple spotbeams and increase the EIRP for the same HPA power. Each beam covers a certainportion on the earth surface called footprint. The gain of the satellite antennas issame both in transmission as well as reception because the generated beam widthsare same. This necessitates two separate antennas on the satellite but the diametersof the antennas will not be the same (depends on uplink and downlink frequencies).The beam width of a satellite antenna is equal to or less than the angle of view of theearth from the satellite, which is 17.5° in case of a geostationary satellite.The core functionalities of satellite antennas are as follows:

• **To capture the radio waves**, that is transmitted from ground station at uplinkfrequency band and with a given polarization; to capture the desirable signals and reject undesired signals as possible.

• **To transmit radio waves**, in a given downlink frequency band and with a given polarization, to a specific region on the earth surface.

• **To transmit more focused power** i.e., reduce wastage of power antennas for Satellite Communication.

The antennas on board the satellite serve as an interface between the Earth stations on the ground and various satellite sub-systems during operations. Antennas receive the uplink signal and transmit to downlink signals. In addition they provide single link for the satellite telemetry, command and ranging systems which in conjunction with attitude control subsystem provides beacon tracking signals for precise pointing of the antenna towards the Earth coverage areas. The design of satellite antenna is conditioned by the required coverage. It should be remembered that antennas are the one of the key elements in a satellite communication system since their gain values directly determine the amount of received power.

b) Ground Segment

The ground segment of satellite communication system supports the space segmentand has a command (uplink) function as well as data (telemetry and missionfunction). It sets up the communications links between the satellite and the user. Inlarge and medium system, the terrestrial microwave link interfaces with the user andthe earth station. However, in the case of small systems, the end user's terminalinterface is located at the earth station. The earth station (Figure 6) consists of:

- Transmit equipment.
- Receive equipment.
- Antenna system.

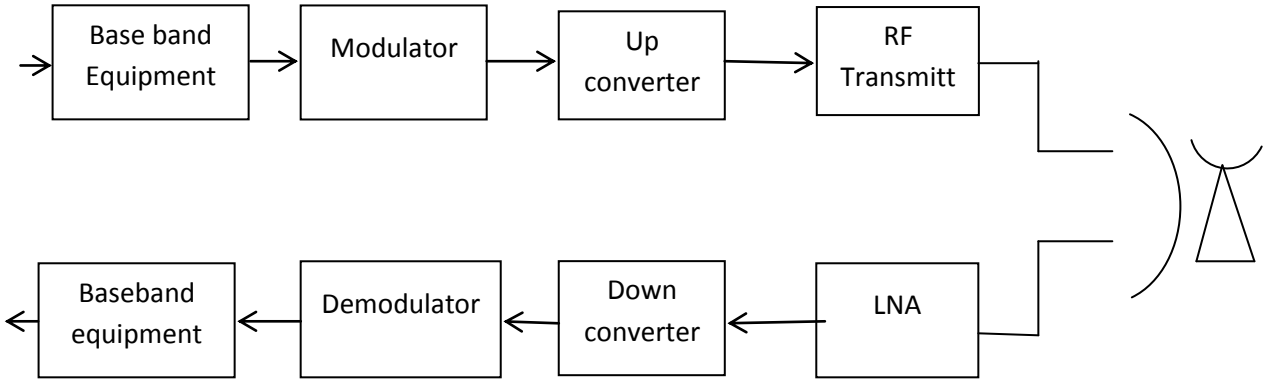

Figure 6: Shows a schematic block diagram of an earth station

In the ground station, the base band signal of terrestrial network is modulated onIF and then up-converted before transmitting to the satellite. The receiving groundstation transmits the base band signal to the user directly or through the terrestriallink.

The baseband signals received at the earth stations are generally telephone, television or data signals. It can relay information from a single source or fromseveral sources through multiplexing of signals from the individual sources.In early days, FM modulation scheme is used for analog voice and video signaltransmission in satellite communications. Now, the transmission signal is mostlydigital for both voice and video and the modulation schemes such as phase shiftkeying (PSK) and frequency shift keying (FSK) are implemented for transmission.

The monitoring, alarm and control equipment of the earth station has the followingpurposes:

- To monitor the network operations and controlling the station and managing the traffic.

• To give alarms in case of inaccurate operation or an occasion that affects the main station equipment or the link performance and allow detection of the equipment which is involved.

• To control the station equipment including adjustment of parameters, switching of redundant equipment and so on, it should keep in mind that the correct functioning of network operations and control center is necessary where the number of users in the network is large.

I.4 Various Types of Antenna with Respect to their Applications (antennas for space applications)

Antenna is the most important part in wireless communication systems. Antenna transforms electrical signals into radio waves and vice versa. The antennas are of various kinds and having different characteristics according to the need of signal transmission and reception(8)

1.4.1 Microstrip Patch Antenna:

Microstrip patch antennas (MPA) are well known for their performance and their robust design, (Figure 7), fabrication and their extent usage. The advantages of this Microstrip patch antenna are to overcome their de-merits such as easy to design, light weight etc., the applications are in the various fields such as in the medical applications, Mobile and satellite communication application , Global Positioning System applications and of course even in the military systems just like in the rockets, aircrafts missiles etc. . It is also expected that due to the increasing usage of the patch antennas in the wide range this could take over the usage of the conventional antennas for the maximum applications(9) .

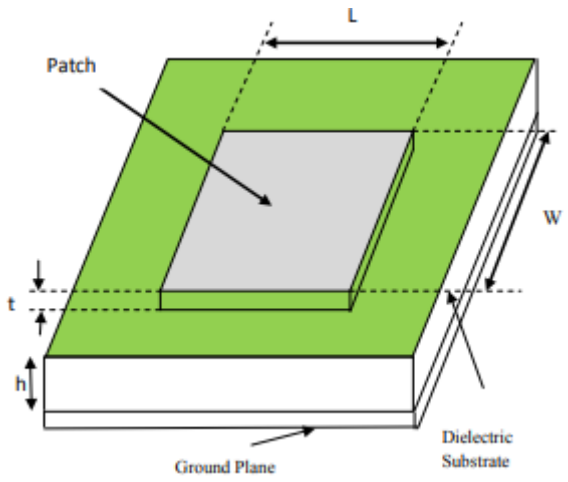

Figure 7: Example of patch antenna.

I.4.2 spiral antenna

Spirals antennas belong to the class of the so called frequency independent antennas, (Figure 8) .Due to their self-invariant scalability it is possible to cover a wide range of frequencies, from 3.1 to 10.6 GHz is indicated Ultra-wideband radio (UWB)(10) . The benefit of spiral antenna is its simple manufacturing, led expenditure, long life, and higher emission performance(11).

The spiral antennas have various applications, in wireless communication due to their high bandwidth(12) also it used inGNSS (GPS), where it is advantageous to have right hand circularly polarized (RHCP) antennas.

Figure 8: Representation of spiral antenna (11).

I.4.3 Helical antenna

A helical antenna is a helical shaped conductor winded around a cylinder,(Figure 9). This antenna can radiate in different modes but the axial mode is one of the most commonly used that because it gives maximum radiation power, Some of the advantages of the helix antennas include their wide bandwidths, easy implementation, real input impedances and circularly polarized fields(13) . Helical antennas have been used in many applications and for different frequency bands; they are the most widely proposed antennas in satellite communications systems.

The main reason why these antennas constitute an asset in applications concerning satellite and space communications generally is circular polarization.

Figure 9: Helical antenna;

I.4.4 Phased array antenna

A phased array antenna is composed of lots of radiating elements each with a phase shifter. Beams are formed by shifting the phase of the signal emitted from each radiating element, to provide constructive/destructive interference so as to steer the beams in the desired direction.

Phased array antennas are becoming increasingly popular in satellite communications because of their inherent advantages of beam reconfigurability(14).

Various applications of phased array antennas including target identification communication.

With the recent advancement of solid state technology and fabrication process the phased array antennas are becoming cost effective and gaining importance due to much flexibility it offers.

I.4.5Mesh reflector:

Deployable mesh reflectors have been successfully used in telecommunications applications for several decades, as shown in Figure 10. The structures are lightweight and can be packaged in a compact form for launch. Once deployed, the antennas are rigid and can be built with surfaces accurate enough for Ka-band operation. Reflector mesh fabrics are available that are fine enough to be highly reflective at Ka-band, yet have relatively low mass(15).

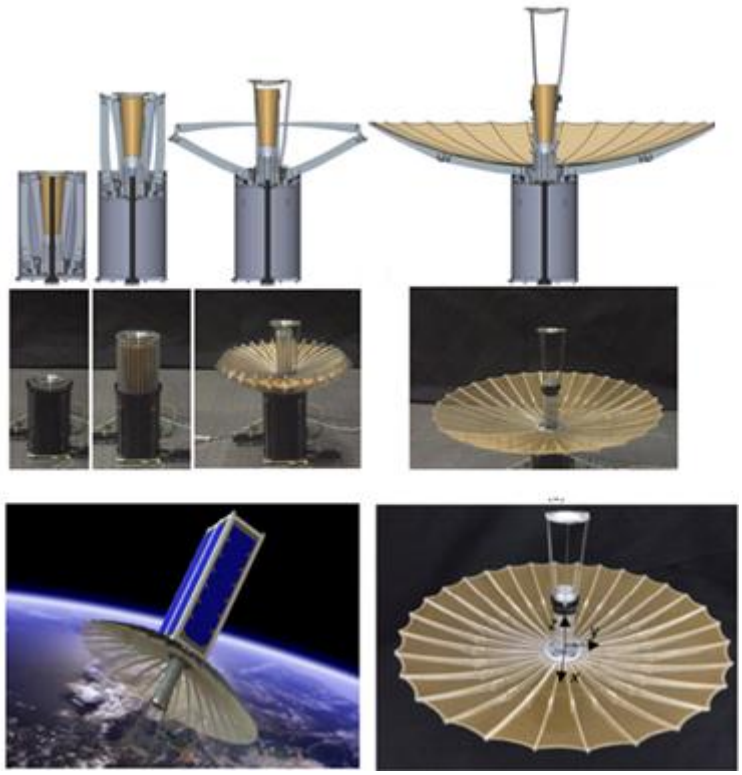

Figure 10: Mesh reflector used in cubesat for Earth Science and Deep Space mission(16)

I.4 Conclusion

In both satellite communication system and navigation satellite system there are a lot of applications that need a high frequency band that means many antennas are required.
Employing individualantennas for reception of each frequency, it will be quite costly in addition to increasedcomplexity of the complete system. Therefore, this necessitates the development of multi-frequency or wide frequency band antennas, and that what we are interested in the next chapters.

CHAPTER II

EBG structure and state of the art on wideband antenna with Artificial Magnetic Conductor

Chapter II:EBG structure and state of the art on wideband antenna with Artificial Magnetic Conductor

II.1 Introduction

In this chapter, we will focus on the definition of EBG structure, their characteristics and applications that have been developed with antennas. Then, we will draw up a state of the art on wideband antennas using the artificial magnetic reflector.

II.2 Background

Antenna designs have experienced enormous advances in the past several decadesand they are still undergoing monumental developments (17). Many new technologies have emerged in the modern antenna design arena and one exciting breakthrough is the discovery/ development of electromagnetic band gap (EBG) structures. The applications of EBG structures in antenna designs have become a thrilling topic for antenna scientists and engineers.

The recent explosion in antenna developments has been fueled by the increasing popularity of wireless communication systems and devices. From the traditional radio and TV broadcast systems to the advanced satellite system and wireless local area networks, wireless communications have evolved into an indispensable part of people's daily lives.

Antennas play a paramount role in the development of modern wireless communication devices, ranging from cell phones to portable GPS navigators, and from the network cards of laptops to the receivers of satellite TVs. A series of design requirements, such as low profile, compact size, broad bandwidth, and multiple functionalities, keep on challenging antenna researchers and propelling the development of new antennas.

Electromagnetic band gap (EBG) structures and their applications in antennas have become a new research direction in the antenna community. It was first proposed to respond to some antenna challenges in wireless communications.

For example:

_ How to suppress surface waves in the antenna ground plane?Or , how to design an efficient low profile antenna near a ground plane?

II.3 EBG definition

EBG structures are usually realized by periodic arrangement of dielectric materials and metallic conductors. In general, they can be categorized into three groups according to their geometric configuration: three-dimensional volumetric structures, two-dimensional planar surfaces, and one-dimensional shown in Figure 11.

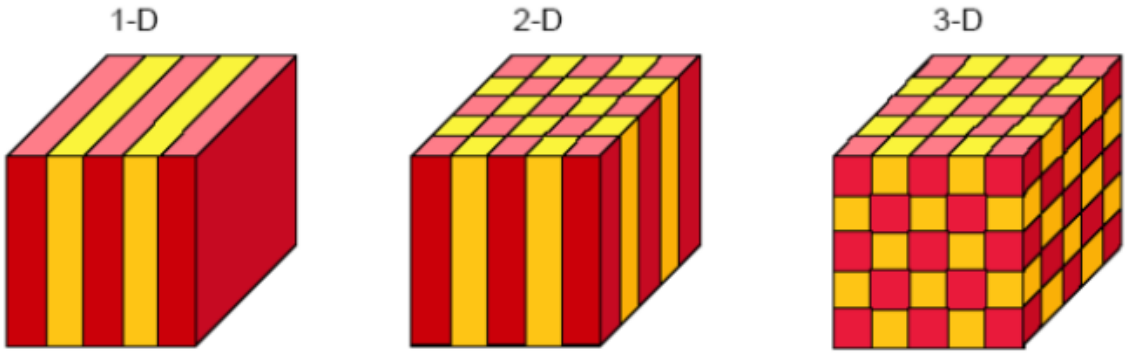

Figure 11: Periodic structure 1D, 2D, 3D(18)

Almost at the same time, another terminology, "*metamaterials*," also appeared and has become popular in the electromagnetics community (18). The ancient Greek prefix, *meta*(meaning "beyond"), has been used to describe composite materials with unique features not readily available in nature. Depending on the exhibited electromagneticproperties, various names have been introduced in the literature, including:

_ *Double negative (DNG) materials* with both negative permittivity and permeability.

_ *Left-handed (LH) materials* inside which the electric field direction, magnetic field direction, and propagation direction satisfy a left-hand relation.

_ *Negative refractive index (NRI) materials* that have a negative refractive index;

_ *Magneto materials* with artificially controlled high permeability;

_ *Soft and hard surfaces* that stop or support the propagation of waves;

_ *High impedance surfaces* with relatively large surface impedances for both TE and TM waves;

_ *Artificial magnetic conductors (AMC)* that exhibit the same properties as a perfect magnetic conductor.

Due to their unique band gap features, EBG structures can be regarded as a special type of met materials(18).

Besides the band gap feature, EBG also possesses some other exciting properties, such as high impedance and AMC. For example, a mushroom-like EBG surface exhibits high surface impedances for both TE and TM polarizations. When a plane wave illuminates the EBG surface, an in-phase reflection coefficient is obtained resembling an artificial magnetic conductor. In addition, soft and hard operations of an EBG surface have also been identified in the frequency-wavenumber plane. These interesting features have led to a wide range of applications in antenna engineering, from wire antennas to microstrip antennas, from linearly polarized antennas to circularly polarized antennas, and from the conventional antenna structures to novel surface wave antenna concepts and reconfigurable antenna designs.
In summary, electromagnetic band gap structures are an important category of met materials.

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II.4 Characterization of EBG structures

To more readily understand the operation of EBG structures, some circuit models have been proposed. A simple two-dimensional planar electromagnetic band gap (EBG) structure, as shown in Figure 12 .This structure was originally proposed in (19) . The EBG structure consists of four parts: a metal ground plane, a dielectric, substrate, periodic metal patches on top of the substrate, and vertical vias connecting the patches to the ground plane. The geometry is similar to the shape of a mushroom.

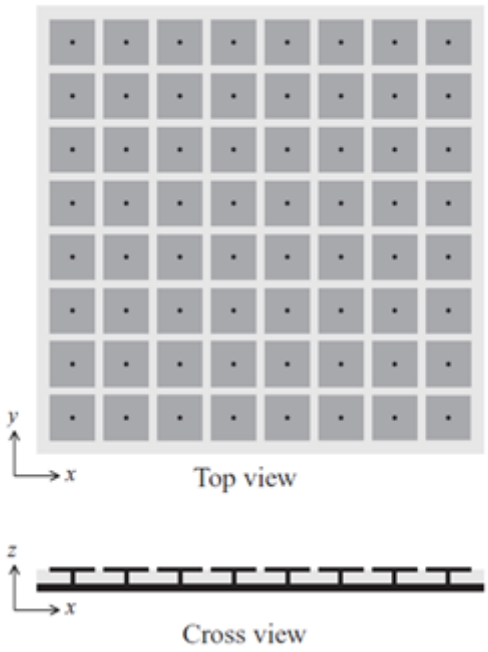

Figure 12: Geometry of mushroom-like electromagnetic band gap (EBG) structure.

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The parameters of the EBG structure are labeled in Figure13.a , as patch width W, gap width g, substrate thickness h, dielectric constant ε_r and vias radius r .When the periodicity (W+g) is small compared to the operating wavelength ,the operation mechanism of this EBG structure can be explained using an effective medium model with equivalent lumped LC elements , as shown in Figure 13.b . The capacitor results from the gap between the patches and the inductor results from the current along adjacent patches. The impedance of a parallel resonant LC circuit is given by:

$$Z = \frac{Z_L \ Z_C}{Z_L + Z_C} = \frac{j\ LW}{1 - LCW^2} \qquad \text{(I)}$$

a **b**

Figure 13: LC model for the mushroom-like EBG structure ; (a) EBG parameter ,(b) model LC.

The resonance frequency of the circuit is calculated as following:

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \qquad \text{(II)}$$

Near the resonance frequency f_0 , high impedance is obtained and the EBG does not support any surface waves, resulting in a frequency band gap. The high surface impedance also ensures that a plane wave will be reflected without the phase reversal that occurs on a perfect electric conductor (PEC).

The value of the capacitor is given by the fringing capacitance between neighboring coplanar metal plates. This can be derived using conformal mapping, a common technique for determining two-dimensional electrostatic field distributions. The derivation starts with a pair of semi-infinite plates separated by a gap situation is given by the following equation:

$$C = \frac{w\varepsilon_0(1+\varepsilon_r)}{\pi} cosh^{-1}\left(\frac{w+g}{g}\right) \qquad \text{(III)}$$

The value of the inductor is derived from the current loop in Figure 13.b, consisting of the vias and metal sheets. For a solenoid current, the magnetic field can be calculated using Ampere's law. The equivalent inductor is then computed from the stored magnetic field

energy and the excitation current. After a simple derivation, the inductance is expressed as below. This depends only on the thickness of the structure and the permeability:

$$L = \mu_0 \mu_r h \qquad \text{(IV)}$$

Substituting (III) and (IV) into (I) and (II) , the surface impedance and resonant frequency can be computed .Other characteristic parameters , such as the reflection phase can also be derived accordingly.

Besides the surface wave property, EBG structure also exhibit interesting reflection phase behavior, which will be discussed .Reflection coefficient is a popular parameter used to describe the reflection property of an object. It I defined as the ratio of the reflected field over the incident field at the reflecting surface. Usually, it has a complex value with the corresponding magnitude and phase. When a ground plane exists in ananalyzed lossless structure, the magnitude is always one because all the energy is reflectedback. In this case, the reflection phase is of special interestwith the traditional conductors, if a planewave is normallyimpinged upon a perfect electric conductor (PEC), the total tangential E field must bezero in order to satisfy the boundary condition. Thus, the reflected E field and the incident E field should have the opposite signs, resulting in a reflection coefficient of −1. Thereflection phase is 180◦ for the PEC case. For a perfect magnetic conductor (PMC), thetotal tangential H field must be zero. Thus, the reflected H field and the incident H fieldshould have the opposite signs whereas the reflected E field and the incident E field havethe same signs. As a result, the reflection coefficient is equal to one and the correspondingreflection phase is 0◦ for PMC case. However, the PMC surface does not exist in nature.

Research onEBGstructures reveals that they can realize thePMCcondition in a certainfrequency band. Thus, they are sometimes referred to as artificial magnetic conductors(AMC). Actually, the reflection phase of an EBG structure is a function of frequency. Itvaries continuously from 180◦ to −180◦ as frequency increases. This reflection phasefeature makes EBG surfaces unique and initiates many low profile wire antenna designson EBG surfaces.

The band gap is defined for a variation of reflection phase between + 90 ° and -90 °, white zone in Figure 14.

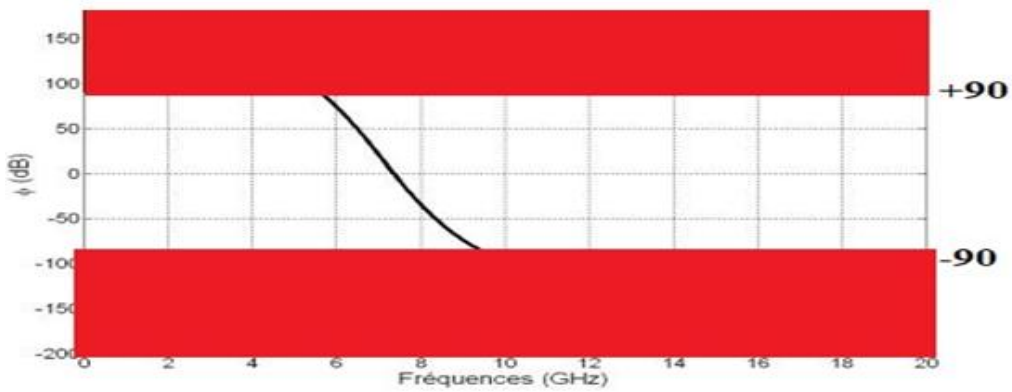

Figure 14: Example of reflection phase.

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II.5 EBG applications in antenna engineering

The unique electromagnetic properties of EBG structures have led to a wide rangeof applications in antenna engineering. This section summarizes several typical EBGapplications in antenna designs.

II.5.1 Application for surface wave suppressions

Surface waves are by-products in many antenna designs. Directing electromagneticwavepropagation along the ground plane instead of radiation into free space, the surfacewaves reduce the antenna efficiency and gain. The diffraction of surface waves increasesthe back lobe radiations, which may deteriorate the signal to noise ratio in wirelesscommunication systems such as GPS receivers. In addition, surface waves raise themutual coupling levels in array designs, resulting in the blind scanning angles in phasedarray systems.

The band gap feature of EBG structures has found useful applications in suppressingthe surface waves in various antenna designs. For example, an EBG structure is usedto surround a microstrip antenna to increase the antenna gain and reduce the back lobe(20).

In addition, it is used to replace the quarter-wavelength choke rings in GPSantenna designs. Many array antennas also integrate EBG structures to reduce the mutual coupling level. For example, Figure.15 shows a comparison of patch antennas with and without EBG structures and an 8 dB reduction in mutual coupling is observed:

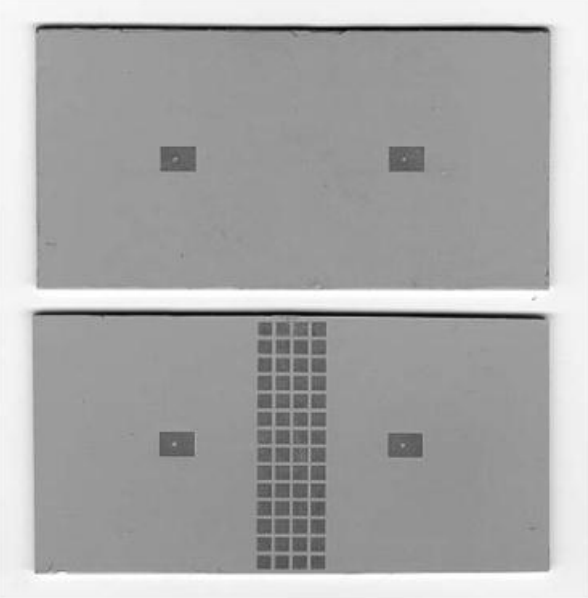

Figure 15: Shows a comparison of patch antennas with and without EBG structures

II.5.2 Application for efficient low profile wire antenna designs

Another favorable application of EBG is to design low profile wire antennas with goodradiation efficiency, which is desired in modern wireless communication systems. Toillustrate the fundamental principle, Table 3 compares the EBG with the traditionalPEC ground plane in wire antenna designs. When an electric current is vertical to a PECground plane, the image current has the same direction and reinforces the radiation fromthe original current. Thus, this antenna has good radiation efficiency, but suffers fromrelative large antenna height due to the vertical placement of the current. To realize a lowprofile configuration, one may position a wire antenna horizontally close to the groundplane. However, the problem is the poor radiation efficiency because the opposite imagecurrent cancels the radiation from the original current. In contrast, the EBG surfaceis capable of providing a constructive image current within a certain frequency band,resulting in good radiation efficiency. In summary, the EBG surface exhibits a greatpotential for low profile efficient wire antenna applications.

Based on this concept, various wire antennas have been constructed on theEBGgroundplane(21). Typical configurations include dipole antenna, monopole antenna, andspiral antenna. EBG surfaces have also been optimized to realize better performancesuch

as multi-band and wideband designs. For example, Figure 16shown a curl antenna on an EBG structure that radiates circularly polarized radiation patterns.

Options	Efficiency	Low profile
J ↑ PEC ↑	**Good**	**Bad**
J → PEC ←	**Bad**	**Good**
J → EBG →	**Good**	**Good**

Table 3: Comparisons of conventional PEC and EBG ground planes in wire antenna designs

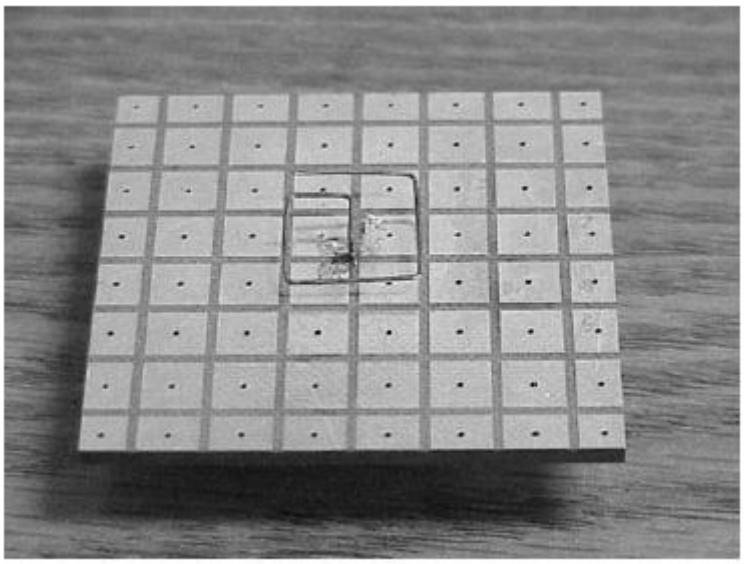

Figure 16: EBG substrate for a low profile curl antenna design (from [24] C _ Wiley InterScience)

II.5.3 Reflection/transmission surfaces for high gain antennas

EBG structures are also applied in designing antennas with a high gain around or above 20 dBi. Traditionally, high gain antennas are realized using either parabolic antennas or large antenna arrays. However, the curved surface of parabolic antennas makes it difficultfor them to be conformal with mobile platforms, while large antenna arrays alwayssuffer from loss in

the feeding networks. The planar EBG surfaces provide an alternative solution to this problem. For example, it is used to design a high gain resonator antenna (22), as shown in Figure17. After optimizing the EBG design, a 19 dBi antenna gain is obtained in the measurement.

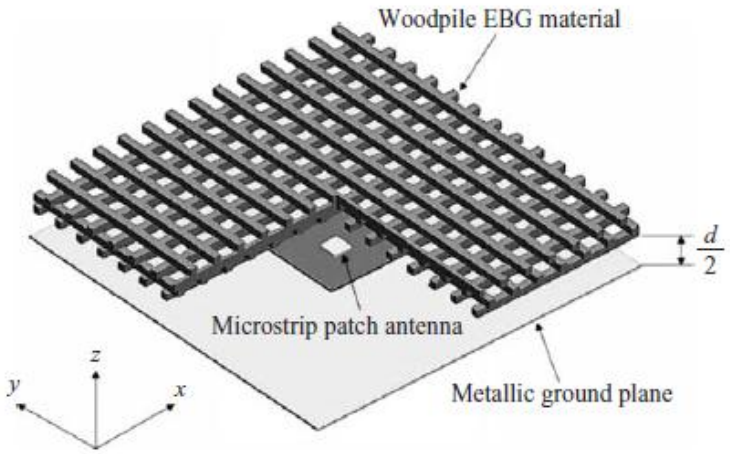

Figure 17: A high gain resonator antenna designs using an EBG structure.

II.6 State of the art on wideband antennas with Artificial Magnetic Conductor

Antennas require being unidirectional for a variety of applications, as shown in Figure.18. For example, an antenna embedded on aircraft or satellite to the outside of the aircraft, while preventing the electromagnetic contamination of its internal environment. To design these antennas with low profile, use of Artificial Magnetic Conductors as reflectors. In addition, multiple functionalities are needed and thus are required. These design requirements, is a real challenge. Therefore, we will focus on the following section on wideband antennas with Artificial Magnetic Conductor

In (23) novel fractal wideband artificial magnetic conductor (AMC) structureis designed as the ground plane of a printed bow-tie antenna forgain enhancement and low profile. The origin printed bow-tieantenna is operated in the range from 1.67 to 2.06 GHzwith a trapezoidal balun connected to the SMA. The AMC structure consists of 6 × 9 first-order fractal unit cellsthat are made up of four circles and four smaller circles as shown in Figure 19.The distancebetween the antenna and the AMC is reduced to one-eighth of

thewavelengthin free space at 1.7 GHz. The composite antenna has a wide bandwidth from 1.64 to1.94 GHz, with a relative frequency bandwidth of 16.7%.

The gain is increased, and the maximum gain is 6,5 dBi and the radiation patterns are stable in the whole operating frequency range, which makes it suitable for wireless communication applications.

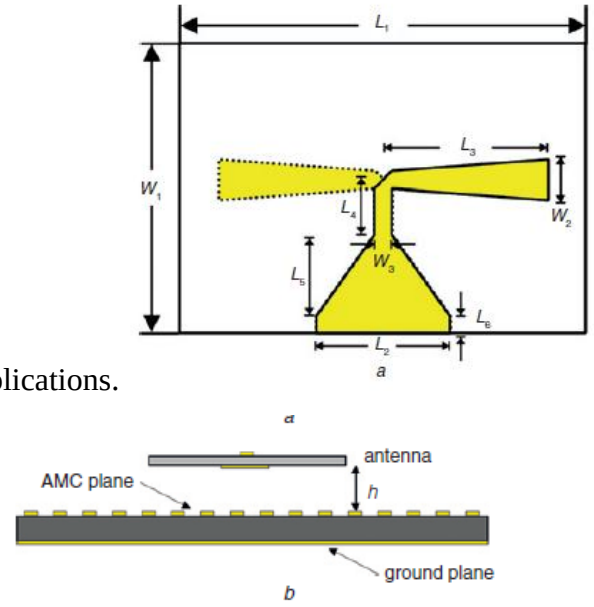

Figure 18: Geometry of Bowtie antenna and composite antenna (23).

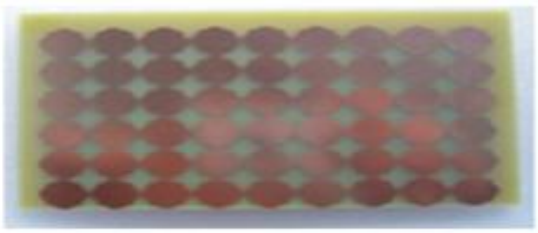

Figure 19: Photograph of fractal AMC plane(23).

In(24)a novel low-profile and highgainantenna which adopts an artificial magnetic conductor(AMC) ground plane as its reflecting surface. Here, the traditional printed dipole

antenna is oriented horizontally over the AMC surface which is consisted of 5*7 square plum-shaped patches unit without vertical via to the ground. The optimized antenna has a height about 9.5mm and its peak gain is closed to 9.7dB at 2.58GHz. Moreover, the operating frequency range is from 2.47GHz to 2.77GHz, its relative bandwidth achieves about 11.63%.

The AMC structure had a 3mm RT/Duroid 6010 dielectric substrate with dielectric constant(equal to 10.2) and the plum-shaped pattern is combined of four symmetrical circular patches and they are designed to be fully symmetrical with r=2,3 mm and bandwith covering from 3,18 GHz to 4,21 GHz .as shown in Figure.20.

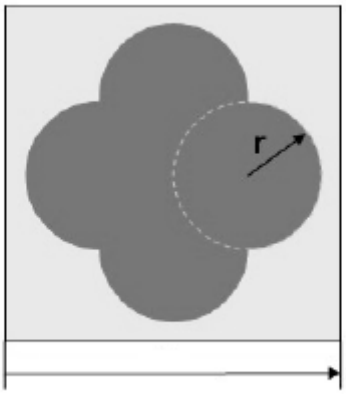

Figure 20: Unit cell of proposed AMC structure.,

The Bowtie antenna presents in Figure.21is etched on a Rogers TMM4(tm) substrate which has a dielectric constant 4.5 and a 0.5mm thickness. The two bowtie arms are on each side of the substrate. The substrate size is 94.15mm (*Dx*) and 56.625mm (*Dy*).The length of eachbow-tie arm *d* is 17.8mm and the long side of the bow-tie patch *l*1 is 11mm, the short one, 4mm.

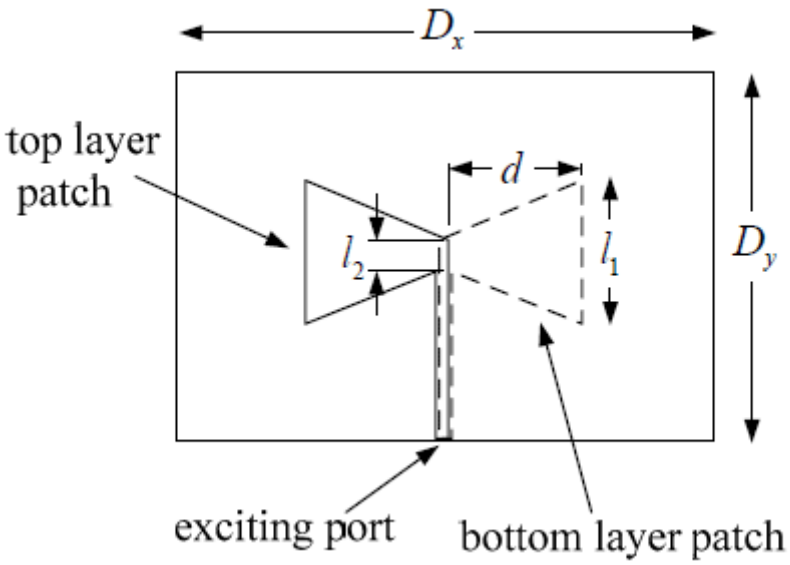

Figure 21: The Bowtie antenna.(24)

The distance between the antenna and the AMC plane is 6 mmwhich cover a wider bandwidth possible, andthe total height of the composite antenna is 9,5m .The frequency range of S11 below -10dB is from 2.47GHz to 2.77GHz, which covers the LTE (Long Term Evolution) range from 2.5GHz to 2.69GHz and the peak gain is 9, 67 dB at 2, 58 GHz.

In(25) a novel combination of coplanar waveguide(CPW)-fed double bow-tie slot antenna and artificial magnetic conductor (AMC), which meets the requirements of a 5.8-GHz .SHF RFID tag antenna usable on metallic objects, is presented.

Double Bowtie antenna is used with RO4003C substrate and relativedielectric permittivity $\varepsilon_r = 3{,}38$ and a thickness of$h = 1{,}524\, mm$ .There is no ground below the dielectric substrate, that is, ungrounded CPW. The AMC structure is a RO4003C substrate with thickness $h = 0{,}762\, mm$and permittivity $\varepsilon = 3{,}38$.As the CPW-fed slot double bow-tie antenna has no ground plane below the dielectric substrate, the AMC's unit cells below the antenna have been removed. The Bow-tie–AMC combination keeps the antenna operating properly in the whole antenna bandwidth. As shown in Figure 22.

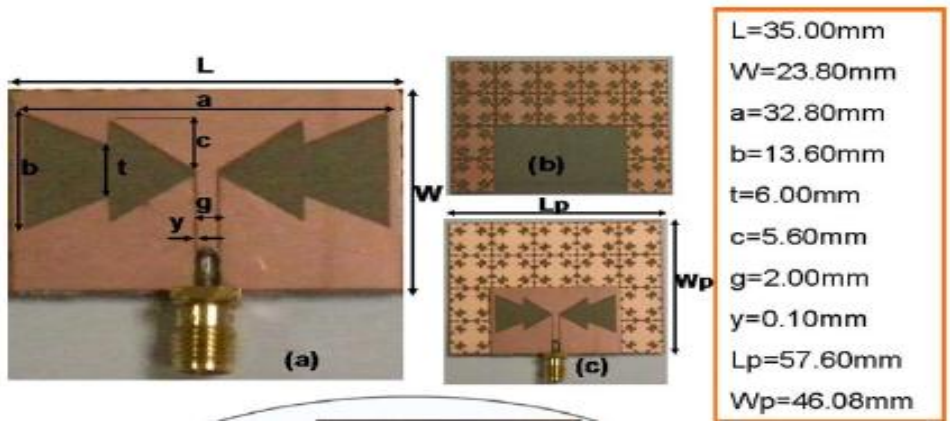

Figure 22: Element of the manufactured prototype ,(a) double bowtie antenna ,(b)AMC unit cells arrangement ,(c) Bowtie AMC prototype .(25)

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The combined structure Bow-tie–AMC is placed on a metallic plate, the current distribution on the bow-tie is not affected, so it is possible to affirm that the AMC electromagnetically insulates the bow-tie antenna from the metallic plate. The Radiation pattern properties of the Bow-tie–AMC for RFID application are still preserved even when placed on a metallic plateand the gain increased until 9, 23 dB.

In (26)the diamond dipole antenna is printed on a CuClad substrate with thickness h_{CuClad}= 1.58 mm, relative permittivity ε_{CuClad}= 2.5, and loss tangent tan δ_{CuClad}= 0.0018 with bandwidth of 53% (4.56-7.84 GHz) which feeding by discrete port.as shown in Figure23. Due to the stacked nature of the antenna with AMC reflector, it is proposed to feed the antenna with a 50 Ω SMA connector placed at the edge of the antenna substrate, that's why the balun is used.

The AMC is an array of square copper patches printed on a FR4 Epoxy substrate with ε_{FR4}= 4.0, *tan* δ_{FR4}= 0.02, and a thickness of h_{FR4}= 3.2 mm backed by a metallic ground plane and the dimensions of AMC are found out to be W_{AMC}= 7.4 mm, g_{AMC}= 1 mm.The phase interval of reflection coefficient leading to constructive interference in antenna plane (-90°, +90°) is from 4.2 to 5.8 GHz (32%).

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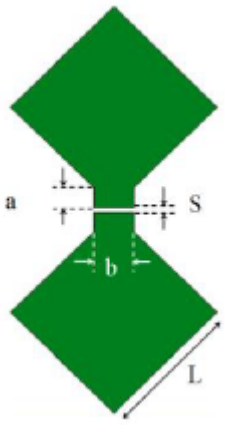


DIMENSIONS OF THE DIAMOND DIPOLE

Parameter	Value (in mm)
L	9.0
S	0.3
a	1.5
b	3.0

Figure 23: Diamond dipole antenna.(26)

A split radiation pattern in the broadside direction appearing when using an Artificial Magnetic Conductor (AMC).The reason behind this behavior is perceived to be the presence of surface currents on the AMC that cause destructive interference and lead to loss of gain in broadside radiation pattern at 5.8 GHz. A hybrid reflector(as shown in Figure.24) is then proposed to mitigate this problem by using both electrical and magnetic conductors. This solution enhances the gain. The antenna has a usable bandwidth of approximately 46% (4.2 - 6.7 GHz) and a variation of gain in the whole band between 4.9 and 7.9 dBi.

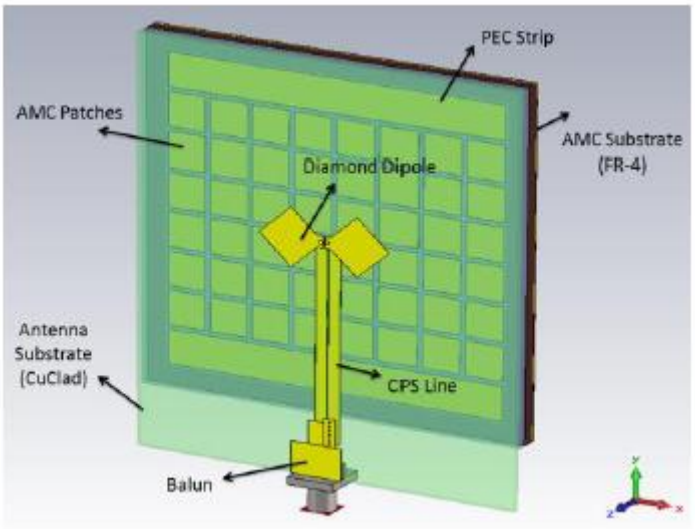


Figure 24: Final antenna with hybrid reflector.

In (27) , a low profile and Broadband slot antenna with an artificial magnetic conductor (AMC) surface is designed for X and Ku communication, fed with the coplanar waveguide (CPW), the designed slot antenna consists of two radiating slot with evolved C-shaped branches.

The proposed structure is designed from the L-slot antenna loaded with C-shaped slot branches and adding two L-shaped branches on the ends of each C-shaped branch.(Figure 25)

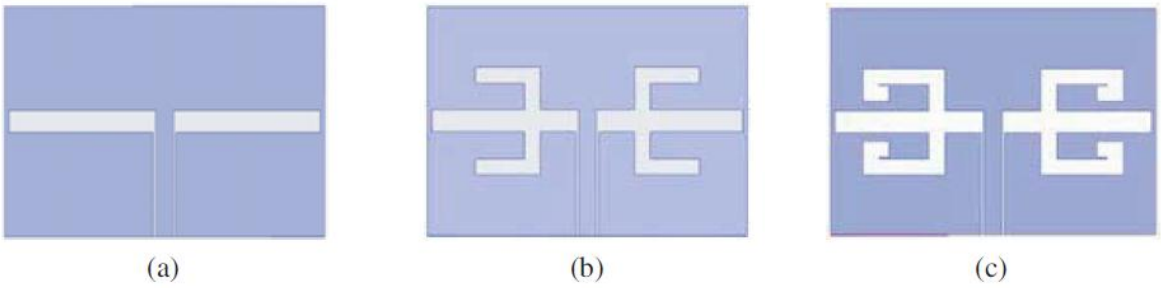


Figure 25: Geometry of the three types of slot antennas. (a) Slot antenna1, (b) Slot antenna2 and (c) the proposed structure.

The AMC unit cell is made up of two central hexagonal with six rectangle branches, operates in a wide in-phase reflection frequency band ranging from 6 to 13.94GHz at the reference plane 4 mm above the AMC surface which is composed of 8 ×10 AMC unite cells located under the slot antenna with a distance of approximately 0.107ʎ .(Figure .26).

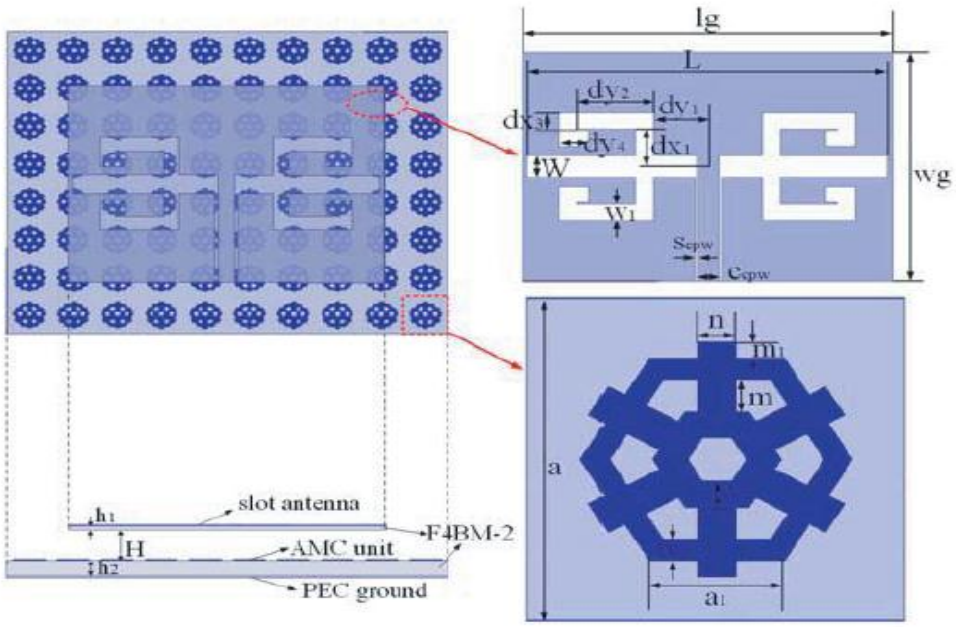


Figure 26: Top and side views of the composite antenna. (27)

The composite antenna achieves a wide impedance bandwidth from 7.64GHz to 14.58 GHz(62.47%). and exhibit a maximum gain of up to 10.26 dBi, high front-to-back ratios and low cross-polarization level, which enable the proposed antenna to be utilized in X and Ku communications.

II.7 Conclusion:

According to the definition and the application of the EBG structures, we have seen the advantages of using artificial magnetic reflector for navigation and communication systems. In fact, we can design antennas with a low profile, and high directivity. In addition, a state of the art on wideband antenna with artificial magnetic reflector has been done.

Chapter III

Wideband bow-tie antenna with an Artificial Magnetic Conductor (AMC)

ChapterIII:Wideband bow-tie antenna with an Artificial Magnetic Conductor (AMC).

III.1 Introduction

In this chapter, a planar wideband bowtie antenna is first presented. This antenna is then studied with an artificial magnetic conductor (AMC) to redirect the energy back in half space and increase the gain, with a reduction of thickness antenna. After that, a parametric studies on structure geometry is done with CST Microwave Studio to have a maximum stable gain on the C band.

III.2 CST Microwave Studio Simulator

Microwave-studio software from CST (Computer Simulation Technology) is electromagnetic simulation software with 3-dimensional structure. We use the time method (Transit solver) of the Microwave software. The choice was focused on this software because the use of such a resolution tool in the time domain is suitable for large structures. CST Microwave Studio uses the Finite Integral Technique. The FIT method is a generalization of the Finite Difference Time Domain method. It consists of a spatio-temporal discretization of Maxwell's equations in an integral formulation. The computational domain is broken down into cubic elementary cells.

III.3 Bowtie Antenna

A compact wideband antenna with an integrated balun, which achieves a very large bandwidth (2.5GHz-14 GHz), is presented in.It consists of a printed modified Bow-tie antenna fed by an integrated compact wideband balun illustrated in Figure .27. The overall size of the antenna printed on FR4 substrate is 75 × 58 mm^2. The antenna achieves a low gain (2.5 dBi) and unstable radiation pattern from 6 GHz. The optimized dimensions of the bow-tie antenna and thebalun are as follows: = 75mm, Ws = 58mm, Lp = 46 mm, Wp = 28 mm, X = 0.3 mm, Wadd = 10 mm, Lmcs = Lm = 12 mm, Wmcs = 3.137 mm,Wm = 20 mm, Lcps = 8.25 mm, Wcps= 0.3mm, Lt = Lk = 18 mm, Wk = 10.15 mm.

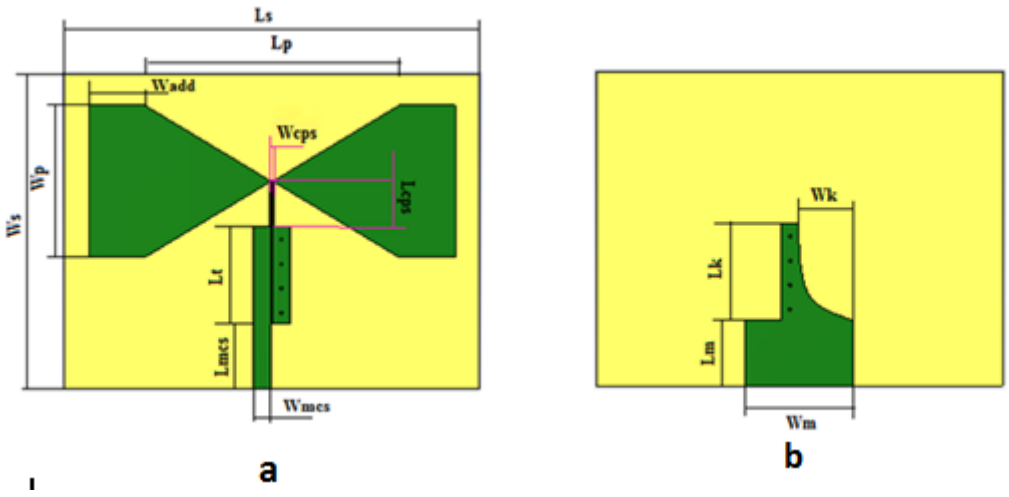


Figure 27: Dimensions of bowtie + balun: (a) Top view and (b) Bottom view(28).

The aim is to provide with this bowtie antenna a better stable radiation patterns in C-band and allow its integration on an satellite with a low thickness and a low weight. For this reason, we propose to put an AMC under the bowtie antenna.

III.4 AMC reflector design

The AMC reflector is composed of metallic square patches etched on a grounded substrate. There is no via between the patch and the ground plane, which enables to reduce the cost and facilitate the realization. The unit cell geometry is presented in Figure 28.

In order to design an AMC whose frequency band is included within the operational band of the Bow-Tie, the following dimensions have been chosen: Lamc=9.4 mm, Wamc=8 mm ,gamc=0.7 mm. The FR4 is used with permittivity εr = 4.3.

To design the unit cell, the appropriate boundary conditions must be defined to introduce a TEM (plane wave) mode whose direct trihedron is formed by the E and H fields. Only one element of the infinite structure is considered. The orthogonally of the fields is obtained from electrical boundary conditions along an axis on either side of the cell and magnetic boundary conditions along the perpendicular axis. The phase of the reflection coefficient of the structure is then determined only for normal incidence. The CST software makes it possible to specify these boundary conditions as shown in Figure 29.

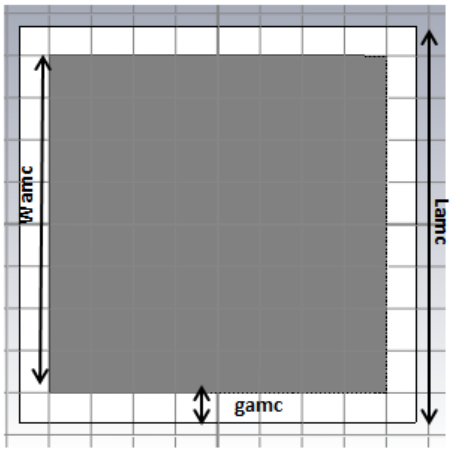


Figure 28: AMC cell.

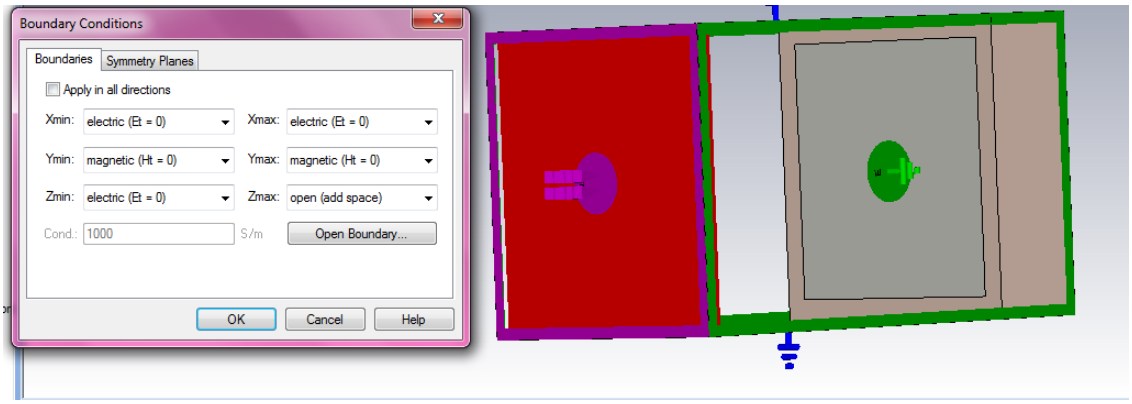


Figure 29: Boundary conditions of the AMC structure.

We put for; **Xmin** and **Xmax**: **Et** = 0 to have the horizontal electric field as shown in Figure 30.a).

Yminand **Ymax**: **Ht** = 0 to have the vertical magnetic cage as shown in Figure 30.b.

Once the boundary conditions are established, the structure is placed at a distance $D \geq \frac{2 \times a^2}{\lambda}$ from the source to be in the far field zone, as shown in Figure31:

- D: distance to the cell in m.

- a: the largest dimension of the antenna expressed in m.

- λ: wavelength in m.

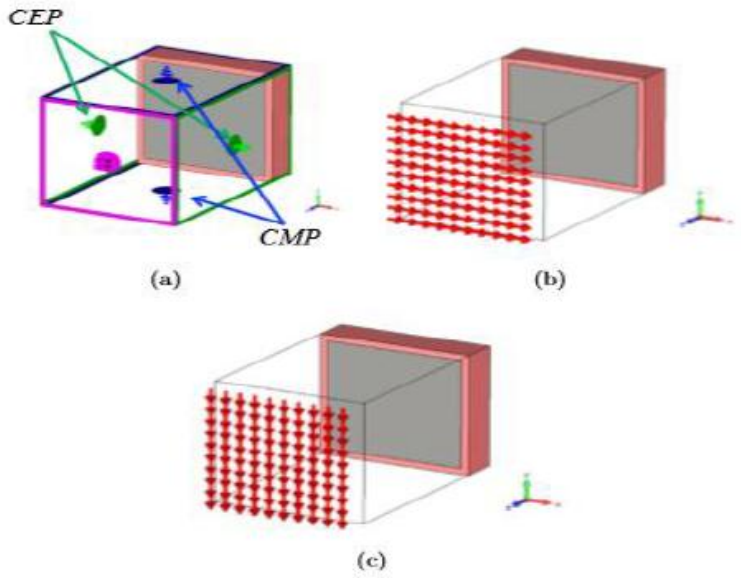


Figure 30: Boundary conditions of a structure.

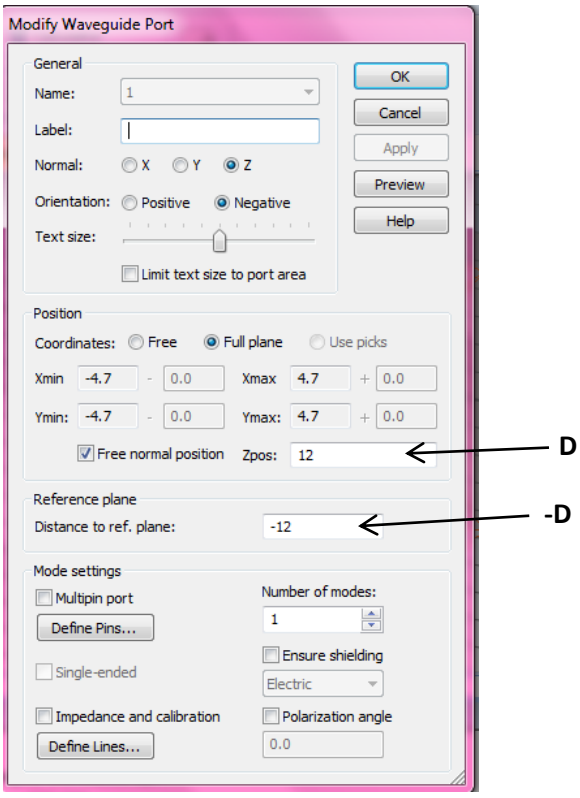


Figure 31: Far filed distance in Wave guide port

After simulation of the AMC cell, we represent the phase diagram in Figure 32. It shows that the high impedance structure has a phase between -90 ° and 90 ° in the frequency band 4.23-5.89 GHz with relative bandwidth of 32.8%.

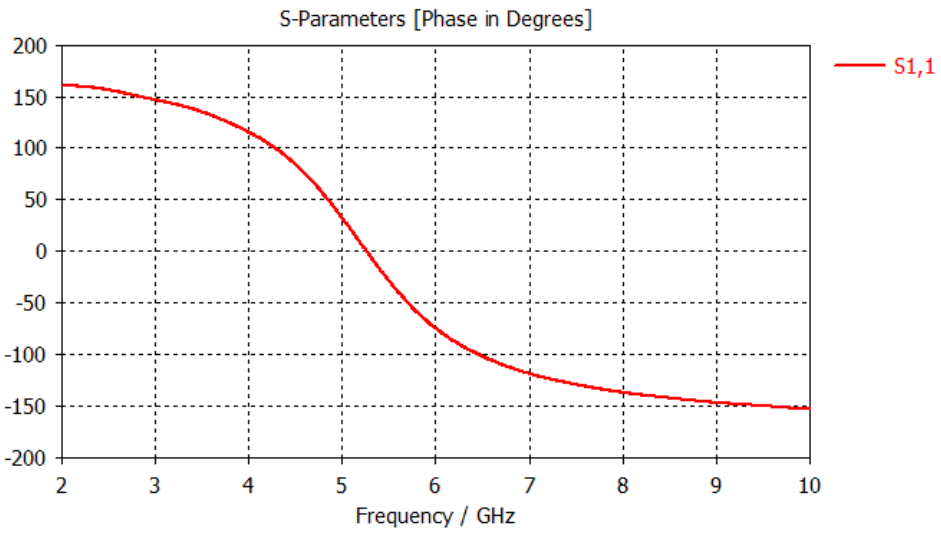


Figure 32: Phase reflection coefficient.

III.5 Bowtie antenna over artificial magnetic conductor

We analyze performance of the antenna when placed over an AMC designed using 8x8 unit cells, as shown in Figure33. For this purpose, simulations are carried out in CST Microwave Studio to see the reflection coefficient and the gain en broad side. The distance between antenna and AMC plane is$h_{air} = 2mm.$. *Hair* is chosen so as keeping the most possible frequency bandwidth matched in the operating frequency band, as well as maintaining constructive interference in broadside direction. The overall thickness of the radiating structure becomes 6.8 mm.

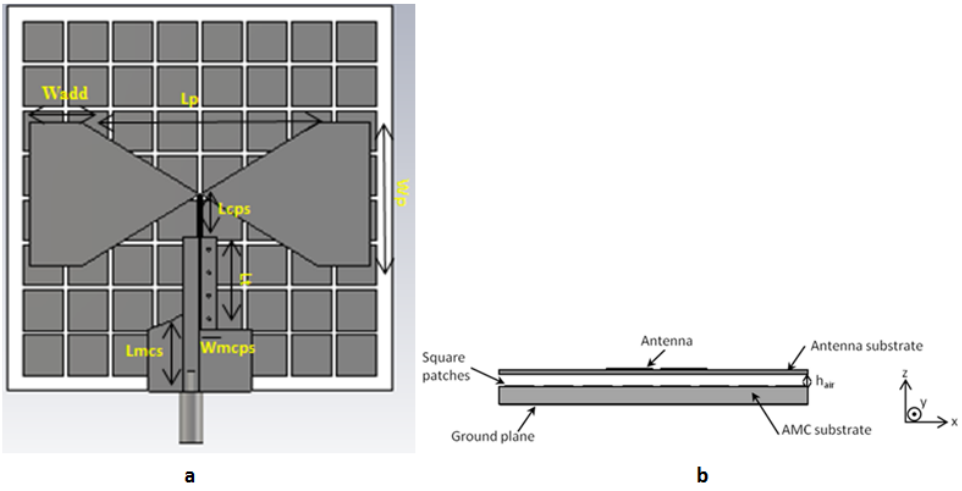


Figure 33: Bowtie antenna over AMC with 8*8 cells: (a) Front view, (b) side view.

The whole structure is simulated with 8*8 cells. Results in terms of reflection coefficient are presented in Figure 34. It observed a antenna mismatching, in particular at low frequency (between 3 and 4 GHz), and around 8 GHz because the reflection coefficient is upper then -10 dB. In addition, the gain in broadside direction still low and not stable in the whole bandwidth, as can be deduced from Figure 35.

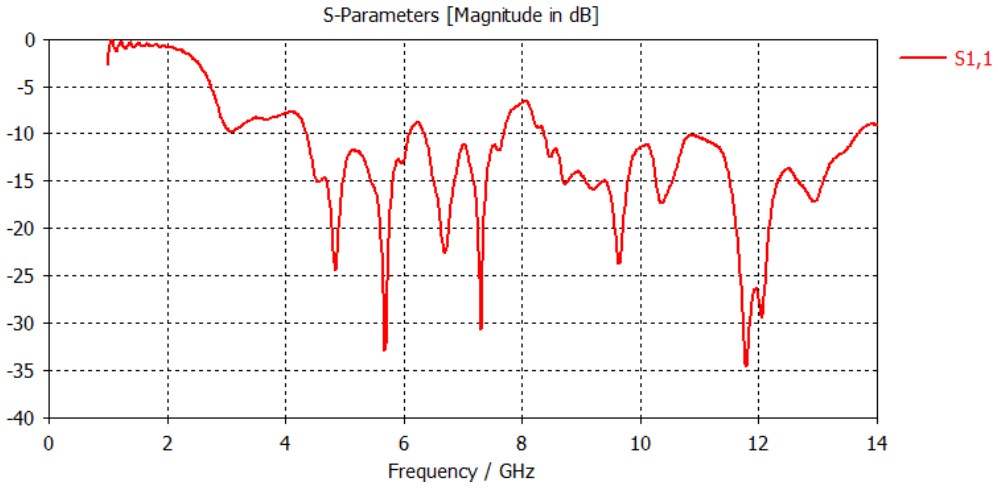


Figure 34: Reflection Coefficient S_11.

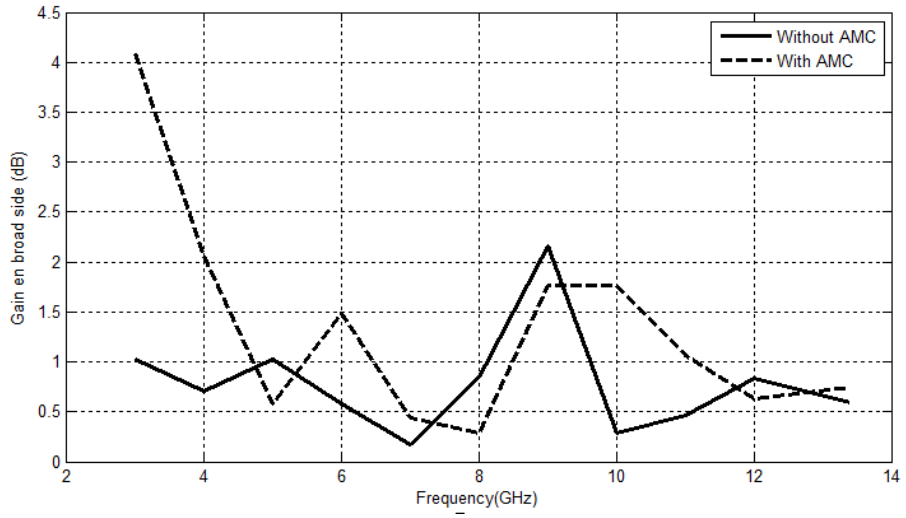


Figure 35: Broadside realized gain of 8x8 AMC-based antenna and without AMC.

The behavior of the whole structure (bowtie+AMC) is studied by analyzing its surface current. In fact, it is well known that a surface on which a uniform current is circulating exhibits a directive radiation pattern with a main beam in the direction normal to the surface (broadside direction). Furthermore, the larger the surface, the greater the directivity. However, when the surface becomes large compare to the wavelength, the current distribution may be not uniform and the current phase may range between 0° and 360° thereby inducing some opposite phase current (26). Consequently, destructive interference may occur a degradation gain. This effect is particularly undesirable. To understand if this effect happens, the surface current of the 8x8 AMC-based antenna designed is observed in Figure 36. The current is mainly concentrated and spread over AMC which led to destructive interference and low gain. In addition, putting AMC cells behind the balun disturb significantly the distribution of current. For this reason, we removed AMC cells that are close to balun as shown in Figure37.

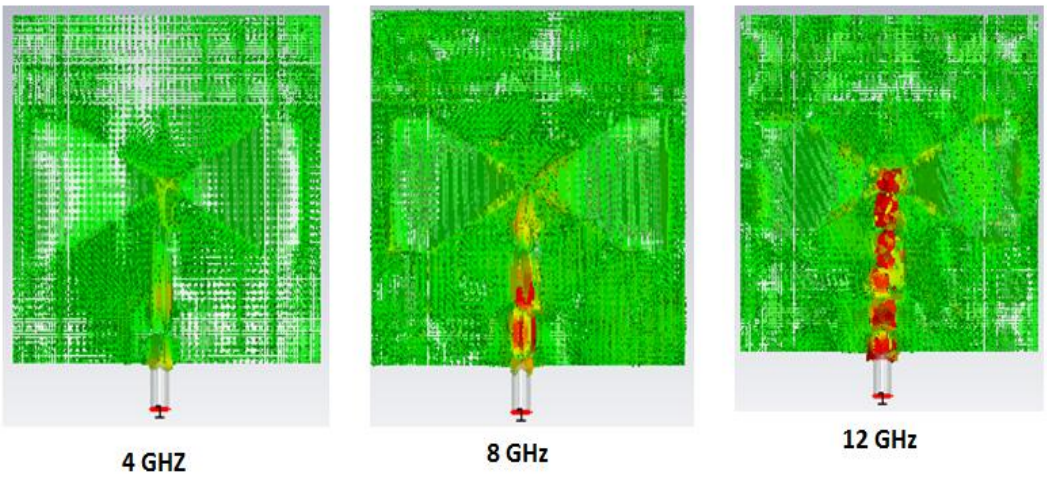
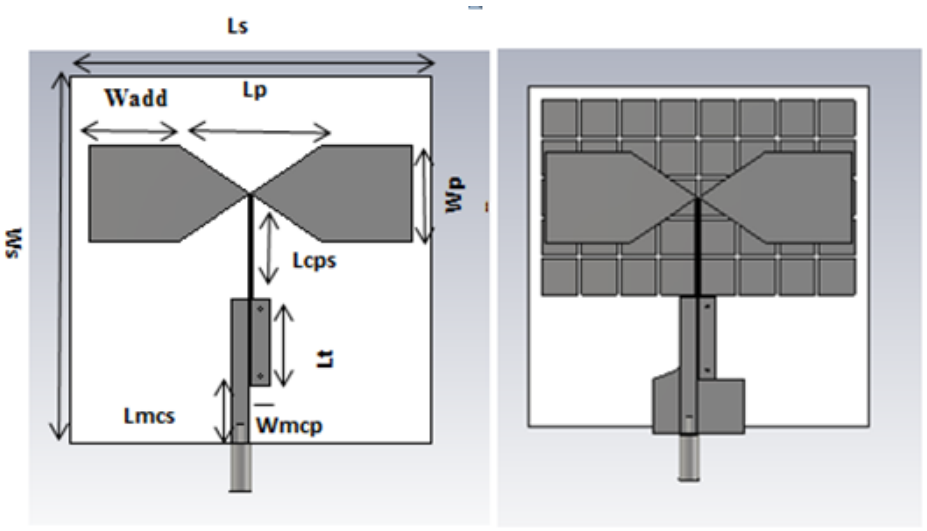


Figure 36 current distribution in AMC 8x8 at: 4 GHz, 8GHz and 12 GHz.



(a) (b)

Figure 37: Dimensions of the overall structure (bowtie + balloon at AMC with 8*5 cells): (a) Top view and (b) Bottom view.

III.6 Prametric study

Antenna structure dimensions affect significantly its performances. A parametric study is done in order to have a reflection coefficient less than -10 dB on the widest possible band (around the C band) with a stable gain.

III.6.1Influence of the parameter Lcps

In this part, we will study the influence of the variation of the length Lcps, on the reflection coefficient and the realized gain in broad side of the antenna as presented in Figure38 and Figure 39. The length Lcps is varied from 16 mm to 22 mm.

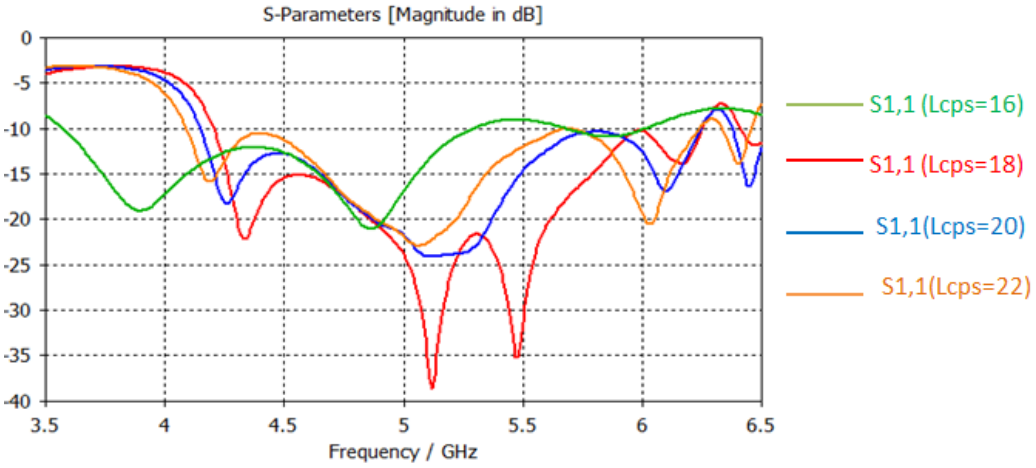


Figure 38: Reflection coefficient of the variation of the parameter Lcps

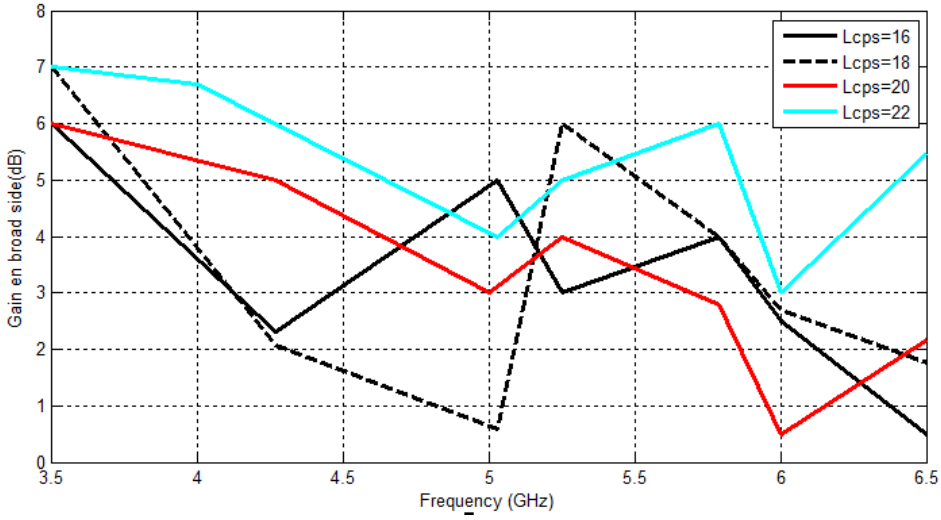


Figure 39: Gain en broad side of the variation of the parameter Lcps.

These results show thatreflection coefficient is less than -10 dB in the C-band for the values 18, 20,and 22 mm. Regarding the realized gain in broadside direction, we observe that we have the best results for whole band for Lcps=22 mm.Therefore we will keep this value for the rest of study.

III.6.2 Influence of the parameter Lp

In this part, we will study the influence of the variation of the length Lp, on the performance of the antenna, presented in Figure 40 and Figure .41. The length Lp is varied from 15mm to 30 mm. This results show that the reflection coefficient is less than -10 dB in the C-band for all Lp values. In the other hand, when Lp decreasesthe realized gain in broadside direction is decreased. Therefore, we will chose Lp=30 mm because it present the maximum gain (between 5.5 and 7.1 dBi in the band 4 to 5.75 GHz).

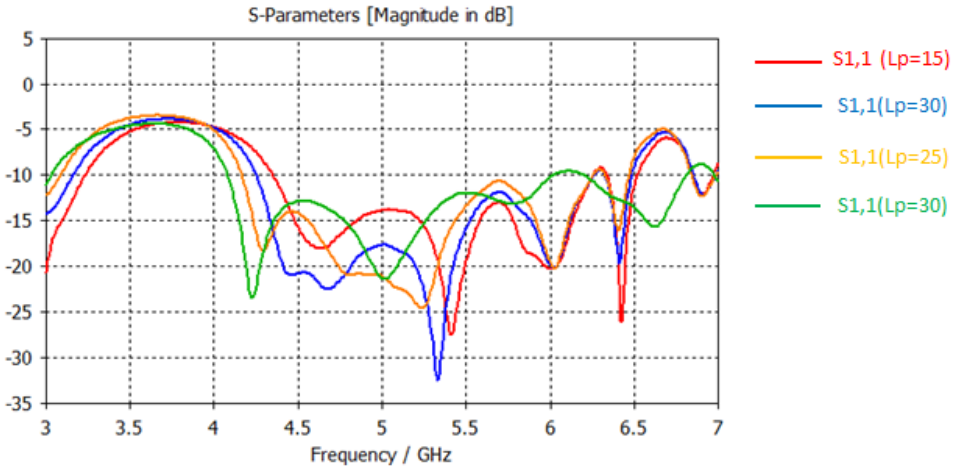


Figure 40: Reflection coefficient of the variation of parameter Lp.

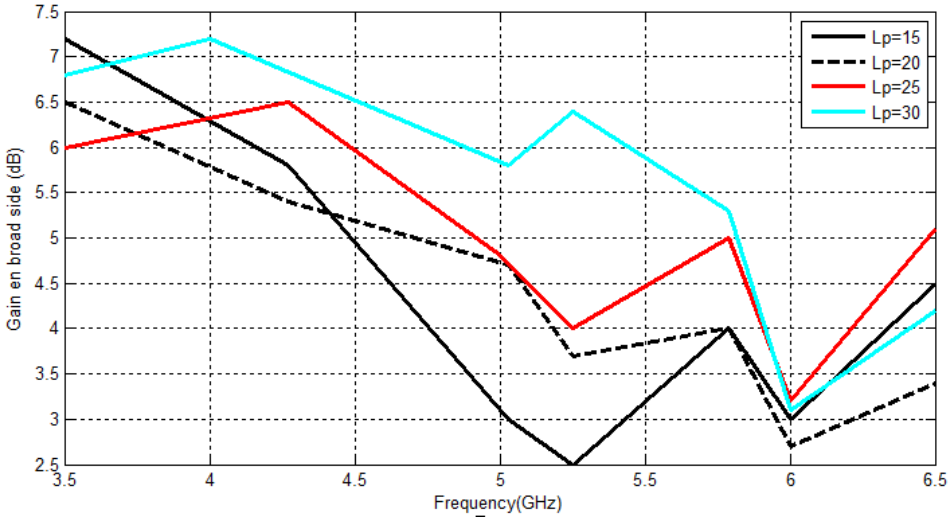


Figure 41: Gain in broad side of the variation of parameter Lp

III.6.3 Influence of the parameter Wp

We will present the influence of the variation of the length Wp on the performance of the antenna, presented in Figure 42 and Figure .43. The length Wp is varied from 15.13mm to 30 .13mm. These results show that reflection coefficient is less than -10 dB in the C-band for the only values 15.13 and 20.13. Regarding the realized gain in broadside direction, we observe that we have the best results for whole band for Lcps=20.13 mm.Therefore we will keep this value for the rest of study.

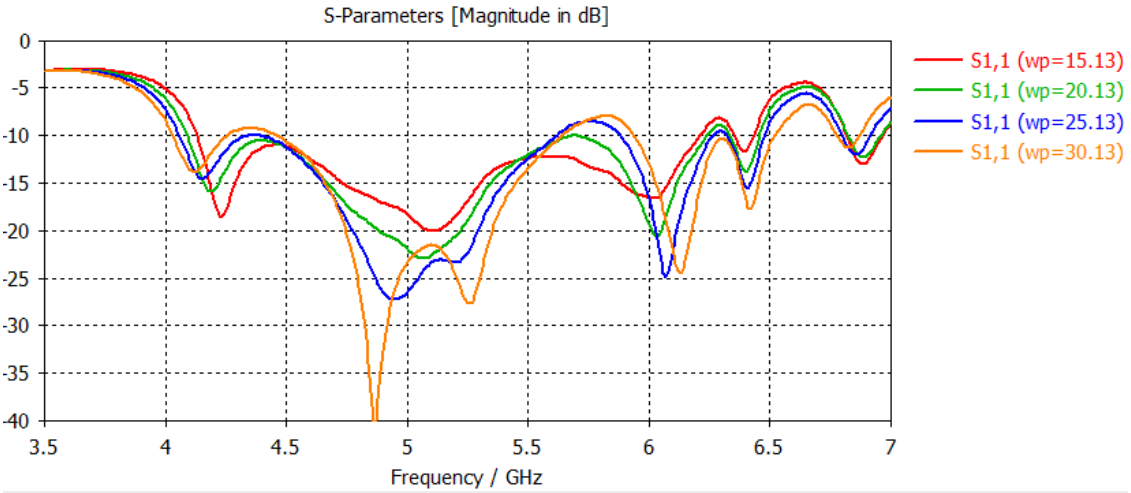


Figure 42: Reflection coefficient of the variation of parameter Wp.

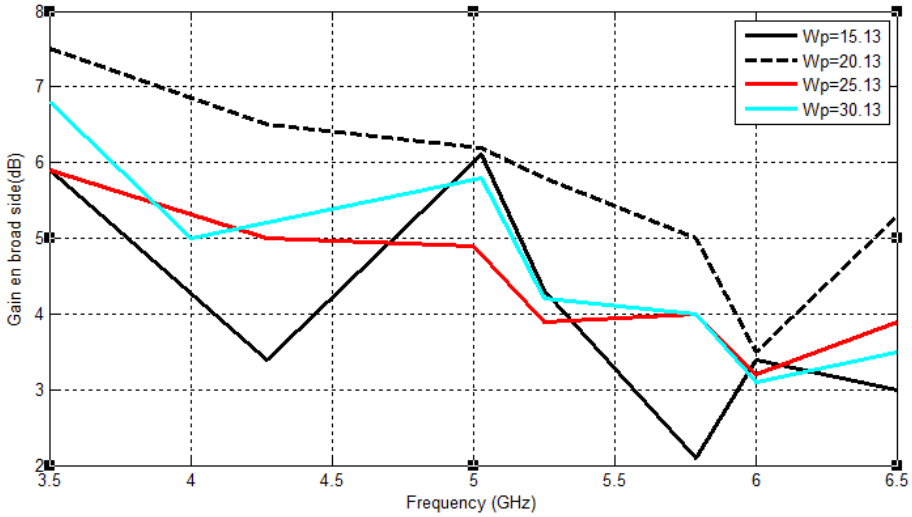


Figure 43: Gain in broad side of the variation of parameter Wp.

III.6.4Influence of the parameter Wadd

Now, we will focus on the influence of the variation of the parameter Wadd on the reflection coefficient and the realized gain in broadside. The length Wadd is varied from 6.66 mm to 24.66 mm, as shown in Figure 44 and Figure 45 . The result shows that all the values of Wadd allow a good marching in the C-band, but the best gain is obtained for when Wadd=18.66mm. Therefore we will keep this value for the rest of study.

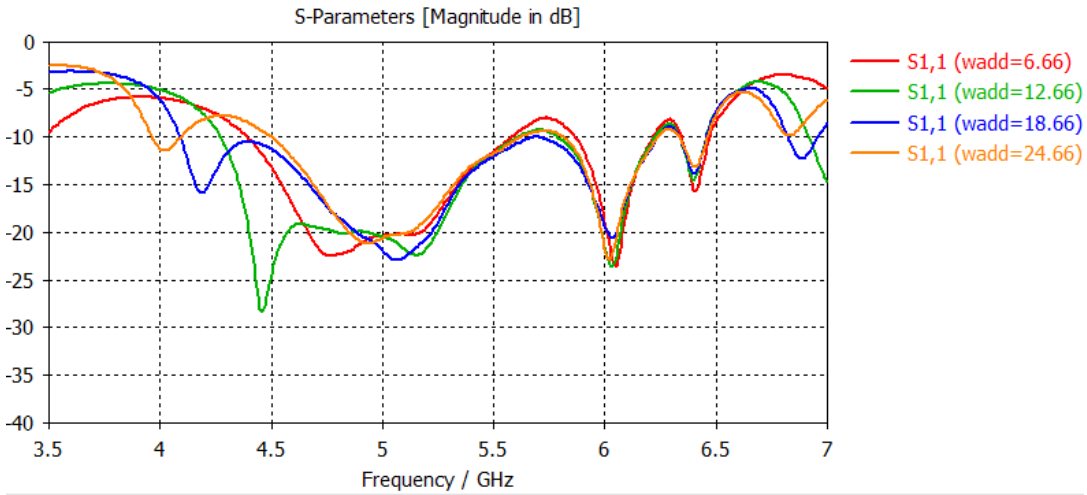


Figure 44: Reflection coefficient of the variation of parameter Wadd.

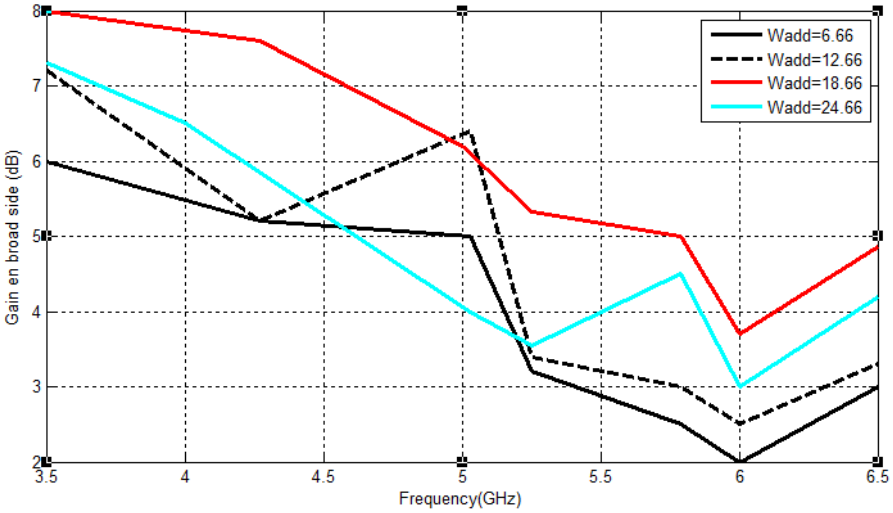


Figure 45: Gain in broad side of the variation of parameter Wadd.

III.6.5 Influence of number of vias

In this section we see reflection coefficient and the realized gain in broadside for different number of vias (2, 3, 4 vias), as shown in Figure 46 and Figure 47. As we can see, there is no significant difference on the impedance matching but a significant enhancement is observed in the realized gain in broadside when we use two vias .

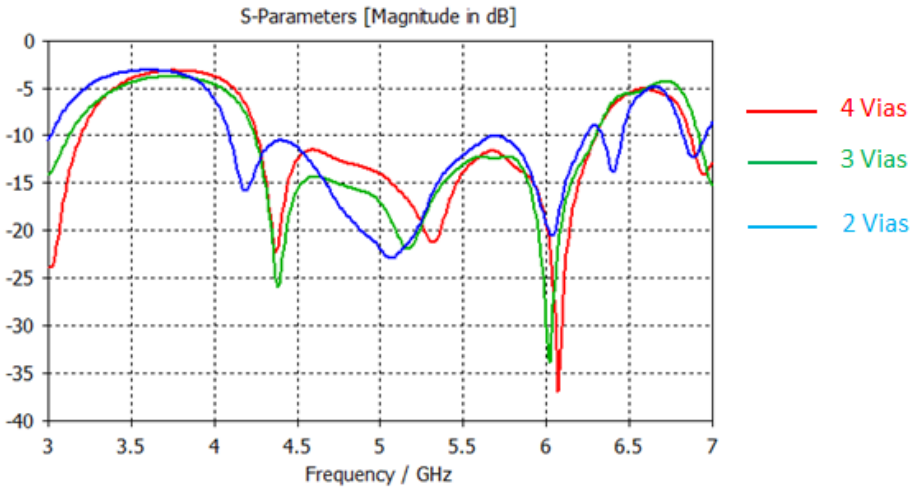


Figure 46 : Reflection coefficient of the variation of vias number.

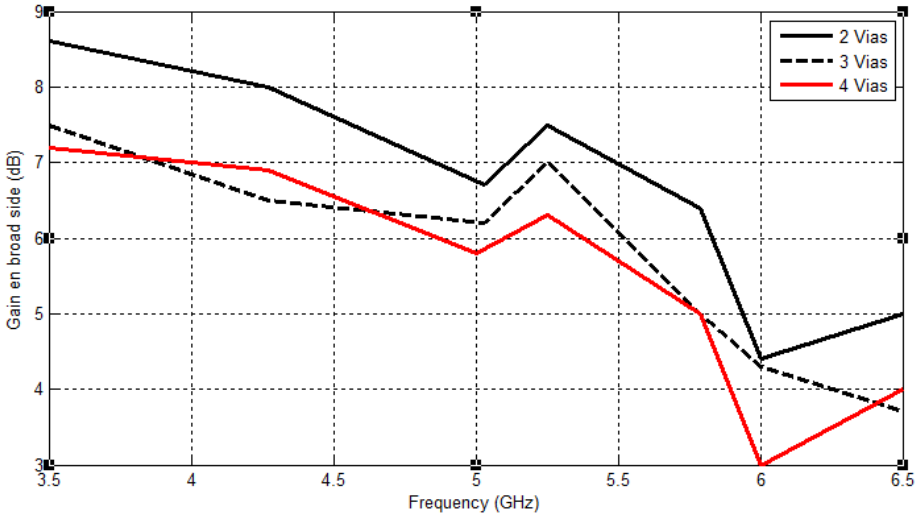


Figure 47: Gain in broad side of the variation of vias number.

III.7 Optimized structure

After the parametric study and optimization, we have obtained the optimal structure.The optimized dimensions of the bow-tie antenna over a AMC with 5*8 calls are as follows: Ls=75 mm, Ws =76.5 mm, gap =0.3mm , Lp=25 mm , Wp=20.13mm ,Lcps=18 mm ,Lt=18mm ,Wcps=0.3mm Lmcs= 12mm ,Wadd=18.66mm, Wmcps=4 mm. Figure.48 shows the simulated magnitude of reflection coefficient performances of the antenna. As seen the simulated bandwidth of this antenna is 2.32 GHz (4.08-6.4 GHz).

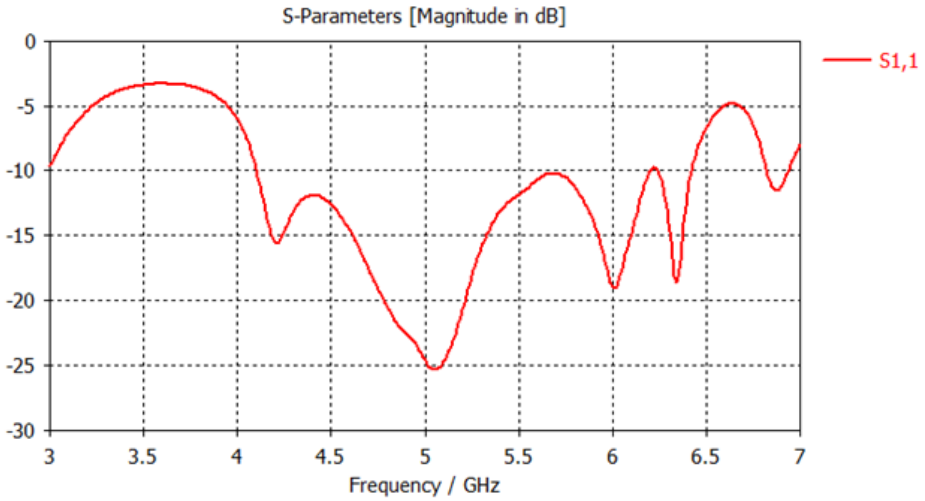


Figure 48: Reflection coefficient of the optimized structure.

In the other hand, a significant improvement is observed in the realized gain of the whole band, as shown in Figure.49. In fact, the comparison of the antenna with and without AMC shows that the gain in broadside increases significantly over the whole band. An improvement of 8 dBi in broadside gain is observed at 4.08 GHz. Maximum gain in the bandwidth is Gmax = 8.8 dB at 4.08 GHz. This is primarily due to the high current concentration on the balun and the bowtie as shown in Figure.50.At 6 GHz, a minimum is observed in the radiation pattern with 4.3 dBi. However, for frequency 6 GHz, the currents are more spread out over the structure leading to the low gain (4.3dBi) as shown in Figure.51. Figure.52 shows the directive radiations patterns of the optimized structure at different frequencies (4.08 GHz, 4.7 GHz, 5.28 GHz, 5.8 GHz and 6.4 GHz.).

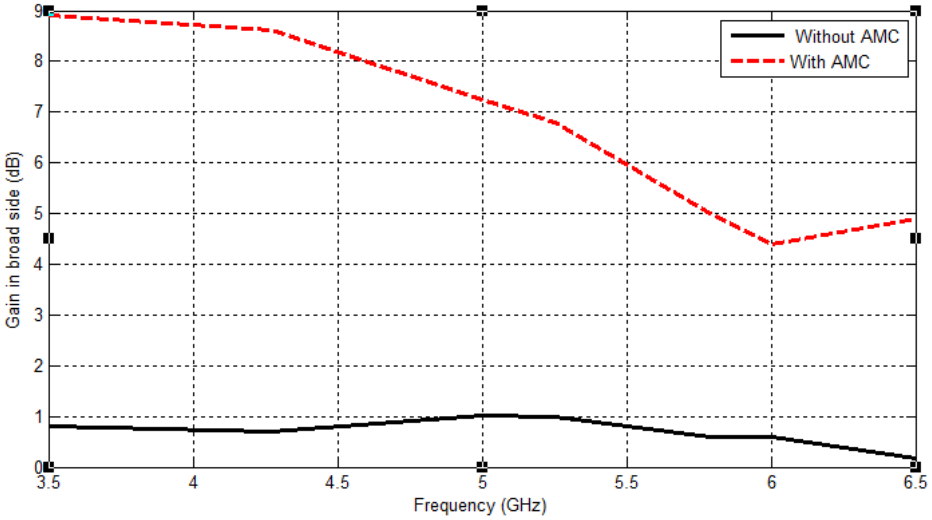


Figure 49: Realized gain vs. frequency in the broadside direction.

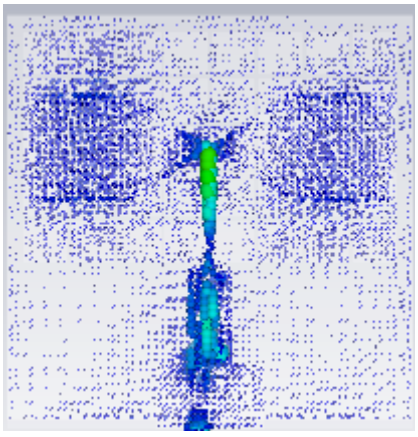


Figure 50 : Current distribution at 4 GHz.

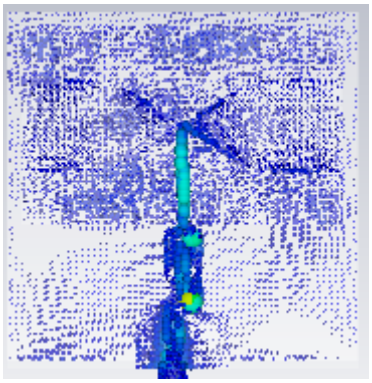


Figure 51: Current distribution at 6 GHz.

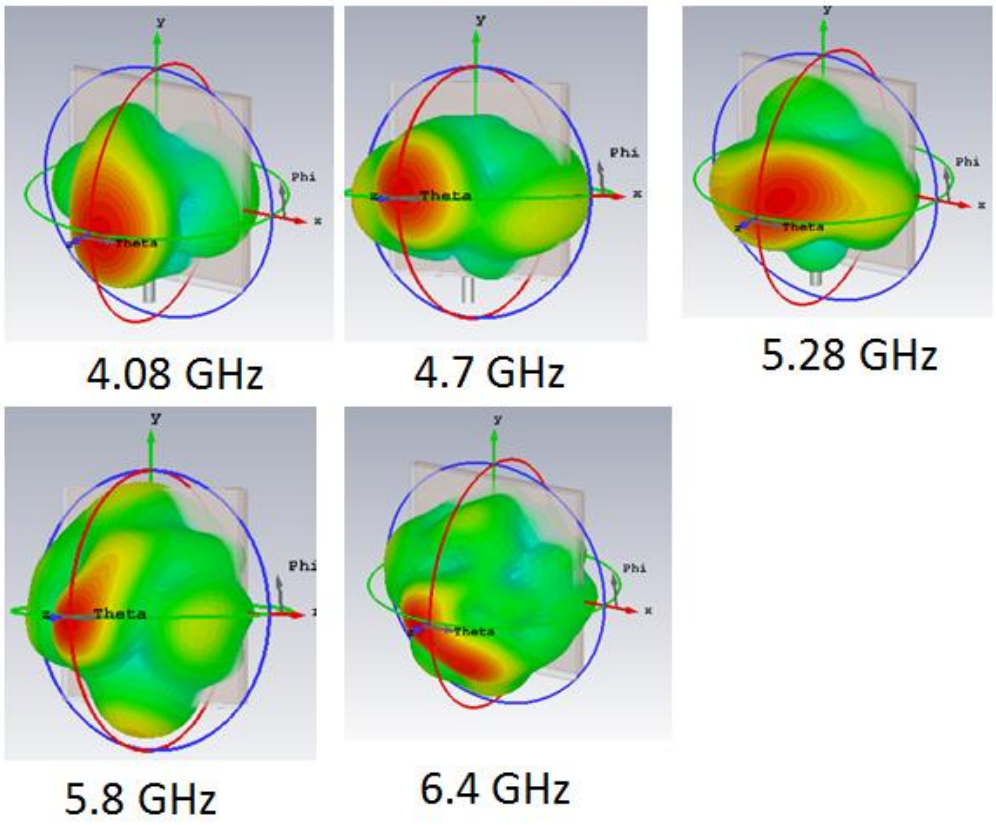


Figure 52: The directive radiations patterns of the optimized structure a t 4.08 GHz, 4.7 GHz, 5.28 GHz, 5.8 GHz and 6.4GHz.

III.8 Conclusion

In this manuscript, Artificial Magnetic Conductor (AMC) reflector is used to improve wideband antennas' performances. AMC is inherently narrow band. However, it has been shown that the bandwidth of AMC-based antennas can exceed the AMC bandwidth alone in terms of impedance matching. Nevertheless, some issues regarding the radiation pattern are reported. In particular, maintaining a high gain value toward a given direction over a wide frequency range is a difficult task. Designing the antenna and the AMC separately does not lead to optimal performances and that adjustment in designs is necessary and done with parametric study. The proposed structure is a compact wideband bowtie antenna with AMC reflector .Besides, its low thickness (λ/10 at the center frequency of operation, i.e. 5.24 GHz), this structure is very simple and low cost. This antenna operates over wide band, is from 4.08 to 6.4 GHz (C band) which suitable for spatial applications. Its radiation patterns are directive and vary from4.3 dBi to 8.8 dBi.

Conclusion and perspectives

The work presented in this manuscript is the design of an antenna with low-profile, high-gain and wide bandwidth for C-band applications such as radar applications and satellite communications. To do this, we first presented the satellite navigation system as well as the satellite communication system. Then we present the different antenna types used in the two space systems. So more applications have frequency deferent required more antennas. In addition, we saw that each application required a specific frequency which needs to have several antennas on the same airborne.Consequently, we propose to use a wideband antenna in order to, avoid using several antennas. In the other hand, an antenna embedded on satelliteneeds to radiate outside the satellite, while preventing the electromagnetic contamination of its internal environment.

According to the EBG definitions and applications, we found that AMC reflector is a good solution to achieve our purpose. A compact wideband bowtie antenna over an AMC reflector of with 5 * 8 cells with dimensions of 75 × 76 × 3.2 mm3, operating in the C-band, is proposed .Besides, its low thickness (λ/10 at the center frequency of operation, i.e. 5.24 GHz), this structure is very simple and low cost. This antenna operates over wide band, is from 4.08 to 6.4 GHz which is suitable for spatial applications. Its radiation patterns are directive and vary from 4.3 dBi to 8.8 dBi in the whole band. Thanks to AMC reflector, an improvement of 8 dBi in broadside gain is achieved.

The perspective of this work is to realize the proposed structure, measured it and validates the simulation results.

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