

WIDE BANDWIDTH MICROSTRIP ANTENNA DESIGNS FOR VARIOUS APPLICATIONS USING PHOTONIC BAND GAP AND DEFECTED GROUND SUBSTRATE METHODS

A thesis submitted towards the partial fulfillment of the requirements

For the award of degree of

MASTER OF ENGINEERING

IN

ELECTRONICS AND COMMUNICATION

Submitted By

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JULY-2016

DECLARATION AND CERTIFICATE


I hereby declare that the thesis entitled “**Wide bandwidth microstrip antenna designs for various applications using photonic band gap and defected ground substrate methods**” is an authentic record of my own work carried out as the requirement for the award of degree of Masters of engineering in ECE at Electronics and Communication Department of Thapar University, Patiala under the guidance of Dr. Jaswinder Kaur (Asst. Prof.), Electronics and Communication Department, Thapar University during the session 2014-2016.

Date: 15 July, 2016

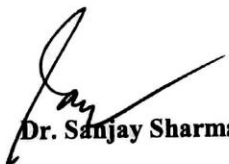

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ACKNOWLEDGEMENT

To discover, analyze and to present something innovative is to endeavor on an ungraded path towards and unexplored destination is an onerous adventure unless one gets a true torch bearer to show the right path. I would have never accomplished in completing my work without the cooperation, encouragement and help provided to me by different people. I am running short of words to reveal my deep regards. I take this opportunity to express my subtle sense of gratitude and respect to all those who supported me through thesis duration. I acknowledge with gratitude and modesty my deficit to **Dr. Jaswinder Kaur (Asst. Prof.)**, Electronics & Communication Engineering Department, Thapar University Patiala under whose direction I had the privilege to complete my thesis. I am really very fortunate to have the opportunity to work with them.

I convey my candid thanks to **Dr. Sanjay Sharma (Head of Department)**, **Dr. Amit Kumar Kohli (PG coordinator)**, entire faculty and staff of Electronics and Communication Engineering Department for their encouragement and cooperation.

I would like to thank my parents for their years of obstinate love and encourage, they have always desired the finest for me and I admire their determination and sacrifice. Above all I render my thanks to the Almighty who bestowed self-confidence, capability and strength in me to bring this work to completion and not letting me down at the time of dilemma. I am greatly obliged to all my friends, who have amicably applied themselves to the task of helping me with abundant moral support and esteemed suggestions helped in successful completion of the present study.



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ABSTRACT

In this modern era, communication has become part and parcel of our lives. Exchange of information over long distances through satellites has also become a vital organ of today's communication system. The current trend in commercial and government communication systems is to develop low cost, minimal weight, low profile antennas which are capable of maintaining high performance over a large range of frequencies. This technological trend has motivated much effort into the design of microstrip patch antennas. With a very simple geometry, these antennas offer many advantages which are not provided by other antenna configurations. For example, they are extremely simple, low profile, lightweight and inexpensive to fabricate using modern printed circuit board (PCB) technology. They are compatible with microwave and millimeter-wave integrated circuits (MMIC) and have the capability to conform to planar and non-planar surfaces. Also, once the shape and mode of operation of the patch are selected, designs become very multipurpose in terms of radiation pattern, operating frequency, polarization, and impedance bandwidth. The variety in designs that is possible with microstrip antennas possibly exceeds that of any other type of antenna element. The rapid advancement in communication industry has increased the demand for development of more novel designs of microstrip antennas capable of operating at more than one frequency bands.

In this thesis work, Transmission line model is used to simulate Microstrip Patch Antenna with the help of microstrip feed line. The aim is to design novel designs of microstrip antennas that are capable of covering a wide range of frequencies. The designing of the proposed antennas is done by utilizing the knowledge of techniques like PBG and DGS in the designs. In this thesis work, different shapes of the patches are discussed like the rectangular shape and circular shape. Various dimensions of the designs like length, thickness and width of the patch, substrate and ground, etc. are optimized for better results. Different types of slots are cut to obtain a wider bandwidth through hit and trial method in the CST 14 Microwave Studio software.

INDEX

S.NO.	CONTENTS	PAGE NO.
	Declaration	i
	Acknowledgement	ii
	Abstract	iii
	Index	iv
	List of figures	vii
	Abbreviations	xii
1	CHAPTER 1 INTRODUCTION	1-20
	1.1 Communication	1
	1.2 Antenna	1
	1.3 Parameters of Antenna	3
	1.4 Microstrip Antenna	5
	1.4.1 Radiation Mechanism	7
	1.4.2 The merits and demerits of microstrip antenna	8
	1.4.3 Applications of microstrip antenna	9
	1.5 Bandgap Structures	9
	1.5.1 Photonic Crystals	10
	1.5.2 Gratings	10
	1.6 Properties of photonic crystals	11
	1.6.1 The unit cell	11
	1.6.2 The bandgap	11
	1.6.3 Antennas with photonic crystal substrates	12
	1.7 Defected ground planes	15
	1.7.1 Defected ground structure	15
	1.7.2 Merit of DGS	16
	1.7.3 Difference between DGS and PBG	17
	1.7.4 Flowchart for design methodology using DGS	18
	1.8 Work covered in Thesis	19

1.9	Thesis Outline	19
1.10	Conclusion	20
2	CHAPTER 2 LITERATURE SURVEY	21-25
2.1	Progress	21
2.2	Thesis Objective	24
2.3	Conclusion	25
3	CHAPTER 3 DESIGN AND ANALYSIS OF A NOVEL KU-BAND MICROSTRIP ANTENNA WITH PBG SUBSTRATE	26-32
3.1	Introduction	26
3.1.1	Advantages of Ku-band	26
3.2	Antenna design	27
3.3	Results	27
3.3.1	Return loss	27
3.3.2	Current distribution results	30
3.3.3	VSWR	31
3.3.4	Gain	32
3.4	Fabrication and measurement results	32
3.5	Conclusion	32
4	CHAPTER 4 A NOVEL SLOTTED MICROSTRIP PATCH ANTENNA WITH SUPER WIDE-BAND (SWB) PERFORMANCE FEASIBLE FOR WIRELESS APPLICATIONS	33-41
4.1	Introduction	33
4.1.1	Advantages and benefits of UWB communication	34
4.2	Antenna design	35
4.3	Results	36
4.3.1	Return loss	36
4.3.2	Current Distribution	38
4.4	Fabrication and measurement results	39

4.5	Conclusion	41
5	CHAPTER 5 A NOVEL CIRCULAR PATCH MICROSTRIP ANTENNA WITH DGS FOR E,G,X AND KU-BAND APPLICATIONS	42-52
5.1	Introduction	42
5.2	Antenna design	43
5.3	Results	45
5.3.1	Return Loss	45
5.3.2	Current Distribution Results	47
5.3.3	VSWR	48
5.3.4	Gain	49
5.3.5	Directivity	49
5.4	Fabrication and measurement results	50
5.5	Conclusion	52
6	CHAPTER 6 CONCLUSION AND FUTURE SCOPE	53-55
6.1	Conclusion	53
6.2	Scope for future work	55
	LIST OF PUBLICATIONS	56
	REFERENCES	57-63

LIST OF FIGURES

Figure no.	Diagrams	Page no.
1	Symbol for antenna	2
2	Geometry of microstrip patch antenna	6
3	Fringing fields	8
4	Three types of photonic crystals	10
5	Gratings	11
6	Transmission loss plot demonstrating a bandgap in a microstrip transmission Line at microwave frequencies	12
7	Illustration of Cross-sectional view of a Patch Antenna radiating from a thick PBG	13
8	Front view of design without PBG Substrate and non-defected ground	28
9	Simulation results for the design with no PBG and no defect in the ground	28
10	Front view of design with long strip acting as a patch and feed	28
11	Back view with a rectangular slot of same dimensions as was the patch earlier	29
12	Simulated results of the above design with rectangular slot in the ground	29
13	Front view of the final design with grooves in the substrate	29
14	Simulated results of the above design with PBG in the substrate	30
15	Illustration of current distribution results at 14.403GHz (a) Front view	30-31

	(b) Back view	
16	VSWR versus frequency plot for the proposed design	31
17	Gain plot	32
18	Front view of the proposed design	35
19	Back view of the proposed design	36
20	Reflection coefficient versus frequency plots	36-37
	(a) With slots 3,4 but without slots 1 and 2	
	(b) With slots 1,2,3 and 4 in the patch on FR4 substrate	
	(c) With slots 1,2,3,4 in the patch on Rogers material substrate	
21	Current distribution results	38
	(a) Current distribution result at frequency 15.5GHz	
	(b) Current distribution result at frequency 12GHz	
22	Photograph of the proposed antenna	39
	(a.) Front view	
	(b.) Back view	
23	Measured results from network analyzer	40
24	Front view of the proposed design	44
25	Back view of the proposed design	45
26	Simulated reflection coefficient versus frequency plots	46
	(a) Circular MPA without rectangular slot and without DGS	
	(b) Circular MPA with DGS but without any slot in patch	

	(c) Circular MPA with DGS and Rectangular slot in the patch	
27	Surface Current distribution results for the proposed antenna design (a.)At resonating frequency 5.25GHz (b.)At resonating frequency 12.3GHz	47
28	VSWR plot for the proposed design	49
29	Gain versus frequency plot of the proposed design	49
30	(a.)Directivity plot at 5.25GHz (b.)Directivity plot at 12.3GHz	50 50
31	(a.)Photograph of the antenna from front (b.)Photograph of the antenna from back	51 51
32	Comparison of simulated and measured results	52

LIST OF TABLES

Table no.	Description	Page no.
1	Difference between DGS and PBG	17
2	Frequency bands and their applications	33-34
3	Frequency bands	42

ABBREVIATIONS

MPA	Microstrip Patch Antenna
DGS	Defected Ground Structure
PBG	Photonic Band Gap
CST	Computer Simulation Technology
EBG	Electromagnetic Band Gap
RF	Radio Frequency
VSWR	Voltage Standing Wave Ratio
RL	Return Loss
EM	Electromagnetic
EMI	Electromagnetic Interference
KU	Kurtz-Under
UWB	Ultra-Wide Band

CHAPTER 1

INTRODUCTION

The word “Communication” is drawn from the Latin word “Communis” which means common. It is defined as the means by which we exchange information. Starting from use of pigeons, drums, smoke, flags, etc. in the early times, we have come a long way in this field. Today, through wireless communication we can convey our messages to anyone sitting in any part of the world. For long distance exchange of information i.e., at different locations on the earth, satellite communication is used. In satellite communication, signal transfer and reception is done through satellites. Before satellites, long distance communication was very difficult and nearly impossible. Antenna is the most noticeable part in this system of communication.

1.1 COMMUNICATION

Nowadays, the wireless system has become an indispensable part of human life. Most of the electrical and electronics equipment around us are based on wireless technology. Antenna is an electrical device which transmits the electromagnetic (EM) waves into space by converting the electrical power at the input into the radio waves and at the receiver side the antenna intercepts these radio waves and converts them back into the electrical power. Antenna is used in numerous systems such as cellular phones, wireless phones, remote controlled television, satellite communication, spacecraft, radars and wireless computer networks. Everyday new wireless devices come up which have increased the demand of compact antennas. Advancement in the field of satellite communication and use of antennas in the spacecraft and aircraft applications has also increased the demand of a low profile antenna that can provide a reliable communication.

1.2 ANTENNA

An aerial or antenna is a transducer which converts electrical power into radio waves, and vice-versa. Fig.1 depicts the symbol for antenna or aerial. The first antenna was created

by Heinrich Hertz in 1888. All radio frequency equipment employ antennas for their operation. Antennas are used for transmission as well as reception of signals. They are used in broadcast television, radar, RFIDs, wireless cellular networks, satellite communication, etc. Antennas may be Omni-directional (radiate equally in all d horizontal directions) or directional (radiate in a particular direction and have high-gain).



Fig.1: Symbol for antenna

Different types of antenna are:

(i) Monopole:

A type of radio antenna that comprises of a straight rod-shaped conductor that is often mounted perpendicularly over some sort of conducting surface (called ground plane) is known as monopole antenna.

(ii) Dipole

A straight electrical conductor measuring half wavelength from one end to the other and connected at the center to a radio-frequency feed line is called a dipole antenna. A half-wave antenna (also known as a dipole, Hertz, or doublet) consists of two lengths of wire rod each one-fourth wavelength long at a certain frequency. It is the basic unit from which various complex antennas are constructed.

(iii) Array

A group of individual antennas employed for transmitting and/or receiving radio waves is known as an antenna array. Individual antennas in an array are connected together in such a way that their individual currents are in specific amplitude and phase relationship.

(iv) Loop

A radio antenna comprising of a loop (or loops) of wire or any other electrical conductor with its ends connected to a balanced transmission line (perhaps via a balun) is called a loop antenna. These antennas have high reactance and low radiation resistance, so that their impedance is hard to match to a transmitter.

(v) Aperture

The open-ended waveguide, slotted waveguide, horn antennas, and reflectors are all different types of aperture antennas. They are typically created with dielectric and metal walls, usually with ridges. Feed pins or waveguide ports are used for excitation.

(vi) Travelling Wave

In telecommunication and radio, a traveling-wave antenna is a type of antenna in which radiating mechanism is through wave traveling on a guiding structure. Their unique feature is that the radio-frequency current that generates the radio waves travels through the antenna in only one direction. This is in distinction to a resonant antenna, such as the monopole or dipole, in which the antenna acts as a resonator, with radio waves/currents traveling in both directions, bouncing back and forth between the ends of the antenna. An advantage of traveling wave antennas is that since they are not resonant, therefore they often have a wider bandwidth than resonant antennas. Some common examples of traveling wave antenna are the rhombic antenna and the Beverage antenna.

1.3 Parameters of Antenna

There are various parameters of antenna which are employed for assessing the efficient functioning of the antenna. Few antenna parameters are as follows:

1. Return Loss: The loss in power of the signal that is reflected due to discontinuity in the transmission line is known as return loss. As we know, when impedance matching between the transmitter and antenna is imperfect, the radiations within the substrate cause standing waves. Accordingly, the return loss is similar to VSWR that indicates the perfect

impedance matching between the transmitter and the antenna. The return loss is formulated as

$$RL = -20 \log_{10} (P_i/P_r)$$

Where P_i = Incident power

P_r = Reflected power

2. Voltage Standing Wave Ratio (VSWR): It states that how well the matching takes place between antenna and transmission line and the receiver which illustrates the maximum energy transfer. Imperfect impedance matching results into reflected back waves approaching the transmitter. The interplay between the reflected waves and the forward waves results into standing waves.

$$VSWR = (1 + \Gamma) / (1 - \Gamma)$$

Where Γ = Reflection coefficient

Ideally, VSWR = 1 is perfectly matched, that is no power is reflected back.

3. Smith Chart: It was created by Phillip H. Smith and is a wonderful tool for viewing the impedance of the transmission line and antenna working as a function of frequency. They are exceptionally advantageous for impedance matching. The complex reflection coefficient denoted by Γ for the load impedance Z_L attached to the transmission line with characteristic impedance Z_0 is represented by:

$$\Gamma = (Z_L - Z_0) / (Z_L + Z_0)$$

We represent all the values of Γ on the real and imaginary axis. The center point denotes the point where the reflection coefficient is zero.

4. Directivity: The measure of directionality of an antennas radiation pattern is known as directivity. An antenna which radiates evenly in every direction has directivity equal to 1 or 0 dB. It is also defined as the radiation intensity in a given direction from the antenna divided by the radiation intensity averaged over every direction. Analytically, it is represented as

$$D = U / U_0 = 4\pi U / P_{rad}$$

U = radiation intensity (power density per unit solid angle)

U_0 = radiation intensity of isotropic source (power density per unit solid angle)

P_{rad} = total radiated power (W)

5. Radiation Pattern: It can be described as “a mathematical function or graphical representation of the variation of the power radiated by an antenna as a function of the direction away from the antenna”. We can also say that the radiation pattern is a graphical or directional dependence of the relative strength of the radio waves transmitted from or received by the antenna or any other source. The plot is typically shown as a three dimensional graph or as a separate graphs in vertical or horizontal plane. It is basically depicted on a linear scale or in dB.

6. Gain: It is relative measure of an antennas ability to direct RF energy in particular direction. It is defined as how much power is transmitted in the direction of peak radiation to that of an isotropic source. Mathematically it is be represented as

$$\text{Gain} = 4\pi U/P_{\text{in}}$$

U = radiation intensity

P_{in} = total input power

1.4 Microstrip Antenna

Antenna engineering is an imperative ground that is erupting with nonstop activities which are going to increase in the coming future. Numerous antenna designs have been made to meet our increasing demands. An example of this is Microstrip antenna.

The microstrip antennas were first proposed in 1950s but serious advancement in this field had begun in 1970s after development of printed circuit technology. They are also known as patch antennas. Microstrip patch antennas or simply patch antennas are most commonly used. After years of research, it was found that the working of a microstrip antenna depends on the characteristics of the printed patch and also on the features of the substrate (such as material used) onto which it is printed. A patch antenna is fabricated by etching the antenna element pattern in metal trace attached to an insulating dielectric

surface, such as a printed board, with a metal layer on the opposite side forming ground plane. Though patch antenna is similar in operation the transmission line but it is much larger in volume than the latter.

As depicted in the Fig.2, the upper layer called “patch” is the source of radiation where electromagnetic energy fringes off the edges of the patch and into the substrate. The lower conduction layer called “ground” acts as a perfectly reflecting surface bouncing energy back through the substrate into the free space.

Mostly patches are in rectangular or circular shape though any shape is workable. Selection of material for substrate is based on the desired performance over particular frequency range. Materials used for substrate are easily obtainable for use at radio frequency and microwave frequencies, specifically for designing printed circuits as well as microstrip antennas. For operation at frequencies from 1 GHz to 100 GHz, values of dielectric constants for substrate materials range from 2.2 to 12.

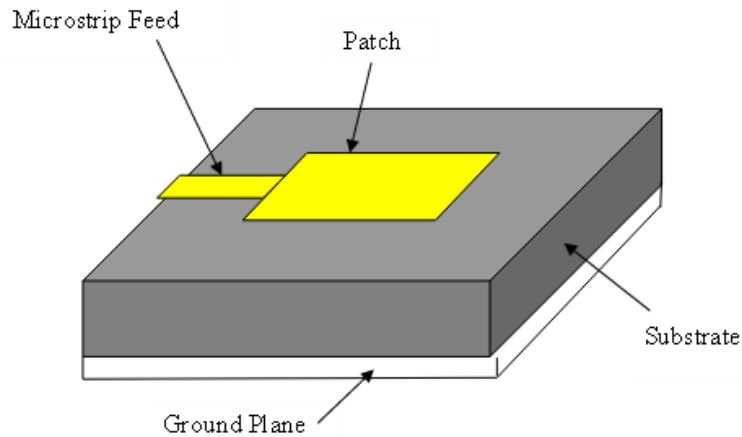


Fig.2: Geometry of microstrip patch antenna [54]

The thickness of substrate has a key role to play in the process of designing microstrip antennas. Substrates that are thick and have small value of dielectric constant are the most desirable ones. Such substrates in antennas produce high efficiency and large bandwidth results because of loosely attached fringing fields that are radiated from the patch and that further spread into the substrate. But, such results come at the price of surface wave formation and increased volume of antenna. Substrates that are thin and

have high dielectric constants have the advantage of being small in size but they produce low bandwidth and less efficient results. Because fringing fields are closely attached to the substrate in such antennas, they are compatible with MMIC devices. Electromagnetic interference (EMI) and coupling issues are also less likely to occur. So, there is a tradeoff that must be kept in mind while designing microstrip antennas that is, to get loosely attached fields that radiate into free space and also holding them closely attached to the feeding circuitry so as to avoid EMI.

1.4.1 Radiation Mechanism

In the year 1969, Denlinger noticed that if the microstrip line is left open on one end and fed on the other end then because of this discontinuity, some part of the power is radiated into space from both the ends as EM waves. He also understood when both the discontinuities are separated by half wavelength or a multiple of half of wavelength from each other, and then the volume of power radiated into space is at its maximum value. Denlinger deduced that radiations take place from the open end because of the fringing fields that occur from the discontinuity. To study the radiation mechanism of the microstrip antenna, consider a rectangular antenna with a half wavelength long patch. Feeding of this patch is done by microstrip feed line. A rectangular antenna can be thought of as a microstrip line left open ended on one side and energy is provided from the other end. Given that the patch is half wavelength long and is left open ended on the other side, there is zero current at the beginning and end of the patch zero and is at its maximum value at the center of the patch. Voltage and current will be 90 degree out of phase. The voltage will be maximum negative at the end and maximum positive at the starting of patch.[44]

The distribution of field along the patch is shown in the figure below. The field lines below the patch near corners are opposite in direction. This field lines do not stop suddenly at the end. At the corners the field lines are in bow shape fringing fields are created. More the fringing field bow more is the radiation. Thus, these fringing fields are the reason behind the radiation from the microstrip antenna.

Fig.3 on next page illustrates the fringing fields.

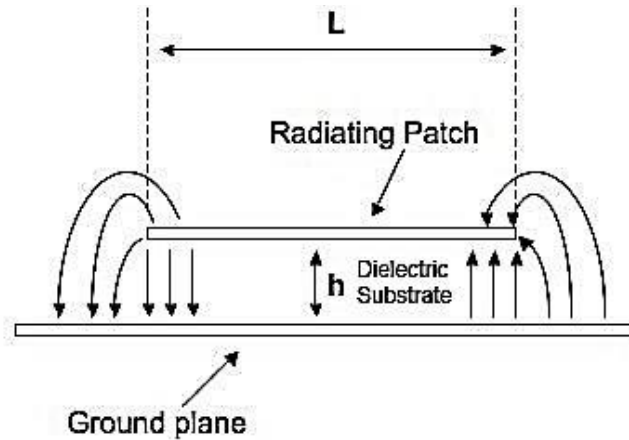


Fig.3: Fringing fields [57]

1.4.2 The Merits and Demerits of Microstrip Antenna

Microstrip antennas have various benefits in comparison to the typical microwave antennas and have many functions that include the broad range of frequency from approximately 100 MHz to 100 GHz. The following advantages are:

- (i) Light weight, low volume, thin structural compositions
- (ii) Both linear and circular polarization is attainable due to simplified feeding technique
- (iii) Low cost of fabrication, easily agreeable to production on a large scale
- (iv) Can be unified with microwave integrated circuits easily
- (v) Dual frequency and dual polarization antennas can be fabricated without difficulty
- (vi) Simultaneously fabrication of feed lines and matching networks along with the antenna configuration

On the other hand, some limitations also exist in comparison to the typical antennas which are as follows:

- (i) Limited bandwidth and correlated tolerance difficulties
- (ii) Enormous ohmic losses
- (iii) Lesser gain of approximately 6 dB
- (iv) Some feeding techniques required for high performance arrays are complicated

- (v) Many of the microstrip antennas emanate into half-space
- (vi) Purity of polarization is cumbersome to achieve
- (vii) Indigent end-fire radiator, except tapered slot antenna
- (viii) Intrinsic radiations from different feed and connections
- (ix) Inferior capability of power handling
- (x) Excitation of surface waves
- (xi) Microstrip antenna attached on a substrate with high value of dielectric constant is mostly preferred for easy integration with MMIC RF front-end circuitry. Use of substrate with high value of dielectric constant gives limited bandwidth and inferior efficiency.

1.4.3 Applications of Microstrip Antenna

The applications of microstrip antenna include a broad range from transportation, communication to biomedical. [2]

- (i) Airplanes and pinnace antennas - Communication and navigation, blind landing
- (ii) Satellite communications – TV broadcasting, whip antennas
- (iii) Missiles systems - Radar, contiguity fuses and telemetry
- (iv) Remote sensing – archaeological surveying
- (v) Mobile communication - radio Pagers and hand phones, resolve light weight man pack jammers or systems, mobile vehicle
- (vi) Biomedical Applications - microwave hyperthermia
- (vii) Additional applications - Interloper alarms, personal communication etc.

1.5 Bandgap Structures

The latest technology of using bandgap substrates is used to make microstrip antennas with ultra-wide bands. In this technique, the substrate gets manipulated in a way that the formation of surface waves is totally prohibited which results in improvements in

bandwidth and efficiency of antenna, at the same time also reduces EMI. Such substrates have Photonic crystals.

1.5.1 Photonic Crystals

The groups of periodic dielectric, metallic, or composite structures that exhibit a prohibited band of frequencies in which waves incident at various directions destructively interfere and therefore are unable to propagate, are called photonic crystals. Photonic crystals can be 1D, 2D or 3D. The defining feature is the periodicity of the dielectric material along one or more axes. The degree of complexity increases as the dimensions increase.

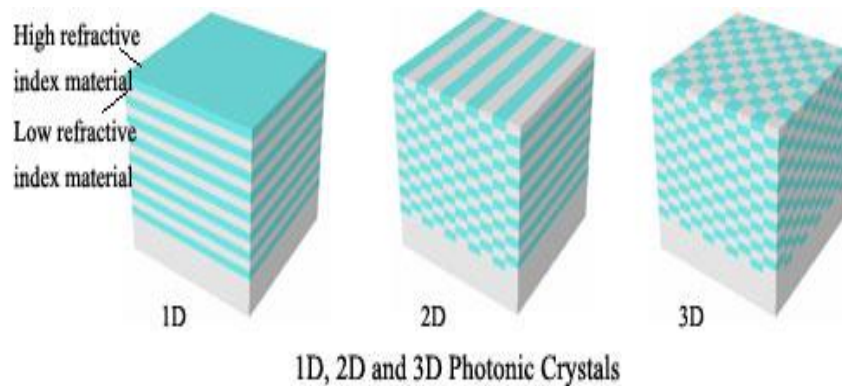


Fig.4: Three types of photonic crystals [44]

An example of one-dimensional photonic crystal is multilayer thin film (shown in the figure). The photonic band gap increases with the increase in dielectric contrast.

Eli Yablonovitch made the first photonic crystal structure in 1991 at Bell Communication research in New Jersey. In this structure, he mechanically drilled a millimeter diameter holes into a high dielectric constant material. It showed a 3-D bandgap, since microwave signals incident on it were forbidden from spreading in any direction along a unit sphere. This first 3-D photonic crystal structure is known as “Yablonovite”.

1.5.2 Gratings

A classic optical grating is a 1-D periodic structure comprising of a series of equally spaced grooves. When light (electromagnetic waves) is incident onto a grating surface, it

can be diffracted by the grooves. Each groove acts as a very small source of reflected or transmitted light. Fig.5 illustrates gratings.

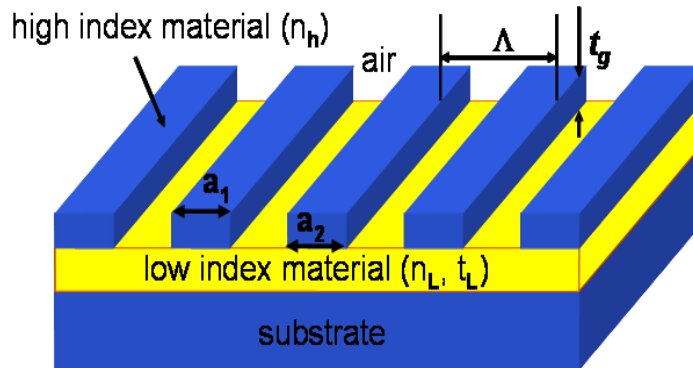


Fig.5: Gratings [44]

1.6 Properties of Photonic Crystals

1.6.1 Unit Cell

According to the American Heritage Dictionary, a crystal is a homogeneous solid formed by a repeating, three-dimensional pattern of atoms or molecules or any other shape which has a fixed distance between the constituent parts. This imitating arrangement is known as unit cell of the crystal. Location and range of the bandgap depends on this repeating unit cell.

1.6.2 The Bandgap

When an electromagnetic field (that is incident on the crystal) travels with a wavelength (guide) nearly same as the lattice spacing in the crystal, a bandgap is achieved in a high dielectric constant material with integrated photonic crystals. This approximate estimate traces the center of the bandgap, which ranges above $\pm 10\%$ of the center frequency for materials with high dielectric constant. For a 2-port network, a classic transmission coefficient plot is similar to a microstrip transmission line, which is fabricated on a photonic crystal substrate as shown in the Fig.6. The curve in the plot shows that when excitation is provided to port 1 of the transmission line, above 20dB of

attenuation is suffered as the energy moves from port 1 to port 2. Therefore, a stopband filter response is presented by the photonic crystal.

In fact, the creation of the bandgap not only depends on the crystal periodicity, but it depends on the ratios of refractive index between the substrate material and the impurities that create the crystal also. Normally, this ratio should be at least 2:1 for the existence of the bandgap. For the triangular structure in 2-D, the broadest bandgap is attainable when the impurities are of air with low dielectric constant ($\epsilon_r = 1$), while the base (substrate) material is a high dielectric constant value (like, $\epsilon_r = 10$). A 3.16:1 refractive index ratio with proper crystal spacing would fulfill this refractive index requirement and form a proper broad bandgap. This clarifies the requirement of a substrate with high dielectric constant value for microstrip patch antennas designed on a photonic crystal substrate.

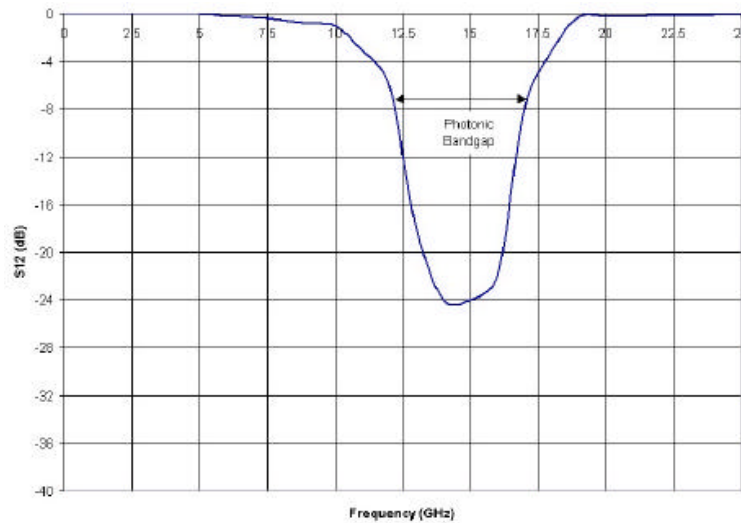


Fig.6: Transmission loss plot demonstrating a bandgap in a microstrip transmission line at microwave frequencies [44]

1.6.3 Antennas with Photonic Crystal Substrates

Since the photonic crystals and their respective bandgaps have the power to absolutely prohibit the propagation of electromagnetic power at particular frequencies, they connect well with the progress of next-generation microstrip antennas. Inclusion of photonic crystals into the substrate does not alter any of the basic trade-offs of these antennas. So,

an antenna designer should choose between utilizing a thin or thick substrate. Therefore, for the bandgap to exist, the refractive index ratio between the substrate and crystals should be greater than 2:1. This is the only necessity. The following segment shows comparison of two methods of using photonic crystals technique into patch antenna designs. The two approaches make use of thick and thin substrate.

(a) Thick Substrates

The idea of designing microstrip antennas on a thick photonic crystal substrate is to use quasi-3D bandgaps to radiate electromagnetic field from the antenna, without employing a ground plane. The ground plane can be removed since the 3D bandgap creates an equivalent ground because of total internal reflections produced by the high refractive index ratios in the vertical axis as shown in the figure.

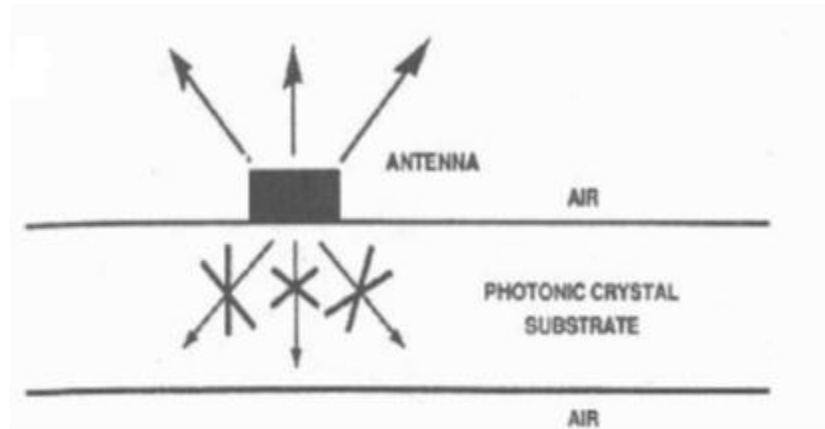


Fig.7: Illustration of a patch antenna radiating from a thick PBG (cross-sectional view)

[44]

Brown et al. did a research, in which a patch antenna with thick substrate was made using a triangular photonic crystal, which is coherent with the figure. These crystals have 2-D periodicity, like for example in the XY plane, forming a 2D bandgap. As a result of total internal reflection, there is a third dimension of periodicity at specific angles of incidence (greater than the critical angle), electromagnetic waves that transverse through a high permittivity material (substrate) into to a lower permittivity material (air) would, ideally, perfectly reflect and become contained within the higher permittivity material. This is

known as a “quasi-3D bandgap” because the energy is allowed to travel at angles lower than the critical angle.

The ground plane can be eliminated because of this third dimension in the bandgap. In a comparison study, when photonic crystals were introduced into the substrate of a basic microstrip antenna Brown came across improvements in the surface wave reduction. In his journal article 36, he also conveyed a reduction in back radiation with a front-to-back pattern ratio of 24 dB, unlike 12 dB that was obtained for the conventional microstrip patch antenna.

In spite of the enhancements known in his study, it was found that this type of antenna is not very practical. The very first reason is that the thicknesses of substrate needed for these antennas are more than eight centimeters for 13.2 GHz frequency. This substrate size is too large at such high frequencies for most standards, making the substrate of a significant size compared to the patch. Second reason is that due the lack of a ground plane many grounding complications occur during antenna feeding. Since microstrips require a ground plane for operation, the direct-coupled microstrip feed is removed. As a result, the antenna is limited to only the proximity coupled and coaxial probe feeds. To overcome these problems, antennas designed on thin substrates including photonic crystals were also examined.

(b)Thin Substrates

The idea of utilizing thin substrates comprising of photonic crystals in microwave devices designing was first considered in 1998 by Radisic et al. In that method fabrication of microstrip filters was done by etching a (two-dimensional) triangular pattern into the ground of a regular microstrip line. As a result, around 100% reflection loss over a range of frequencies was obtained governed by the lattice spacing, in contrast to the 100% transmission that was hoped to obtain from the microstrip line.

The designs with thin substrates give similar results to that of the designs with thick substrates. The only drawback is that the bandgap is demoted to two dimensions. Total internal reflections condition is sacrificed because of the presence of the ground.

1.7 Defected Ground Planes

Because of their interesting features such as size miniaturization, arbitrary stop bands and suppression of surface waves, etc. defected ground planes have gained the attention of numerous researchers,. They have been utilized in numerous applications till date like antennas; waveguides, low pass and band pass filters, etc. Also, this technique can also enhance and increase not only the bandwidth but the resonant frequency of the antenna too. For example, a DGS unit cell is a defect deliberately designed on the ground plane of the antenna structure, which builds extra effective inductance and capacitance. This method could be utilized for designing microstrip lines with required features such as band rejection, size reduction higher impedance and slow-wave characteristics. The first DGS announced in 1999 was the dumbbell shaped DGS. Ever since then, this practice has gathered a lot of interest from number of researchers. Variety of DGS slot shapes have been explored in patch antenna designs, which provide number of good performance characteristics such as size reduction, impedance bandwidth enhancement and increase in gain. Furthermore, DGS is also useful in lessening the mutual coupling between the arrays of antenna. Also, it has the ability to eliminate the harmonics and improve the return loss level.

1.7.1 Defected Ground Structure

DGS was formed to improve the characteristic features of patch antennas and microwave devices. Although it has many merits in the field of the microwave filter design, amplifiers, oscillators, couplers to increase the coupling, etc., it is also used in the microstrip antenna design for various applications such as reduction in size of antenna, cross polarization reduction, decline of mutual coupling in antenna arrays and harmonic suppression, etc.

The DGS is encouraged by the study of Photonic/ Electromagnetic Band gap structures. The etching of one or more than one PBG elements creates defect in the ground plane and is used for the same function. An L-C resonator circuit is realized easily using it. The area and size of the defect affect the value of inductance and capacitance. The desired resonance frequency can be obtained, by varying various dimensions of the defect. DGS

may be one-dimensional or two-dimensional. Shape of the slot varies from a single hole to a complex one.

1.7.2 Merits of DGS

- **Reduction in size of microstrip patch antenna:**

Antenna size reduction becomes necessary in many cases. For example an antenna is designed using transmission line model for a specific frequency is large and is not suitable for various other applications. Different types of techniques are used for this purpose like using a substrate with higher dielectric constant, using a shorting pin at a suitable position, etc. Etching a defect in the ground is another such technique for reducing size of patch antenna.

- **Reduces harmonics:**

Harmonic radiation is considered as one of the drawbacks of integrated patch antennas. DGS/PBG structures are utilized to lessen higher order harmonics in them. Various DGS shaped have been used for this purpose such as dumbbell-shape, H-shape, spiral shaped DGS, etc.

- **Reduces Cross Polarization:**

Since, DGS is cheap and easy to etch on the microstrip substrate; it is used for reducing cross polarization (XP) radiations in the antenna.

- **Reduces Mutual Coupling:**

Input impedance, radiation pattern, effective reception area, gain, etc. are all affected by the mutual coupling. This problem arises in array since the field emitted by one element produces voltages across the terminals of other elements and then further scatters from these elements into the far field. The defected ground structure is used to overcome this problem. It is much successful than other techniques used for this purpose.

1.7.3 Difference between DGS and PBG

The microstrip patch antenna technology consists of a microstrip transmission line made of a conducting material (patch) on one side of a substrate that is dielectric in nature and a conducting ground on the other side. There are two types of standard structures which are used for designing miniature microwave components with high performance. These are the Electromagnetic band gap (EBG) structure and defected ground structure (DGS), which are normally called photonic band gap structures (PBG). These structures are utilized for the objective of rejecting unwanted frequency and reducing circuit size. DGS cells naturally have resonant property. Many of them have also been employed in filter circuits. But, due to difficult modelling, it is tough to use a PBG structure for designing microwave wave components. Another difficult in using PBG is its radiation from the periodic etched defects. DGS is achieved by etching off a simple shape in the ground plane. The current distribution in the ground plane is disturbed, depending on the shape and dimensions of the defect. This results in a regulated excitation and propagation of the EM waves through the substrate. For the better performance, shape of the defect may be changed from a simple one to a complicated one. The PBG changes the properties of the microstrip line such as characteristic impedance and propagation constant. The DGS with the microstrip line uses a defect in the ground that is deliberately made and it offers band rejection feature from the resonance property. The cutoff frequency of the DGS depends on the square area that is etched in the ground plane. Thus, the proposed DGS section is fully explained by two parameters: the gap distance and the etched lattice dimension.

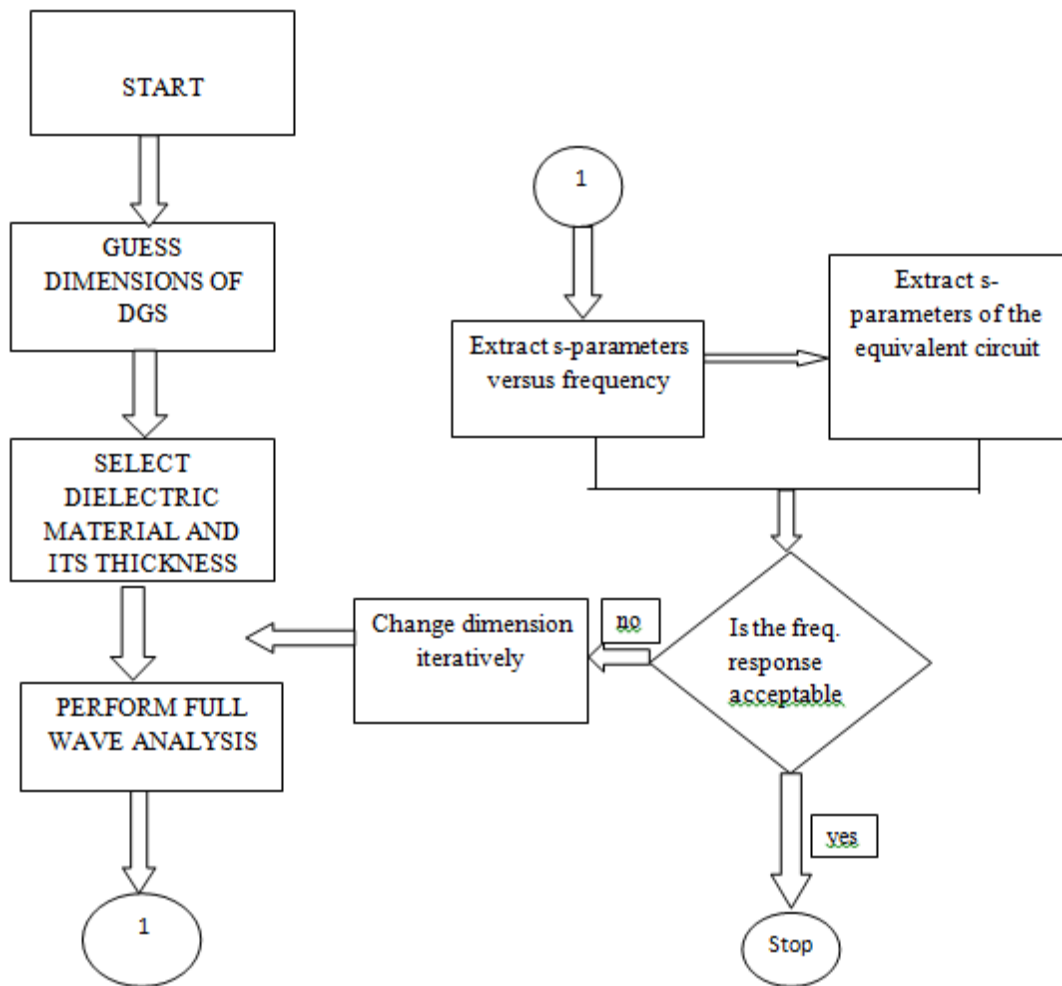
The difference between the PBG and DGS is presented in the table.

Table1. Difference between DGS and PBG

	DGS	PBG
Implementation	Easy	Difficult
Geometry	One or few etched structures	Periodic/recurring etched structure
Equivalent Circuit Extraction	Easy	Difficult
Microwave circuit properties	Same	Same

1.7.4 Flowchart for design methodology using DGS

The flowchart given below shows the designing procedure and the various steps involved in designing of a DGS employed microstrip antenna.



1.8 Work Covered in the Thesis

The Thesis basically covers the basic principles of design of microstrip antenna for broad bandwidth using PBG and DGS. A novel microstrip antenna design for Ku-band has been made using PBG in substrate. Simulation results for the same have been shown. A super-ultra-wideband antenna has been made with a simple design. Its fabrication and testing has also been done. Third design has been designed using defected ground structure. It also covers entire range for satellite applications. Its fabrication and testing have been performed too.

1.9 Thesis Outline

The synopsis of the thesis is given below

Chapter 1: The basics of communication and antenna particularly microstrip antenna are discussed. Advantages, disadvantages and applications of microstrip antenna as well as its parameters are also discussed. The knowledge of PBG and DGS technologies is also covered. Difference between these two technologies is mentioned as well.

Chapter 2: A brief literature review of the microstrip antenna in order to get its basics clear is presented in chapter 2. Different approaches used for the improvement of bandwidth, efficiency, return loss and suppression of the surface waves by various authors is described in this chapter.

Chapter 3: It depicts the design process of a novel Ku-band microstrip antenna design using PBG substrate for satellite applications. The designing and simulation of this proposed design is done with the help of CST 14.0 Microwave Studio. Bandwidth is improved with the help of following techniques:

- By using PBG grating in the substrate.
- Using DGS (rectangular slot in the ground)
- Using a rectangular strip which performs the function of a feed and radiating patch as well.

Chapter 4: This chapter discusses the design and analysis of a super-wide band slotted MPA. Improvement in various parameters like bandwidth and return loss is observed with inclusion of slots, changes in ground and change of material, etc.

Chapter 5: This chapter includes the design and analysis of a novel circular MPA using DGS technique. This design covers number of frequency bands, namely S, E, G, X, Ku bands. Therefore, it covers wide range of applications. Bandwidth enhancement and reduction in return loss is achieved through:

- Circular shape of the patch
- DGS
- Rectangular slot in the circular patch
- Change in material of the substrate

Chapter 6: The conclusion to this thesis and scope for future work are presented in this chapter.

1.10 Conclusion

In this chapter, overview of the communication system, antenna particularly microstrip antenna, its advantages, disadvantages, parameters involved in its study, etc. are examined. Various parameters that affect the performance of a microstrip antenna are discussed. Techniques such as PBG and DGS are shown and difference between them is also discussed.

CHAPTER 2

LITERATURE SURVEY

In this chapter, overview of the work, regarding microstrip antennas and microstrip patch antennas utilizing PBG and defected ground structures and their design methods have been discussed. Advancement in the field of microstrip antennas using various techniques for enhancing bandwidth has been discussed.

2.1 Progress

Pravin Ratilal *et al.* presented a circularly polarized (CP) compact microstrip antenna for frequency range that covers mobile satellite communication band of India that is, 1.492 to 1.518 GHz. For realization of CP radiation, two rectangular shape slots with asymmetrical lengths that are perpendicular to each other are printed on the circular patch. For improving the performance parameters of patch antenna such as return loss bandwidth, radiation efficiency and axial ratio (AR) bandwidth, etc. a new technique is presented for the first time in CP antennas designing that is combination of fractal theory and DGS. After inclusion of Koch curve fractal DGS in the ground plane, boost of 62.73% in AR bandwidth, 44.74% size reduction in size of patch, 4.03% improvement in radiation efficiency and 70.74% in return loss bandwidth is obtained as compared to normal patch antenna. The performance comparison of other available L-band planar antennas in the literature is done with this developed antenna, and it is found that the developed antenna design is better in many ways. Fabrication and testing of laboratory prototype of the antenna is done for verifying the simulated results. [36]

T.Sudha *et al.* showed the ability of a PBG substrate to minimize the surface wave effects. This is analyzed for a thick and high dielectric constant material substrate. Two different types of PBGs are used; one is the conventional dielectric PBG and the other a metallodielectric PBG. The patch antenna with PBG showed lowered levels of surface

modes compared to normal patch antenna and therefore enhancement in gain and far-field radiation pattern is obtained. The results also showed that introducing metallic cylinders in dielectric crystals is more effective in suppressing side lobe radiation. [35]

M. K. M. Amin *et al.* (2012) proposed a dual rectangular ring microstrip antenna with DGS for wireless applications. The rectangular ring using as a patch with DGS effect has been done and enhance the antenna's performance. This antenna design can be operated in 3G and 4G frequency spectrum bands and also to industrial, scientific and medical (ISM) radio bands. This antenna has small size of low gain. Omni directional antenna using defected ground structure has gain enhancement, it does not affect bandwidth, radiation pattern and also the beam width of antenna. [30]

C. Kumar *et al.* (2012) suggested the circular patches with probe feed using normal and defected ground planes flashed. Some were relating to cross-polarized (XP) electric fields and related radiations. These led to understanding of the nature of XP fields and to deal with them using DGS for improved XP performance. There phase of investigation limitations of dot-shaped DGS in reducing XP level. Two new DGS geometries for example the annular ring and circular arcs are explored. The arc-DGS emerges to be highly efficient one in suppressing of XP fields. [31]

J. Wang *et al.* (2012) proposed a miniature improved (dumbbell-shaped) DGS resonator on coplanar waveguide in this paper. The path difference for the electromagnetic wave propagation is increased by adding a smaller square resonator to the normal modified dumbbell-shaped DGS with highest M-DGS size reduction. The scheme for the reconfigurable band stop resonator is depicted after considering the effect of the inserted short circuits on the resonant frequency. By increasing the dimensions of the smaller square, the resonant frequency can be decreased further. [18]

H. Liu *et al.* (2005) proposed that a micro strip patch antenna integrated a one dimensional DGS and a two-dimensional PBG jointly in ground plane. It is shown that application of both DGS and PBG eliminates the second and third harmonics. It also improves the return loss level. Furthermore, the combination use of DGS and PBG reduces the occupied area by 70% as compared to the normal PBG patch antenna [19].

M.Rahman *et al.* proposed a square patch design for wide impedance bandwidth. To obtain wider bandwidth for this single feed antenna, multiple resonance technique has been used. This antenna also provides circular polarization within the bandwidth with good AR. Further investigation was done using PBG structure and improved results were obtained. [34]

Naizhi Wang *et al.* presented a broadband EBG resonator antenna design for Ku band. For improving the bandwidth of the antenna, the EBG structure was constructed by two dielectric substrates with different thicknesses and dielectric constants. An improved 3dB gain bandwidth of 26% was obtained with 15dBi peak gain. [39]

Sudhir Bhaskar *et al.* discussed two facets of designs of microstrip antenna. The first aspect comprises of the analysis of single element narrowband rectangular microstrip antenna operating at the central frequency of 3.3 GHz. The second aspect is the design and analysis of H-shaped slot-cut microstrip antenna. The H-shaped microstrip patch antenna presented here has a size which is nearly half the size of the rectangular patch antenna and has larger bandwidth. Reduction in the quality factor of the patch resonator is the reason behind larger bandwidth, which is because of comparatively less energy being stored underneath the patch. [38]

Saeed I. Latif *et al.* showed that the change in the slot shape, from straight to L and T shapes, helps in creating additional resonances, which when coupled to the original resonances of the slot, further promote increase in bandwidths. The bent shapes like L and T slots decrease their height and also offer more space on the ground for electronics. At two adjacent corners of the ground plane, a mirror image dual L-slot antenna is placed and is also examined and optimized for the polarization diversity. They provide an impedance bandwidth of 87%, with near orthogonal radiation characteristics. By appropriately selecting their design parameters, the measured impedance bandwidths of up to 60%, 80 % and 84%, are achieved for these straight, T and inverted L slots respectively.[40]

Jia-Yi Sze *et al.* demonstrated that by loading a pair of right-angled slots and an amended U-shaped slot in a rectangular MPA, bandwidth improvement is achieved. Dimensions of the right-angled slots and amended U-shaped slot for increasing bandwidth with good radiation characteristics have been obtained experimentally and it is observed that the achieved antenna bandwidth can be as large as about 2.4 times that of a corresponding rectangular microstrip antenna with no slots. [41]

J.Constatine *et al.* presented a multi-band patch antenna design approach by introducing rectangular slots and also a slot of triangular shape into the patch, which denotes a combination of an isosceles triangular and a rectangular patch. The presented antenna has numerous applications, and can be used to cover GPS, GSM, WiMAX, Wi-Fi, Bluetooth, video and all other wireless communication applications. The idea of including slot array behind a known antenna array distribution has proved to give notable functionality to the antenna. Due to it, it radiates significantly at several ranges of frequencies, with use of a single feed point. [42]

2.2 Thesis Objective

- To design and simulate a novel microstrip antenna design that covers the entire Ku-band with the help of PBG substrate and DGS techniques
- To design and simulate a novel slotted MPA which covers a wide range of frequencies (Super wideband Antenna).
- To design and simulated a circular MPA with rectangular slot covering number of frequency bands and thus wide range of frequencies.
- To fabricate the antenna using PCB Technology and testing the antenna using VNA.
- To publish research papers associated to work done.

2.3 Conclusion

The literature survey of microstrip patch antennas and methods to improve the antenna parameters has been studied in this chapter. The thesis objective is also mentioned in this chapter.

CHAPTER 3

DESIGN AND ANALYSIS OF A NOVEL Ku-BAND MICROSTRIP ANTENNA USING PBG SUBSTRATE

3.1 Introduction

The Ku-band (Kurtz-under band) covers 12-18 GHz portion in the electromagnetic spectrum. It is basically utilized for satellite communications especially for fixed and broadcast applications. Some frequencies in this band are used for vehicle speed detection by law enforcement in Europe. It used for some specific applications for NASA. It provides high speed connectivity not only between the personal organizers but also for other wireless digital appliances. This radio band is quite secure since it avoids signal interference from other communication systems. Another merit is that it supports large bandwidth applications. There are various other applications of this band like in weather forecasting radars, vehicle tracking, VSAT, fire detection radars, aircrafts and Microelectromechanical systems, etc. The objective of this design is to cover the entire Ku-band.

3.1.1 Advantages of Ku-band

- Large bandwidths
- More targeted coverage
- Versatile spectrum with increased reliability
- Devoted support with high quality
- Targets enterprise and government markets
- Avoids signal interference from other communication systems
- Secure and adaptable connectivity

3.2 Antenna Design

The microstrip antenna comprises of a copper strip working as a radiating patch on the top of a Photonic crystal substrate. Grooves of varying widths are cut in the substrate resulting in gratings. The ground plane is defected by cutting a rectangular slot in it. The front and back view of the antenna are shown in the figures respectively. The substrate is made of FR4 material with dimensions $L_S \times W_S \times H_S = 60 \times 60 \times 1.57 \text{ mm}^3$, relative permittivity $\epsilon_r = 4.4$ and loss tangent, $\tan \delta = 0.002$. A microstrip line with 50-ohm characteristic impedance is used for excitation. A long rectangular strip acts as a radiating patch as well as microstrip feed with dimensions $L_p \times W_p = 32.33 \times 2.96 \text{ mm}^2$ is used. A rectangular slot of dimensions $L_G \times W_G = 28.23 \times 40 \text{ mm}^2$ is cut in the ground plane. Height of the ground and patch is 0.02 mm^2 .

Slots are cut in the substrate of varying widths. Different widths were tried by hit and trial approach. At last, the grooves yielding best results were adopted.

3.3 Results

3.3.1 Return Loss

Return Loss, which is measured in decibels, is difference between forward and reflected power. CST MWS V14.0 software has been used for the investigation and optimization of geometrical specifications of the suggested antenna. Simulated results of reflection coefficient versus frequency with and without defected substrate are shown in figures respectively. Using the parameter sweep option, the analytical parameters were regulated precisely after executing a number of experimental repetitions. Finally, for the suggested configuration, optimal parameters were obtained. Microstrip feed line with characteristic impedance of 50ohm was used for matching the input impedance of the patch.

The designed antenna exhibits a return loss of -34.249 dB at a single resonating frequency 14.403 GHz. The bandwidth obtained over the band with a return loss less than 10 dB is 6.835 GHz (11.783 to 18.618 GHz). Ku-band covers frequency range 12-18 GHz. So, this design also covers a small portion of the X-band and some frequency range above Ku-band too.

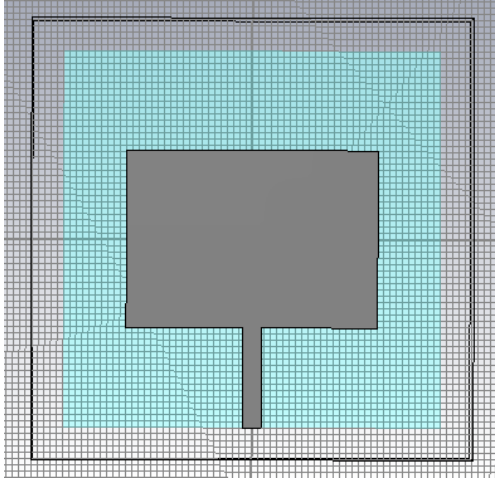


Fig.8: Front view of design without PBG Substrate and non-defected ground

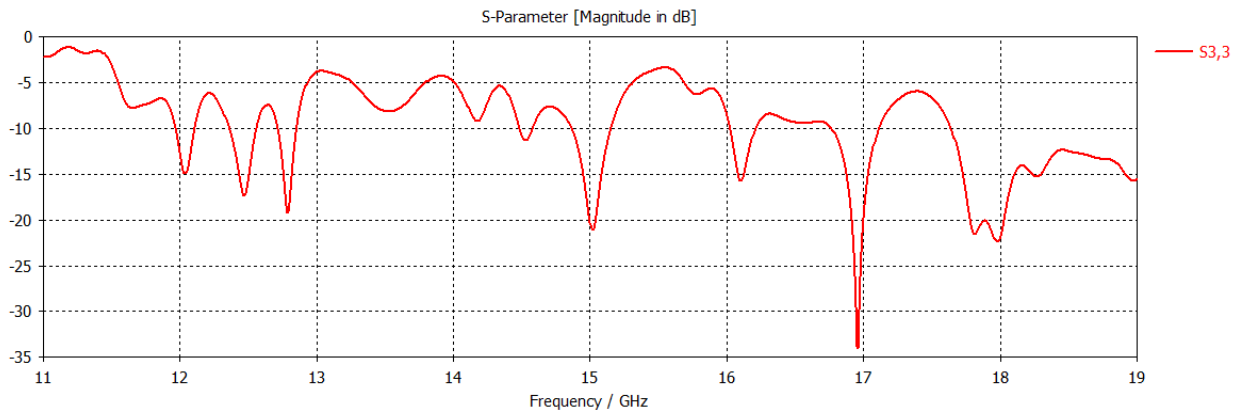


Fig.9: Simulation results for the design with no PBG and no defect in the ground

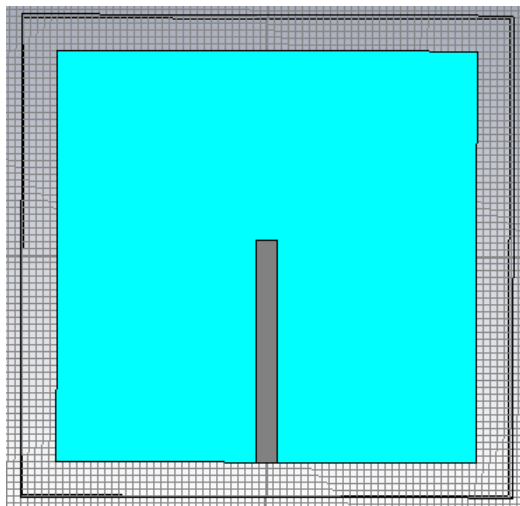


Fig.10: Front view of design with long strip acting as a patch and feed

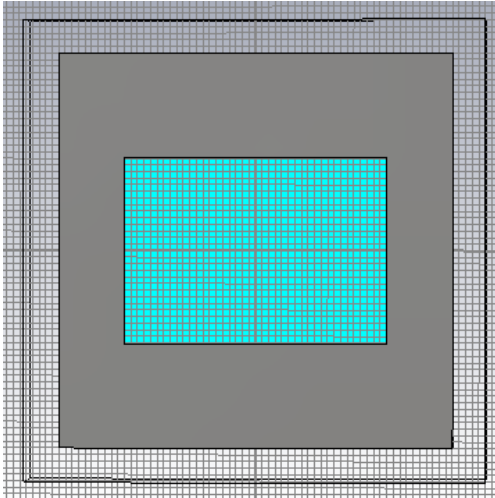


Fig.11: Back view with a rectangular slot of same dimensions as was the patch earlier

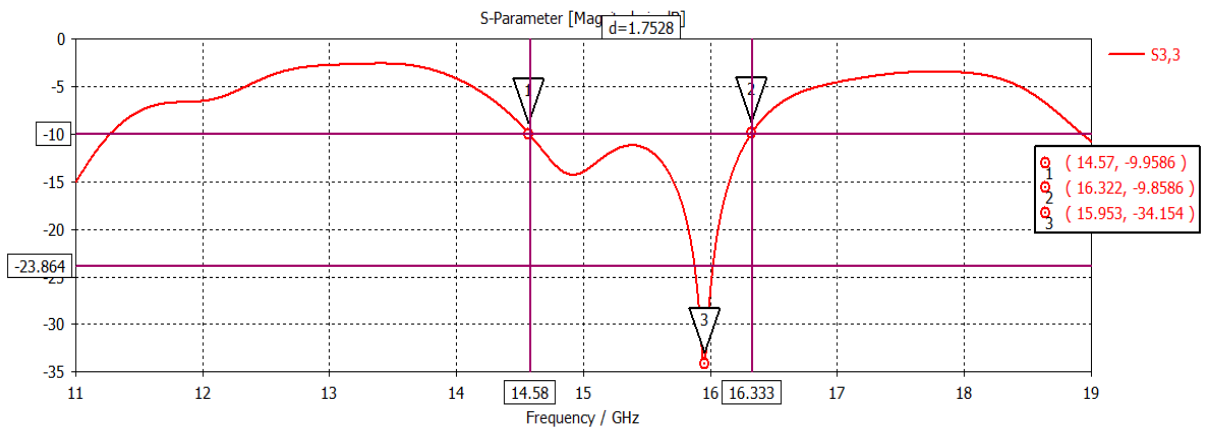


Fig.12: Simulated results of the above design with rectangular slot in the ground

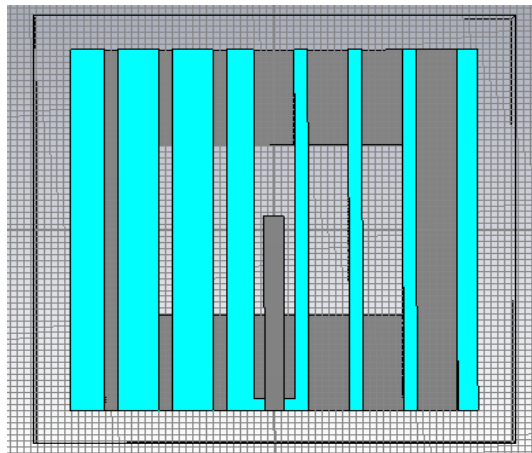


Fig.13: Front view of the final design with grooves in the substrate

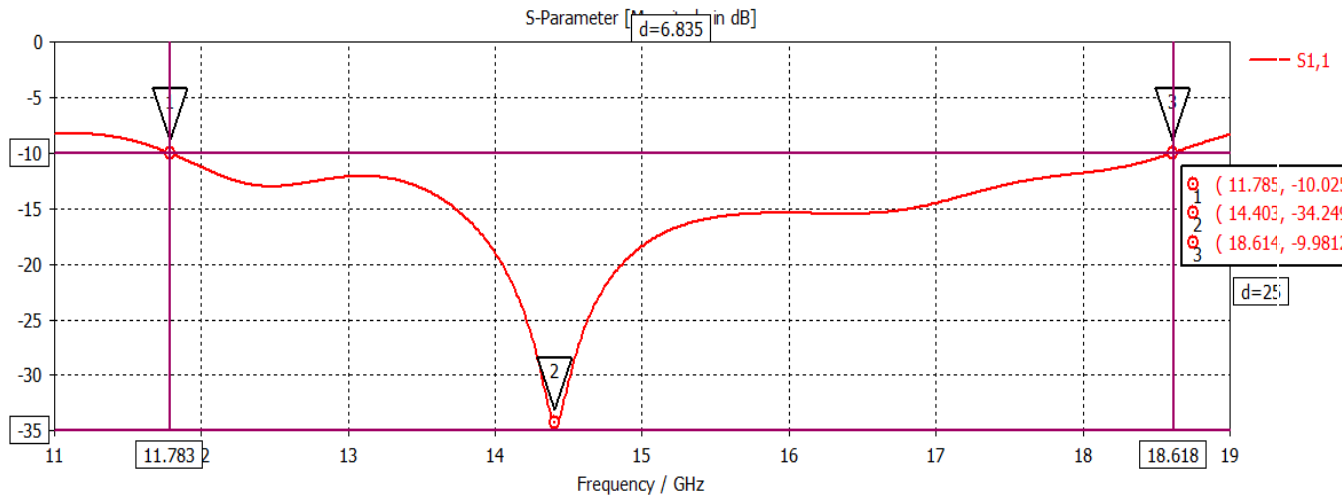
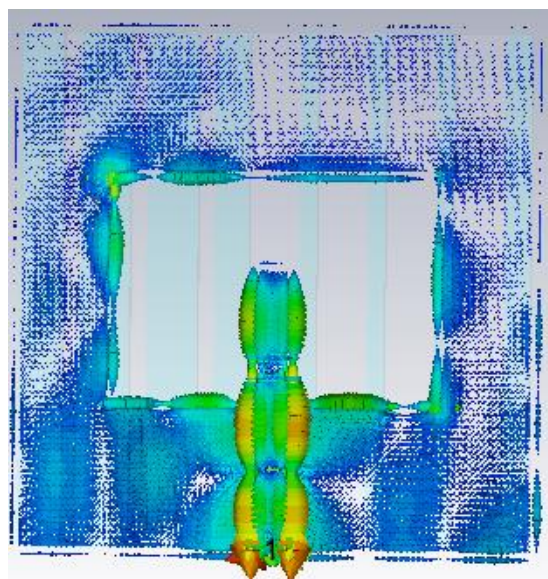


Fig.14: Simulated results of the above design with PBG in the substrate

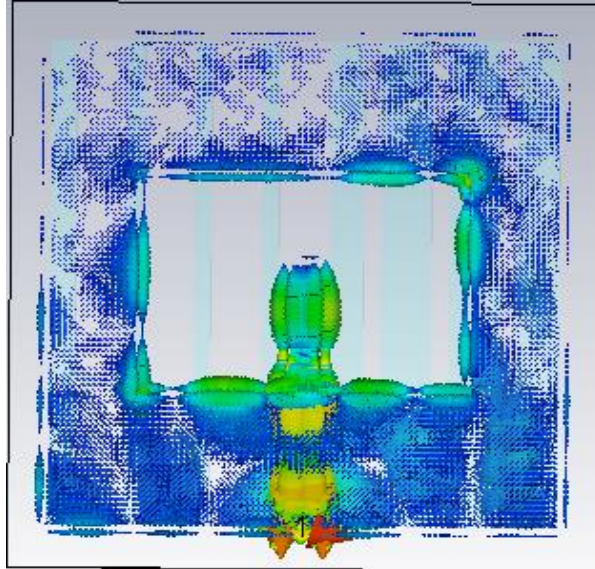
With this final design, we obtain entire Ku-band coverage. A resonating frequency with return loss of -35 dB is obtained.

3.3.2 Current Distribution Results

The complete electromagnetic behavior of the antenna can be found through the analysis of current/field distributions over and below the patch. Distributions of surface currents at resonating frequency 14.403 GHz are shown in Fig.15 below.



(a) Front view



(b) Back view

Fig.15: Illustration of current distribution results at 14.403GHz

3.3.3 VSWR

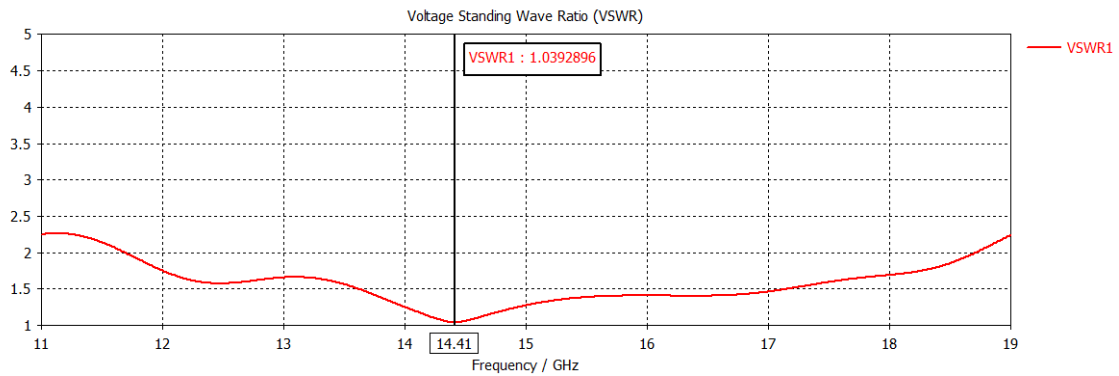


Fig.16: VSWR versus frequency plot for the proposed design

3.3.4 Gain

Gain for the proposed design is depicted in the Fig.17. We obtain a gain of 2.5148 dB at resonating frequency of 14.4 GHz.

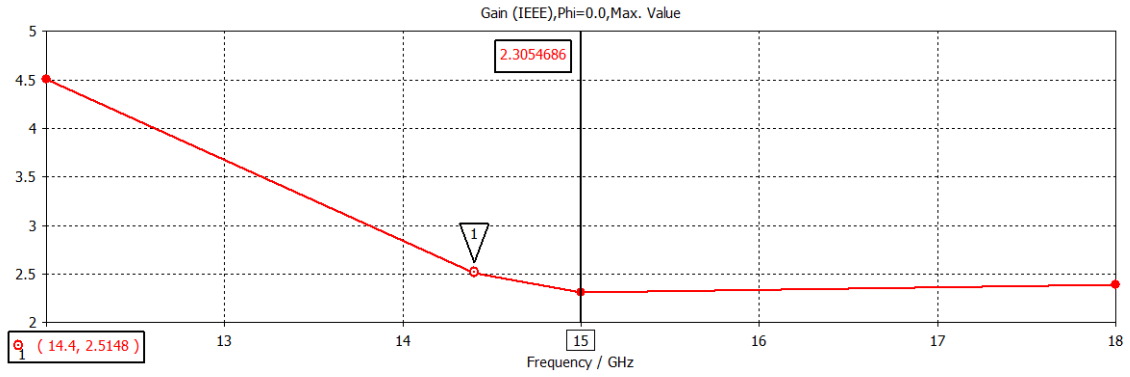


Fig.17: Gain plot

3.4 Fabrication and measurement results

Since this proposed design requires precise cutting in the substrate in order to create grooves, its fabrication is quite a complex task. Due to unavailability to precise cutting tools, this design could not be fabricated. Hence, only simulated results are available for this proposed design.

A NOVEL SLOTTED MICROSTRIP PATCH ANTENNA WITH SUPER WIDE-BAND (SWB) PERFORMANCE FEASIBLE FOR WIRELESS APPLICATIONS

4.1 Introduction

The latest trends in wireless communication systems need wide bandwidth antennas, by which the data, speech and video information can be transmitted. Some of the applications of wireless communication systems include fixed broadband local multipoint communication services, small mobile units for example cellular phones or other hand held units, laptops and several remote-sensing devices. Nearly all of these applications require miniaturized antennas [40]. Microstrip antennas are best suited for these applications but the only drawback is their narrow bandwidth. To overcome this problem, without sacrificing their other merits (like planar structure, cheap in cost and easy PCB fabrication, etc.) different techniques during designing are kept in mind. Selection of material for substrate, its thickness, dimensions of patch, width of feed line, etc. play an imperative role in the performance of a microstrip antenna. Cutting slots in the patch for achieving better results (wider bandwidth) is also one of the methods. When a microstrip slot antenna is fed using a microstrip line it neither adds weight nor size to the system. Also it is a suitable design for such applications.

Our motive is to design an antenna which covers wide range of applications. Various applications for different frequency bands are mentioned in the table given below.

Table 2: Frequency bands and their applications

Frequency band(GHz)	Bandwidth	Applications
1.710-1.805	95MHz	GSM1800

1.850-1.990	140MHz	GSM1900
2.3-2.4	100MHz	IMT
2.7-2.9	200MHz	IMT
3.4-4.2	800MHz	IMT
4.4-4.9	500MHz	IMT
2.4-2.484	84MHz	WLAN
5.15-5.35	200MHz	WLAN
5.725-5.825	100MHz	WLAN
2.4-2.5	100MHz	Bluetooth
2.5-2.69	190MHz	WiMAX
3.4-3.69	290MHz	WiMAX
5.25-5.85	600MHz	WiMAX
Uplink 5.9-6.4(C-band) Downlink 3.7-4.2(C-band)	500MHz	Fixed, point to point ground stations, non-military
Uplink 7.9-8.4(X-band) Downlink 7.25-7.75(X-band)	500MHz	Mobile(Ships, aircrafts),radio relay, Military
Uplink 14-14.5(Ku-band) Downlink 11.7-12.2(Ku-band)	500MHz	Broadcast and fixed point service, on military

4.1.1 Benefits and Advantages of wide bandwidth communication

- Large channel capacity
- Low probability of intercept and detection
- Enables ultra-low power, smaller form factor, and better mean time between failures, all at a reduced cost
- Resistance to jamming
- High bandwidth can support real-time high-definition video streaming

4.2 Antenna Design

The proposed design consists of a rectangular radiating patch with total four slots in it over a 1.56 mm thick substrate. Two cases are considered here, one using FR4 material for the substrate and another using Rogers material. FR4 material has relative permittivity $\epsilon_r = 4.4$ and loss tangent, $\tan \delta = 0.002$. Rogers RT5880 has relative permittivity $\epsilon_r = 2.2$ and loss tangent, $\tan \delta = 0.0009$ (at 10 GHz). Thickness of the substrate used is 1.56 mm. A microstrip line with 50-ohm characteristic impedance is used for excitation. Dimensions of the substrate are $L_s \times W_s$ mm². Overall dimensions of the patch are $L_p \times W_p$ mm². A ground strip of copper is used as the ground plane with thickness 0.018 mm. Dimensions of the copper strip acting as the ground plane are $L_g \times W_g$ mm². There are 4 slots in the patch, namely 1, 2, 3 and 4. Dimensions of slot 1 are equal to slot 2 and that of slot 3 are equal to slot 4.

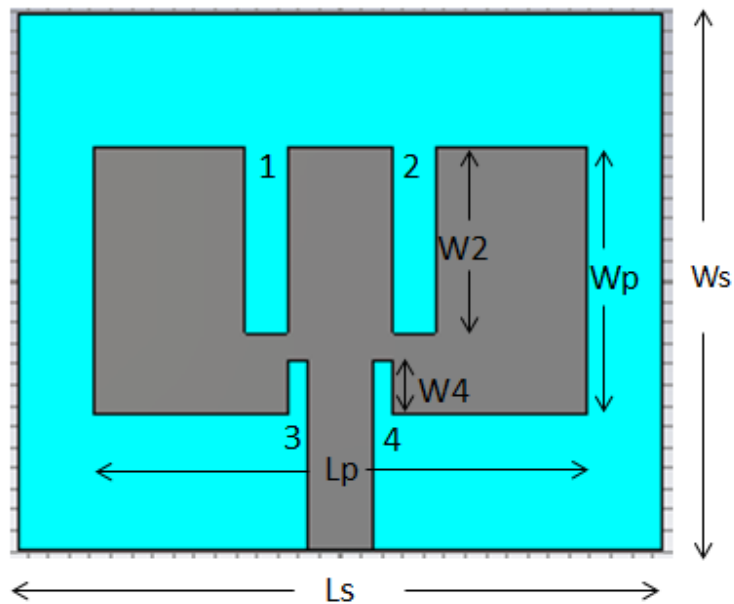


Fig.18: Front view of the design

Dimensions of the rectangular patch and that of ground plane are modified number of times for the optimization of the antenna. The size of the slots in the patch is also adjusted many times in order to get desired radiation characteristics.

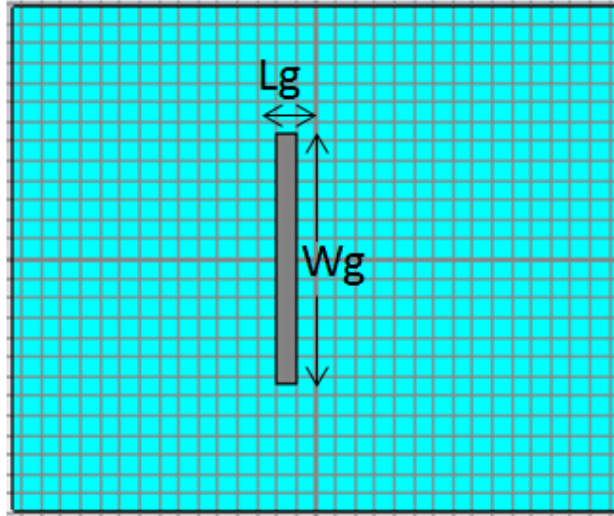


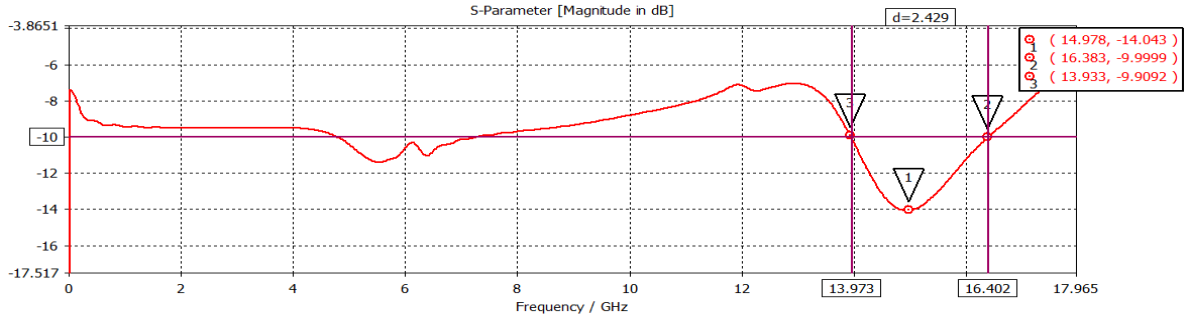
Fig.19: Back view of the design

4.3 Results

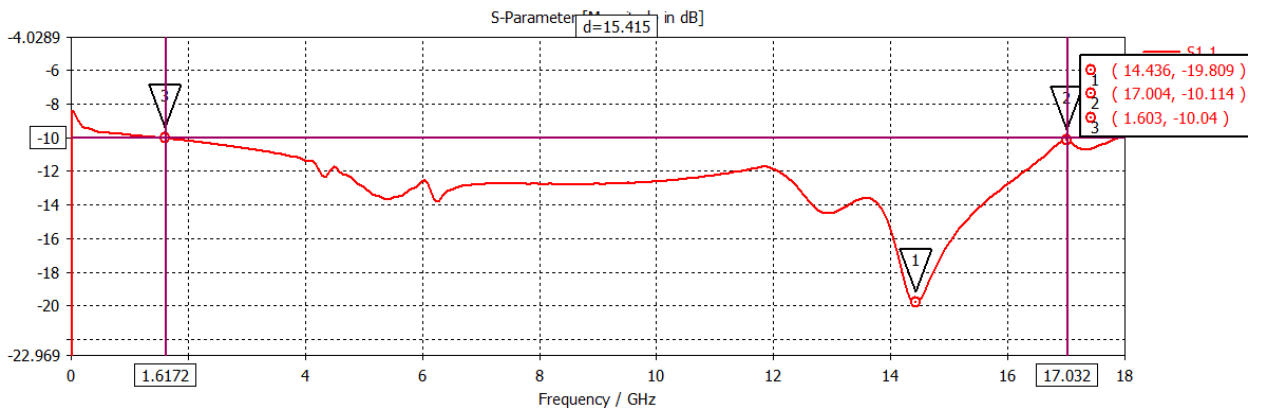
The results of the proposed design were obtained by using the commercially available simulation software, CST Microwave Studio software V10.0. Transient solver in the main menu has a parameter sweep option; with the help of it analytical parameters were regulated precisely after executing experimental repetitions number of times. Finally the optimal parameters for proposed configuration were obtained as follows: $L_s= 30.9$ mm, $W_s= 25.7$ mm, $L_g= 1$ mm, $W_g=12.8$ mm, $L_p=23.5$ mm, $W_p=12.8$ mm, $W_2=8.9$ mm and $W_4=2.55$ mm. Slots 1 and 2 are 2 mm wide and slots 3 and 4 are 1mm wide.

4.3.1 Return Loss

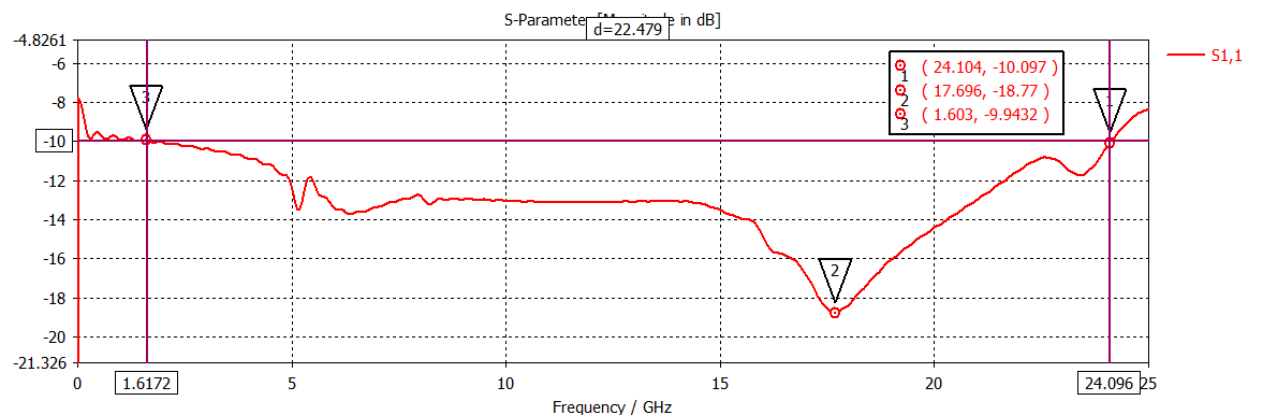
S_{11} parameter shows return loss and it is defined as maximum power reflected from the given antenna. The simulated results are taken for three different cases of proposed antenna as depicted in Figure 20 (a), (b) and (c). Part (a) of the figure depicts the result for the design with slots 3 and 4 in the patch. Part (b) depicts results for the design with slots 1, 2, 3 and 4 with FR4 material substrate. Part (c) shows result for the design same as part (b) but with Rogers RT5880 material substrate.



(a) Reflection coefficient versus frequency plot (with slots 3,4 but without slots 1 and 2)



(b) Reflection coefficient versus frequency plot (with slots 1, 2, 3 and 4 in the patch on FR4 substrate)



(c) Reflection coefficient versus frequency plot (with slots 1,2,3,4 in the patch on Rogers material substrate)

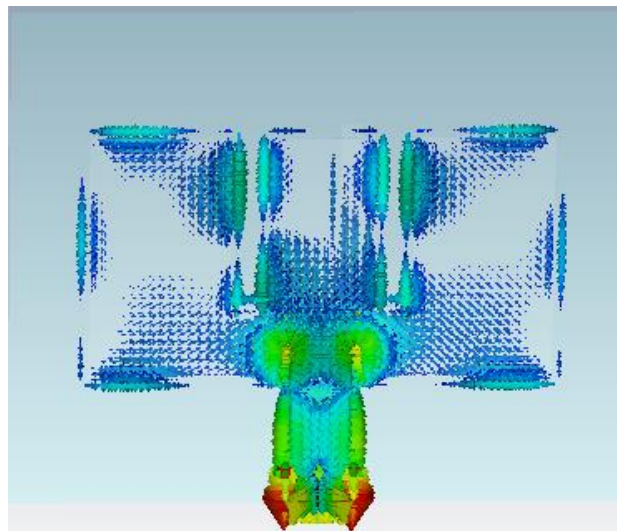
Fig20. Reflection coefficient versus frequency plots

Return loss plot (b) using FR4 substrate indicates a bandwidth of 15.415GHz (from 1.6 to 17GHz) with resonating frequency 14.436GHz and return loss of 19.8dB. Impedance bandwidth of 165% is obtained. So, this proposed antenna covers a wide range of applications as mentioned in the table.

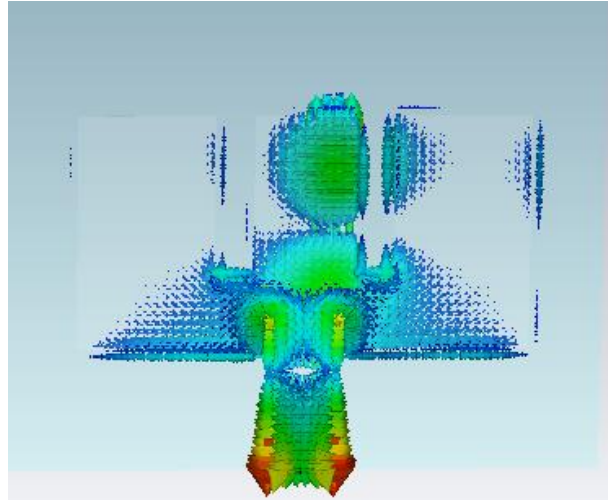
With the use of Rogers's material for the substrate we get increased bandwidth of 22.479GHz (from 1.6 to 24GHz) corresponding to impedance bandwidth of 175.6% as clear from return loss versus frequency plot (c).

4.3.2 Current Distribution

The return loss can only portray the performance of the antenna as a lumped load at the end of the feed line. The study of current/field distributions below and over the patch can only disclose the complete electromagnetic behavior of the antenna. Figure 21 illustrates current distribution. Part (a) of the Figure below depicts current distribution at frequency of 15.5GHz and part (b) shows the result at frequency of 12GHz.



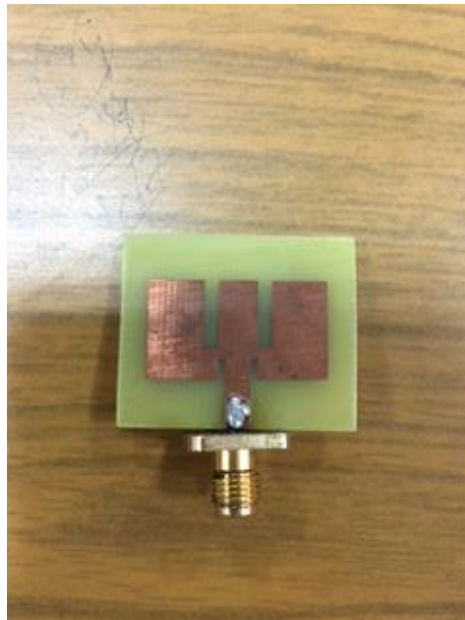
(a) Current distribution result at frequency 15.5GHz



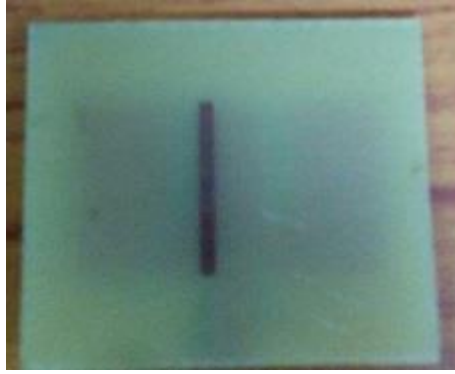
(b) Current distribution result at frequency 12GHz

Fig.21: Current distribution results

4.4 Fabrication and measurement results



(a.) Front view



(b.) Back view

Fig.22: Photograph of the proposed design

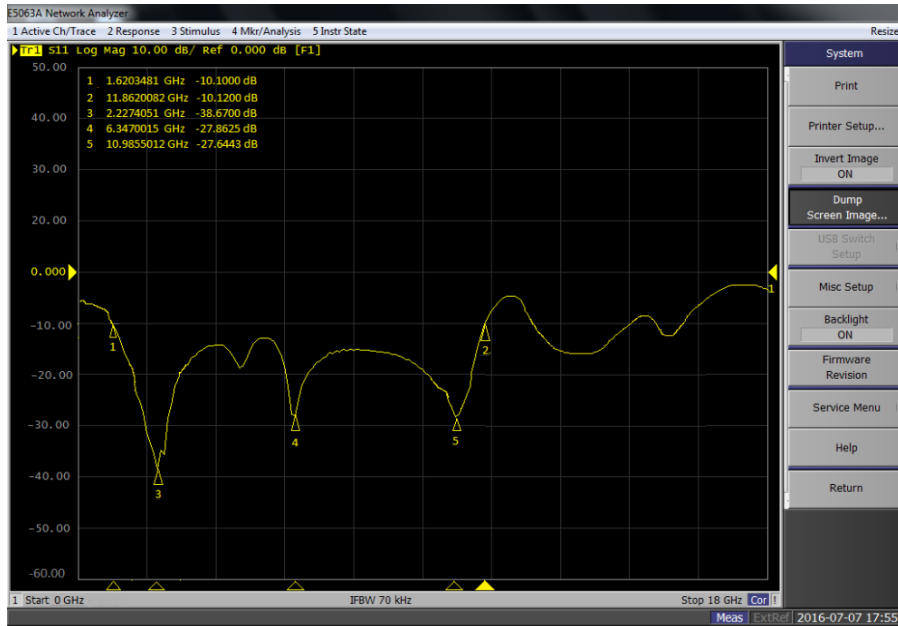


Fig.23: Measured results from network analyzer

The measured impedance bandwidth of the wide band obtained from 1.62 GHz to 11.86 GHz is approximately 10.24 GHz, corresponding to an impedance bandwidth of 152%. We get three resonating frequencies at 2.2 GHz, 6.34 GHz and 10.98 GHz in this wide band. Second band is obtained from 12.5 GHz to 13.9 GHz with bandwidth of 1.4 GHz and a small band ranging from 14.7 GHz to 15.5 GHz with impedance bandwidths of 10.6% and 5.3% respectively. Reasonable agreement between the simulated and the

measurement is achieved beyond a frequency deviation of $\leq 13\%$. Such variations usually occur due to fabrication errors, connector losses, etc. The difference may therefore be attributed to the connector and the antenna feeder.

4.5 Conclusion

A compact slotted microstrip antenna utilizing DGS technique is designed, fabricated and then tested for measurement results. The main objective of this design is to get a wide band covering wide range of applications. Although, reduction in impedance bandwidth is obtained after testing the fabricated design but that is due to various losses and errors involved. The measured impedance bandwidth of the wide band obtained from 1.62 GHz to 11.86 GHz is approximately 10.24 GHz, corresponding to an impedance bandwidth of 152%. It covers R, D, S, E, G and X frequency bands. Therefore, it covers applications like GSM 1800, GSM 1900, IMT, WLAN, Bluetooth, WiMAX and satellite applications as well.

A NOVEL CIRCULAR PATCH MICROSTRIP ANTENNA WITH DGS FOR E, G, X AND KU-BAND APPLICATIONS

5.1 Introduction

The rapid advancement in communication sector has increased demand for development of more novel designs of miniaturized antennas capable of operating at more than one frequency bands. The need for multi-band antennas to cover very wide bandwidth is of unending importance, particularly in the field of electronic warfare, satellite communication, wideband radar and measuring system. Microstrip antenna, popularly also known as patch antenna or printed circuit antenna is suitable for such applications. The Microstrip Patch antenna has advantage of light weight, low cost, planar profile, design flexibility, simple printed circuit fabrication and ease of installation [1]. The radiating elements (copper patch) together with feed line are photo etched on a thin dielectric sheet (substrate) on a ground plane (copper layer). The patch can be of any shape (square, rectangular or circular, etc.). Although microstrip patch antennas have extremely desirable features, they generally suffer from limited bandwidth. Narrow bandwidth is their most critical disadvantage. To overcome this problem without spoiling its principal advantages, a number of techniques and structures have been investigated till date. Particularly in satellite applications, there is a need of light-weight, low profile and highly reliable antennas. Numerous techniques have been presented by antenna researchers for miniaturization of size like using inductive and capacitive loading [46], using substrates with high dielectric constant [47], using fractals [48], using slots on a patch [50], using metamaterials [49] and the use of shorting pins and plates [51].

Various antennas have been designed having different shapes of defects in the ground plane. Invariably, applying defected ground structures (DGSs) is found to be a successful method in the size reduction of antennas, besides exciting additional resonant modes. DGS is realized by etching a certain shape in the ground of the patch antenna. Due to the additional lumped inductance introduced by DGS, the phase velocity of the wave gets

reduced, thus producing the slow wave effect [45, 50]. The slow wave factor is defined as the ratio of propagation constant β and free space wave number k . The slow wave effect causes the effective electrical length of the antenna to increase or in other words decrease its resonance frequency which leads to reduction in antenna size for the frequency of operation [52,53]. A number of shapes of DGS, such as dumbbell [53], partial ring [52], spiral [54], annular ring [55] etc. have been suggested to improve performance characteristics of the antenna, that is, to improve impedance bandwidth, enhance radiation efficiency, to suppress higher harmonics, to reduce size of patch, to reduce mutual coupling, and to suppress cross polarization of the antenna etc. Different frequency bands along with their frequency ranges are given in the table below.

Table 3. Frequency Bands [37]

BAND	FREQUENCY RANGE(GHz)
R	1.70-2.60
D	2.20-3.30
S	2.60-3.95
E	3.30-4.90
G	3.95-5.85
X	8.2-12.4
Ku	12.4-18
K	15-26.5

5.2 Antenna Design

The geometry of the proposed designed is shown in the Fig.24 and Fig.25. Circular patch is the radiating element. Circle shaped patch occupies slightly smaller area than the rectangular patch. Furthermore, circular disc can be easily adjusted to produce a range of impedance values, radiation patterns and frequencies of operation by varying a single parameter that is, radius. The proposed antenna is designed using Rogers RT5880 (duroid) material for substrate and copper for patch and ground. Rogers RT5880 has relative permittivity $\epsilon_r = 2.2$ and loss tangent, $\tan \delta = 0.0009$ (at 10 GHz). Thickness of the

substrate is 1.57 mm and that of both patch and ground is 0.02 mm. Dimensions of the substrate are $L_s \times W_s$ mm². Circular patch is of radius r mm. DGS is used with dimensions $L_g \times W_g$ mm². A rectangular strip of dimensions $L_r \times W_r$ mm² is cut from the patch. A 50- Ω microstrip line was used to feed the patch for impedance matching.

Dimensions of the circular patch and that of ground plane are modified number of times for the optimization of the antenna. The size of the rectangular slot in the patch is also adjusted many times in order to get desired radiation characteristics. The rectangular slot, circular shape of the patch and DGS play a significant role in the favorable excitation of the resonating frequency bands obtained.

The results of the proposed design using DGS were obtained by using the commercially available simulation software, CST Microwave Studio software V10. Transient solver in the main menu has a parameter sweep option; with the help of it analytical parameters were regulated precisely after executing experimental repetitions number of times. Finally the optimal parameters for proposed configuration were obtained as follows: $L_s=30$ mm, $W_s=30$ mm, $r=11$ mm, $W_f=2.8$ mm, $L_r=16$ mm, $W_r=2$ mm, $L_g=30$ mm and $W_g=3$ mm.

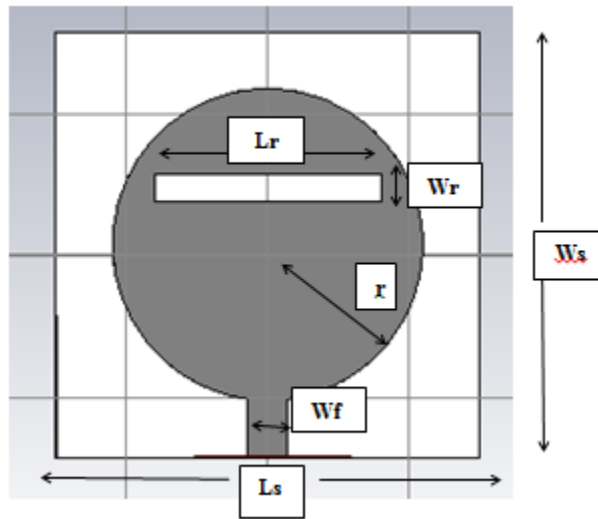


Fig.24: Front view of the proposed design

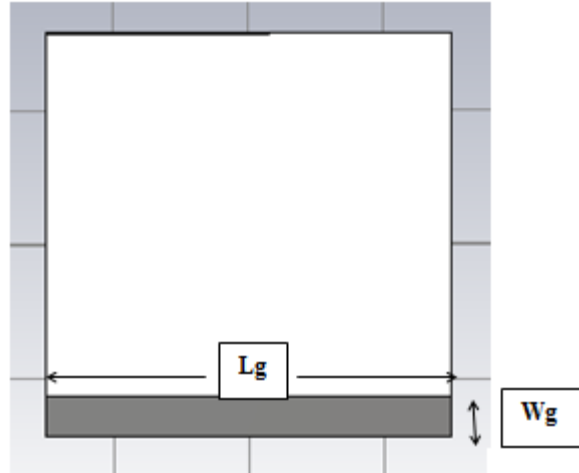


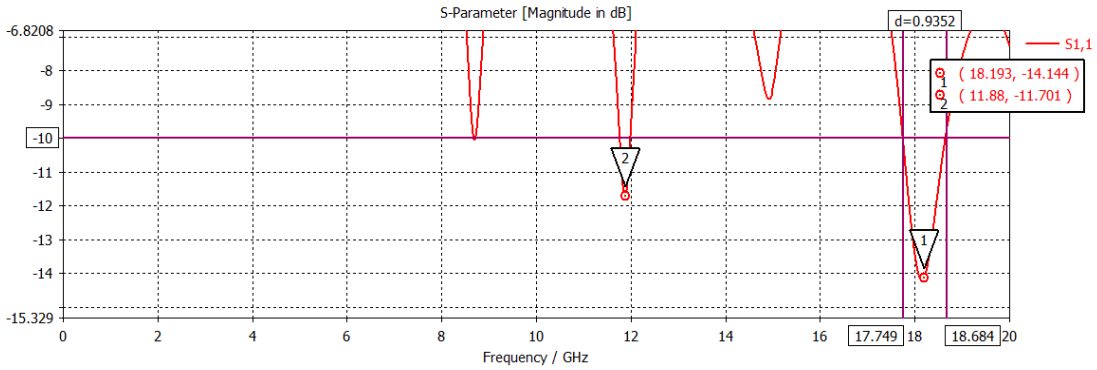
Fig.25: Back view of the proposed design

5.3 RESULTS

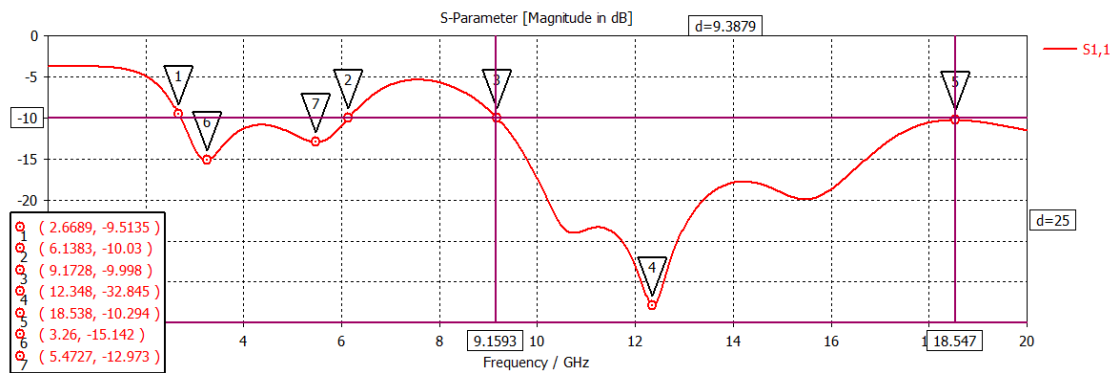
The results of the proposed design using DGS in terms of return loss have been obtained by using the CST Microwave StudioV14.0 software. Transient solver in the main menu has a parameter sweep option; with the help of it analytical parameters were regulated precisely after executing experimental repetitions number of times. The proposed design of antenna with optimal parameters is shown above.

5.3.1 Return Loss

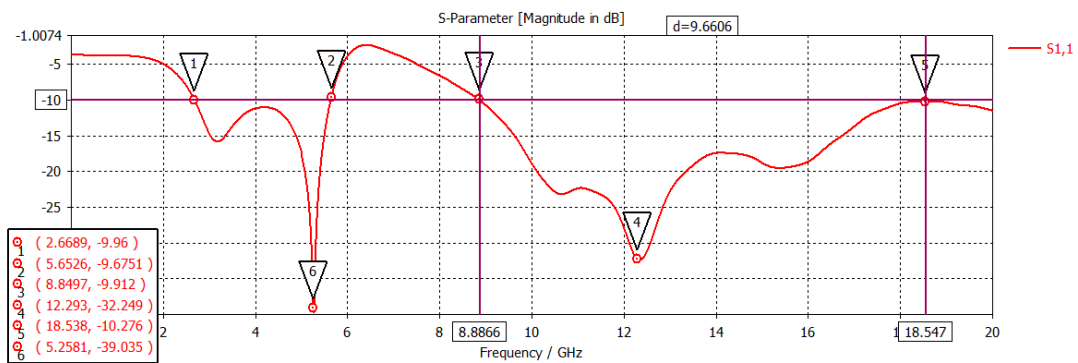
Return Loss, which is measured in decibels, is difference between forward and reflected power. Firstly a circular MPA design is simulated and results are obtained. Two resonating frequencies at 11.88 and 18.193 GHz are obtained as shown below. After number of trials for different dimensions of the ground, a 3 mm wide DGS is used and simulated results are obtained for the same. Two wide bands with impedance bandwidths 3.5 GHz (2.6-6.1 GHz) and 9.33 GHz (9.17 – 18.5 GHz), corresponding to impedance bandwidths of 80.4% and 67.4% respectively are obtained. After that when a rectangular slot is cut in the patch, we obtain reduced return loss results for the lower band and also an increase of 272 MHz impedance bandwidth for the upper band is obtained.



(a) Simulated reflection coefficient versus frequency plot of circular MPA without rectangular slot and without DGS



(b) Simulated reflection coefficient versus frequency plot of circular MPA with DGS but without any slot in patch



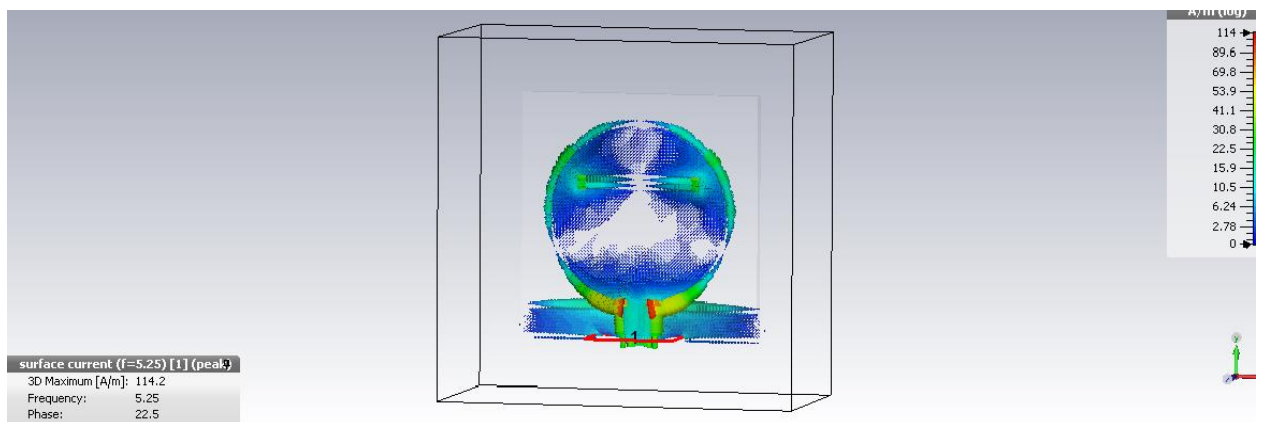
(c) Simulated reflection coefficient versus frequency plot of circular MPA with DGS and Rectangular slot in the patch

Fig.26. Simulated reflection coefficient versus frequency plots

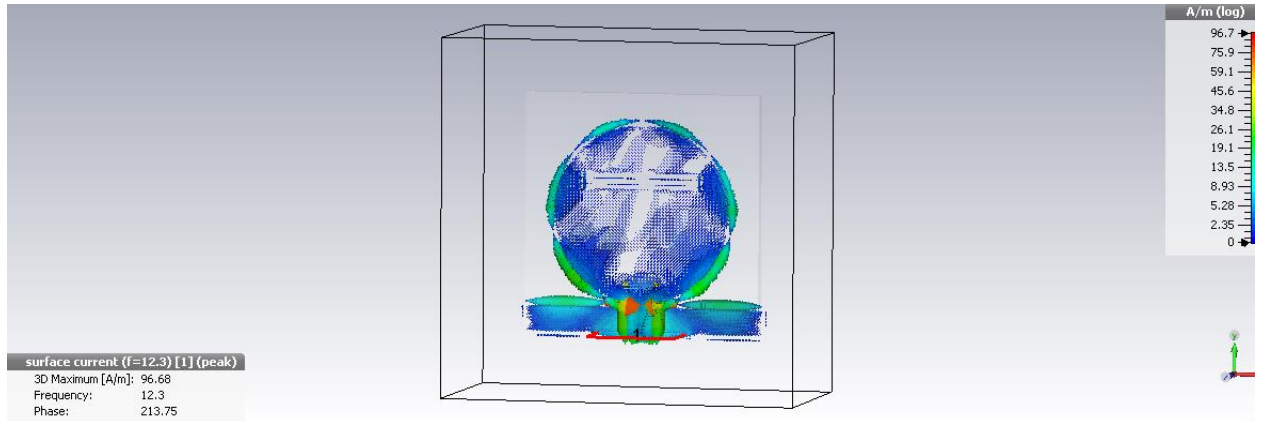
After inclusion of both DGS and rectangular slot in the circular patch, we obtain dual wideband microstrip antenna. A lower band covering S, E and G frequency bands is obtained from 2.67 GHz to 5.65 GHz with 2.98 GHz of bandwidth, corresponding to impedance bandwidth of 71.6%. The resonating frequency obtained for this band is at 5.25 GHz with return loss of -39.035 dB. The upper band covers both X and Ku-frequency bands from 8.85 GHz to 18.538 GHz with 9.68 GHz of bandwidth, corresponding to impedance bandwidth of 70.6%. The resonating frequency at 12.293 GHz has a return loss of -32.249dB.

5.3.2 Current Distribution Results

The return loss can only describe the behavior of the antenna as a lumped load at the end of the feed line. The analysis of current/field distributions underneath and above the patch can only disclose the detailed electromagnetic behavior of the antenna. To clarify more details on the excited resonant modes of the proposed patch antenna, the simulated current distributions at two resonant frequencies of 5.25 GHz and 12.3 GHz are shown in Fig. 27(a) and 4(b) revealing that the defected DGS was responsible for the resonance at 12.3 GHz and the rectangular slot in the circular patch was responsible for resonance at 5.25 GHz.



(a) Surface Current distribution result at resonating frequency 5.25GHz



(b) Surface Current distribution result at resonating frequency 12.3GHz

Fig.27: Surface Current distribution results for the proposed antenna design

As it is clear from the surface current distributions, circular shape of patch and DGS are responsible for resonating frequency at 12.3 GHz. As seen in Fig. (a), the rectangular slot in addition is strongly responsible for the resonating frequency at 5.25GHz. The slot also decreases the return loss at this frequency.

5.3.3 VSWR

Transmission line imperfections are measured through VSWR. Due to mismatches in impedance within the connector, some of the signal power is reflected. VSWR is defined as the ratio of the maximum voltage to the minimum. The larger the impedance mismatch, larger is the amplitude of the standing wave. A perfect impedance match would produce no voltage standing wave, so the ratio of the maximum to the minimum voltage would be 1 (1:1). This ratio when measured in decibels (dB) is called return loss. Fig. 28 demonstrates the VSWR for the proposed design. We obtain 1.0312 VSWR value at 5.25 GHz frequency and 1.0499 VSWR value at 12.3 GHz frequency.

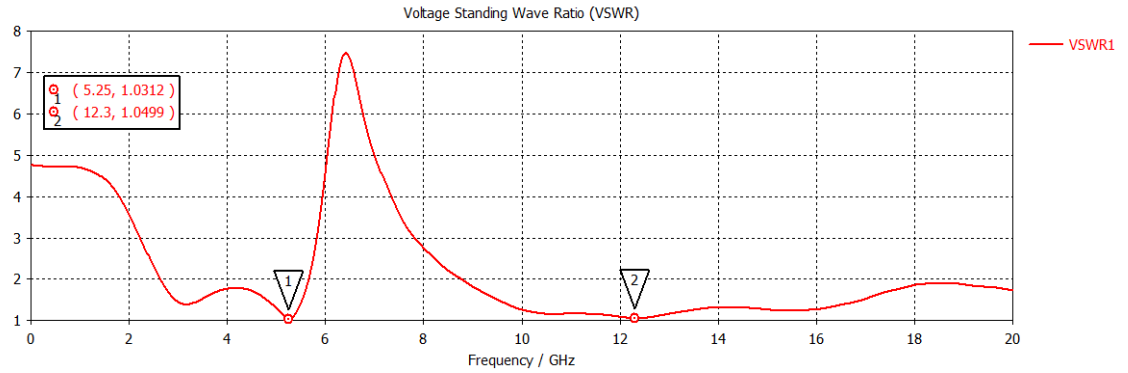


Fig.28: VSWR plot for the proposed design

5.3.4 Gain

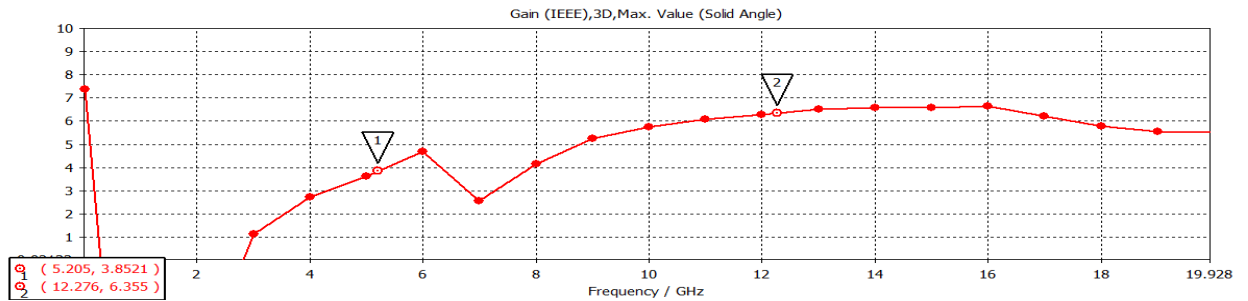
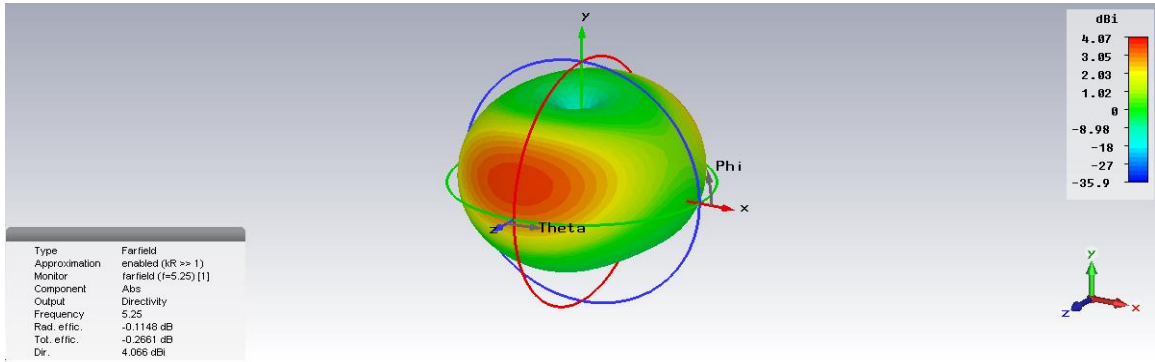


Fig.29: Gain versus frequency plot of the proposed design

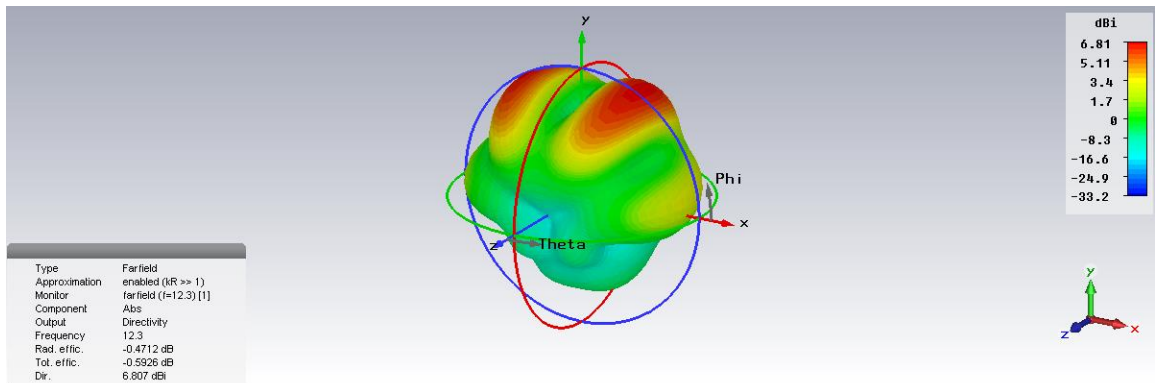
As clear from the plot, gain at resonating frequency 5.205 GHz is 3.8521 dB and that at 12.276 GHz is 6.355 dB approximately.

5.3.5 Directivity

As we know, directivity is defined as the radiation intensity in a given direction from the antenna divided by the radiation intensity averaged over every direction. In this proposed design, directivity of 4.05 dB is obtained at frequency of 5.25 GHz and 6.5 dB at 12.3 GHz. Directivity plots are shown in the Fig.30 shown below.



(a) Directivity plot at 5.25GHz



(b) Directivity plot at 12.3GHz

Fig.30: Directivity plots for the proposed design

5.4 Fabrication and measurement results

Photographs of the front and back view of the fabricated antenna are shown in the Fig. 31 and Fig.32. Keysight E5063A (100 kHz-18 GHz) ENA network analyzer is used for testing the fabricated antenna. Comparison of the measured and simulated results is depicted in Fig.33.

We obtain the lower band ranging from 3.28 GHz to 5.12 GHz with 1.84 GHz of bandwidth, corresponding to impedance bandwidth of 43.8%. The upper band is obtained with bandwidth of 6.14 GHz ranging from 9.36 GHz to 15.5 GHz; corresponding impedance bandwidth is 49.4%. A small band from 15.8 to 16.1 GHz is also obtained.

Due to number of factors like connector losses, fabrication errors, etc. the bandwidth of the fabricated antenna is reduced in comparison to the bandwidth obtained from simulation. Due to various errors and losses, we obtained an additional band from 6.38 to 7.36 GHz.



(a) Front view



(b) Back view

Fig.31: Photograph of the fabricated design

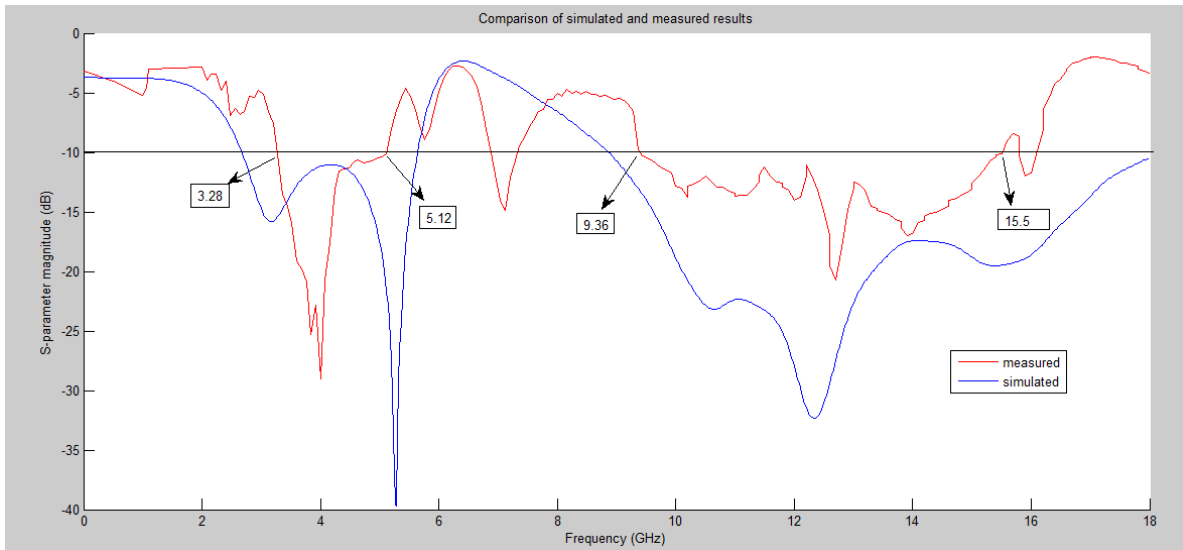


Fig.32. Comparison of simulated and measured results

5.5 Conclusion

A compact circular patch antenna with DGS is designed and fabricated to cover a wide range of applications of E, G, X and Ku-band. Therefore, this design could be used in applications such as WiMAX, WLAN and satellite applications as well. DGS and the rectangular slot in patch played an important role for obtaining such a wide band. Although, due to errors and various losses, the measured bandwidth is lesser than the simulated results, but still we obtained an appreciable value of bandwidth and gain. The measured impedance bandwidths are about 1.84 (3.28 to 5.12 GHz) and 6.14 GHz (9.36 to 15.5 GHz), corresponding to an impedance bandwidth of 43.8% and 49.4% respectively. The reduction in the bandwidth obtained in measurement from the simulated result is may be attributed to factors such as fabrication losses, connector losses, cable losses, etc.

CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

In this dissertation, research has been done on designing different types of microstrip antenna utilizing the concepts of photonic band gap and defected ground structures for wideband high frequency applications. With the utilization of the software, processing time for the simulation and calculations of the design is reduced.

In **Chapter 1**, the basics of communication and antenna particularly microstrip antenna are discussed. Advantages, disadvantages and applications of microstrip antenna as well as its parameters are also discussed. The knowledge of PBG and DGS technologies is also covered. Difference between these two technologies is mentioned as well. The antenna with PBG structure suppresses the surface wave propagation to large extent in comparison to the antenna without PBG structure. Improvement in the bandwidth is achieved with inclusion of DGS. The antenna designs show a good return loss more than -10dB.

In **Chapter 2**, a brief literature review of the microstrip antenna in order to get its basics clear is presented in chapter 2. Different approaches used for the improvement of bandwidth, efficiency, return loss and suppression of the surface waves by various authors is described in this chapter.

In **Chapter 3**, the design process of a novel Ku-band microstrip antenna design using PBG substrate for satellite applications is depicted. The designing and simulation of this proposed design is done with the help of CST 14.0 Microwave Studio. Bandwidth is improved with the help of following techniques:

- By using PBG grating in the substrate.
- Using DGS (rectangular slot in the ground)
- Using a rectangular strip which performs the function of a feed and radiating patch as well.

Since this proposed design requires precise cutting in the substrate in order to create grooves, its fabrication is quite a complex task. Due to unavailability to precise cutting tools, this design could not be fabricated. Hence, only simulated results are available for this proposed design.

In **Chapter 4**, the design and analysis of a super-wide band slotted MPA are discussed. Improvement in various parameters like bandwidth and return loss is observed with inclusion of slots, changes in ground and change of material, etc. The main objective of this design was to get a wide band covering wide range of applications. Although, reduction in impedance bandwidth is obtained after testing the fabricated design but that is due to various losses and errors involved. The measured impedance bandwidth of the wide band obtained from 1.62 GHz to 11.86 GHz is approximately 10.24 GHz, corresponding to an impedance bandwidth of 152%. It covers R, D, S, E, G and X frequency bands. Therefore, it covers applications like GSM 1800, GSM 1900, IMT, WLAN, Bluetooth, WiMAX and satellite applications as well.

In **Chapter 5**, the design and analysis of a novel circular MPA using DGS technique are included. This design covers number of frequency bands, namely S, E, G, X, Ku bands. Therefore, it covers wide range of applications. Bandwidth enhancement and reduction in return loss is achieved through:

- Circular shape of the patch
- DGS
- Rectangular slot in the circular patch
- Change in material of the substrate

This design could be used in applications such as WiMAX, WLAN and satellite applications as well. DGS and the rectangular slot in patch played an important role for obtaining such a wide band. Although, due to errors and various losses, the measured bandwidth is lesser than the simulated results, but still we obtained an appreciable value of bandwidth and gain. The measured impedance bandwidths are about 1.84 (3.28 to 5.12 GHz) and 6.14 GHz (9.36 to 15.5 GHz), corresponding to an impedance bandwidth of 43.8% and 49.4% respectively. The reduction in the bandwidth obtained in measurement

from the simulated result is may be attributed to factors such as fabrication losses, connector losses, cable losses, etc.

As an overall conclusion, all the planned works and the objectives of this project that is suppression of the surface waves, improvement of return loss, improvement of bandwidth, have been successfully implemented and achieved.

6.2 Scope for future work

The research work on rectangular dielectric resonator antenna and microstrip patch antenna presented in the thesis can be further extended in following ways:

- To miniaturize the PBG structure to achieve the compact antenna designs.
- Study different structures utilizing PBG and DGS in order to improve the performance of the microwave devices.
- The performance of the antennas can be optimized by employing appropriate optimization techniques and therefore the gain and bandwidth can be increased.

LIST OF PUBLICATIONS

1. Apleen Kaur, Jaswinder Kaur “A novel slotted microstrip patch antenna with super wide-band (SWB) performance feasible for wireless applications”, *IET Microwaves Antennas and Propagation*, 2016. **(Communicated)**
2. Apleen Kaur, Jaswinder Kaur “A novel circular patch microstrip antenna with DGS for E, G, X and Ku-band applications”, *Chinese Journal of Electronics*, 2016. **(Communicated)**

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