VOT 79017

ELECTROMAGNETIC BAND GAP (EBG) STRUCTURE IN MICROWAVE DEVICE DESIGN

(STRUKTUR ELEKTRO MAGNETIK SELAR JALUR (EBG) DALAM REKA BENTUK PERANTI GELOMBANG MIKRO)

MOHAMAD KAMAL A. RAHIM

RESEARCH VOTES NO:
79017

Jabatan Kejuruteraan Radio
Fakulti Kejuruteraan Elektrik
Universiti Teknologi Malaysia

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UNIVERSITI TEKNOLOGI MALAYSIA

BORANG PENGESAHAN
LAPORAN AKHIR PENYELIDIKAN

JUDUL: **ELECTROMAGNETIC BAND GAP (EBG) STRUCTURE IN MICROWAVE DEVICE DESIGN**

Saya **MOHAMAD KAMAL A. RAHIM**
(HURUF BESAR)

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Nama & Cop Ketua Penyelidik

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MOHAMAD KAMAL A. RAHIM

Jabatan Kejuruteraan Radio
Fakulti Kejuruteraan Elektrik
Universiti Teknologi Malaysia

JUN 2008

DECLARATION

I declare that this thesis entitled "Electromagnetic Band gap (EBG) structure in microwave device design " is the result of my own research except as cited in the references

Signature : ....

Name of Supervisor : PROF. MADYA DR. MOHAMAD KAMAL B. ABD. RAHIM

Date : JUNE 2008

ACKNOWLEDGEMENT

In finishing this project, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I am also very thankful to Mr. Thelaha, a Ph.D. Student of UTM, Mr Osman Ayop, a Master Student of UTM and all my fellow researchers for their helps. Without their continued support and interest, this project would not successfully complete as good as presented here.

I am also indebted to Universiti Teknologi Malaysia (UTM) for funding my research. Besides, librarians at UTM also deserve special thanks for their assistance in supplying the relevant literatures.

My fellow researchers should also be recognized for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. Last but not least, I am truly grateful for having such a supportive family members.

ELECTROMAGNETIC BAND GAP (EBG) STRUCTURE IN MICROWAVE DEVICE DESIGN

(Keywords: Electromagnetic band gap, band reject, Microstrip antenna)

The research in the field of electromagnetic band gap or well known as EBG structure has becoming attractive in antenna community. This structure has a unique property such as the ability to suppress the propagation of surface wave in specific operating frequency defined by the EBG structure itself.

The electromagnetic band gap structure always used as a part of antenna structure in order to improve the performance of the antenna especially for improves the gain and radiation pattern. In this project, microstrip antenna is used due to the advantages such as easy and cheap fabrication, light weight, low profile and can easily integrated with microwave circuit. This project involves the investigation of various EBG structure and the integration of the EBG structure with various antenna design through the simulation and fabrication process. The simulation is done by using microwave office software (MWO) and CST. The fabrication process involves the photo etching technique while the substrate used for antenna fabrication is FR4 board which has relative permittivity 4.7 and tangent loss 0.019.

From the simulation done, most of the antenna which has been incorporated with EBG structure show the enhancement of the performance in term of radiation pattern, gain and return loss, S_{11}. The 1 dB gain increment is noticed for microstrip array antenna with incorporated with EBG structure. The radiation pattern also improves where the side and back lobes are decreasing by using EBG structure surrounding the patch antenna. Other than that, the EBG structure also can be used as a band reject especially for ultra wide band application which operates at very wide frequency ranges. The simulation and measurement result for ultra wide band with and without band rejection has been shown in this thesis.

Key Researcher:

Assoc. Prof. Dr. Mohammad Kamal A. Rahim (Head)
Mr Osman Ayop
Mr. Thelaha Masri
Mr Nazri A. Karim
Mr Huda A. Majid

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Tel No. : 07-5536038
Vote No. : 79017

STRUKTUR ELEKTOMAGNETIK SELAR JALUR DALAM MEREKA BENTUK PERANTI GELOMBANG MIKRO

(Katakunci: Elektromagnetik selar jalur, Penolakan jalur, Antena mikrojalur)

Penyelidikan dalam bidang electromagnetic selar jalur atau lebih dikenali sebagai struktur EBG telah menjadi satu bidang yang cukup menarik dan mendapat perhatian dalam komuniti antena. Struktur ini memiliki sifat yang unik iaitu keupayaannya untuk menekan perambatan golombang permukaan untuk frekuensi kendalian tertentu yang dipengaruhi oleh struktur EBG itu sendiri.

Struktur elektomagnetik selar jalur selalunya dijadikan sebahagian daripada struktur antena untuk membaiki prestasi antena terutamanya untuk meningkatkan gandaan antena dan juga membaiki corak pemancaran antena. Dalam projek ini, mikrostrip antenna digunakan kerana memiliki kelebihan berbanding antenna lain seperti mudah dan murah untuk membuat reka bentuk, ringan, strukturnya yang nipis, dan juga mudah untuk dipadukan dengan litar gelombang mikro. Projek ini melibatkan teknik mengikisan cahaya manakalan substrat yang digunakan ialah FR4 yang mempunyai kebertelusan relatif 4.7 dan kehilangan tangen 0.019.

Daripada simulasi yang dijalankan, hampir kesemua antenna yang digunakan bersama struktur EBG menunjukkan peningkatan dalam prestasi bagi corak pemancaran, gandaan dan juga kehilgan kembali, S_{11}. Peningkatan sebanyak 1 dB dilihat untuk antenna mikrostrip tatasusunan yang digunakan bersama struktur EBG. Corak pemancaran juga bertambah baik di mana alur tepi dan alur belakang telah berkurang dengan meletakkan struktur EBG di sekeliling struktur antena tersebut. Selain itu, struktur EBG juga boleh digunakan sebagai penolakan jalur untuk sebahagian jalur terutamanya untuk aplikasi antenna “Ultra Wide band” yang beroperasi pada jalur frekuensi sangat besar. Keputusan dari simulasi dan pengukuran untuk antenna “ultra wide band” dengan dan tanpa struktur penolakan jalur telah ditunjukkan di dalam thesis ini.

Penyelidik :

Prof. Madya Dr. Mohamad Kamal A. Rahim (Ketua)
Mr Osman Ayop
Mr. Thelaha Masri
Mr Nazri A. Karim
Mr Huda A. Majid

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c	-	Speed of Light
E	-	Electric Field
H	-	Magnetic Field
Z	-	Impedence
ε	-	Permittivity
μ	-	Permeability
λ	-	Wavelength
β	-	Propagation Constant
σ	-	Conductivity of Metal
η	-	Normalized wave impedence
Γ	-	Reflection Coefficient

End of Project Report For ScienceFund

A. Description of the Project

1. Project number: 79017

2. Project title: ELECTROMAGNETIC BAND GAP (EBG) STRUCTURE IN MICROWAVE DEVICE DESIGN

3. Project leader: Assoc. Prof Dr Mohamad Kamal A Rahim

4. Project Team:

(Please provide an assessment of how the project team performed and highlight any significant departures from plan in either structure or actual man-days utilised)

Assoc. Prof. Dr. Mohammad Kamal A. Rahim
Mr Osman Ayop
Mr. Thelaha Masri
Mr Huda A. Majid

5. Industrial Partnership:

(Please describe the nature of collaborations with relevant industry)
At this moment, no collaborations with relevant industries involve.

6. National/International Collaboration

(please identify research organisations and describe the nature of collaboration)
No research organisation involve.

7. Project Duration: ___20___months

8. Budget Approved: RM 79,298.00

B. Objectives of the project

1. Socio-economic Objectives (SEO)

Which socio-economic objectives are addressed by the project? (Please identify the Research Priority Area , SEO Category and SEO Group under which the project falls. Refer to the Malaysian R&D Classification System, 4th Edition.

Research Priority Area

SEO Category: Information Communication and Technology (ICT)

SEO Group : Communication Sevices

2. Fields of Research (FOR)

Which are the two main FOR Categories, FOR Groups, and FOR Areas of your project? (Please refer to the Malaysian R&D Classification System, 4th Edition)

a. Primary field of research

FOR Category: Information Communication and Technology (ICT)
FOR Group : Communication
FOR Area: Antenna Technology

b. Secondary Field of research

FOR Category: Information Communication and Technology (ICT)
FOR Group : Communication
FOR Area: Wireless Communication and Technologies

C. Objectives achievement

- **Original project objectives** (Please state the specific project objectives as described in Section II of the Application Form)

1. To design and develop the new electromagnetic band gap (EBG) structure for microstrip antenna application.
2. To develop a prototype of electromagnetic band gap structure for 2.4 GHz ISM band.

- **Objectives Achieved** (Please state the extent to which the project objectives were achieved)

New structure of electromagnetic band gap (EBG) has been succesfully designed and fabricated operating at 2.4 GHz ISM. The prototype of this EBG structure has been tested and verify with the simulation using AWR and CST software.This structure has been incorporated with the antenna and the performance of this antenna has been analysed

- **Objectives not achieved** (Please identify the objectives that were not achieved and give reasons)

D. Technology Transfer/Commercialisation Approach, if any. (Please describe the approach planned to transfer/commercialise the results of the project)

A new structure of electromagnetic band gap (EBG) structure has been successfully designed and fabricated. For a commerciallisation approach, it's need some extra work in a market planning and need some funding for the packaging of this antenna

E. Assessment of Research Approach (Please highlight the main steps actually performed and indicate any major departure from the planned approach or any major difficulty encountered)

According to the project schedule.

F. Assessment of the Project Schedule (Please make any relevant comment regarding the actual duration of the project and highlight any significant variation from plan)

Project follow as schedule

G. Assessment of Project Costs (Please comment on the appropriateness of the original budget and highlight any major departure from the planned budget)

The budget is not enough to buy any equipment on network analyzer. We managed to use the echo analyzer that has been bought from the prvious grant. For high frequency design we have a limitation on the measurement process..

H. Additional Project Funding Obtained (In case of involvement of other funding sources, please indicate the source and total funding provided)

The other funding is from EScience . The project is Design and Development of fractal antenna. We are using the same equipment for both project.

I. Benefits of the Project (Please identify the actual benefits arising from the project as defined in Section III of the Application Form. For examples of outputs, organisational outcomes and sectoral/national impacts, please refer to Section III of the Guidelines for the Application of R&D Funding under ScienceFund)

Prototype of the ebg structure with antenna operating at 2.4 GHz ISM band using planar structure.

1. Direct Outputs of the Project (please describe as specifically as possible the outputs achieved and provide an assessment of their significant to users)

i . Technical contribution of the project

a. What was the achieved direct output of the project:

For basic oriented research projects ?

☐ Algorithm

☐ Structure

- [ ] Data
- [ ] Other, please specify: ______________________________

For applied research (technology development) projects:

- [ ] Method/technique
- [x] Demonstrator/prototype
  Prototype of EBG structure incorporated with antenna operating at 2.4 GHz ISM band.

- [ ] Product/component
- [ ] Process
- [ ] Software
- [ ] Other, please specify:

b. How would you characterise the quality of this output?

- [ ] Significant breakthrough
- [x] Major improvement
- [ ] Minor improvement

ii. Contribution of the project to knowledge

a. How has the output of the project been documented?

- [x] Detailed project report
- [ ] Product/process specification documents
- [x] Other, please specify: Papers publication

b. Did the project create an intellectual property stock?

- [ ] Patent obtained
- [ ] Patent pending
- [x] Patent application will be filed
- [ ] Copyright

c. What publications are available?

- [ ] Articles (s) in scientific publications — How many: ______
- [x] Paper(s) delivered at conferences/seminars — How many: 4 papers

- [ ] Book
- [ ] Other, please specify:

d. How significant are citations of the results?

- [ ] Citations in national publications — How many: ______
- [ ] Citations in international publications — How many: ______
- [x] None yet
- [ ] Not known

2. Organisational Outcomes of the Project (Please describe as specifically as possible the organisational benefits arising from the project and provide an assessment of their significance)

i. Contribution of the project to expertise development

a. How did the project contribute to expertise?

- [ ] PhD degrees — How many: ______
- [x] MSc degrees — How many: 2
- [ ] Research staff with new specialty — How many: ______
- [ ] Other, please specify: ______

b. How significant is this expertise?

- [x] One of the key areas of priority for Malaysia (ICT Research Area)
- [ ] An important area, but not a priority one

ii. Economic contribution of the project?

a. How has the economic contribution of the project materialised?

- [x] Sales of manufactured product/equipment
- [ ] Royalties from licensing
- [ ] Cost savings
- [ ] Time savings
- [ ] Other, please specify: ______

b. How important is this economic contribution?

- [ ] High economic contribution — Value: RM ______
- [x] Medium economic contribution — Value: RM -

☐ Low economic contribution Value: RM ______________________

c. When has this economic contribution materialised?

☐ Already materialised

☐ Within months of project completion

☐ Within three years of project completion

☐ Expected in three years or more

☑ Unknown

iii. Infrastructural contribution of the project

a. What infrastructural contribution has the project had?

☐ New equipment (Spectrum & Eco analyzer) Value: RM ______________________

☐ New/improved facility Investment: RM ______________________

☐ New information networks

☑ Other, please specify: Computers RM 3,450.00

b. How significant is this infrastructural contribution for the organisation?

☑ Not significant/does not leverage other projects

☐ Moderately significant

☐ Very significant/significantly leverages other projects

iv. Contribution of the project to the organisation's reputation

a. How has the project contributed to increasing the reputation of the organisation

☐ Recognition as a Center of Excellence

☐ National award

☐ International award

☐ Demand for advisory services

☑ Invitations to give speeches on conferences

☐ Visits from other organisations

☐ Other, please specify: ______________________

b. How important is the project's contribution to the organisation's reputation?

☐ Not significant

☑ Moderately significant

☐ Very significant

3. National Impacts of the Project (If known at this point in time, please describe as specifically as possible the potential sectoral/national benefits arising from the project and provide an assessment of their significance)

i. Contribution of the project to organisational linkages

a. Which kinds of linkages did the project create?

☐ Domestic industry linkages

☐ International industry linkages

☐ Linkages with domestic research institutions, universities

☑ Linkages with international research institutions, universities

b. What is the nature of the linkages?

☐ Staff exchanges

☐ Inter-organisational project team

☐ Research contract with a commercial client

☑ Informal consultation

☐ Other, please specify: ______

ii. Social-economic contribution of the project

a. Who are the direct customer/beneficiaries of the project output?

Customers/beneficiaries:	Number:
Wireless industries such as mobile , satellite, microwave and etc.	To all wireless communication industries using 2.4 GHz ISM band.

b. How has/will the socio-economic contribution of the project materialised?

☐ Improvements in health

☐ Improvements in safety

☐ Improvements in the environment

- [ ] Improvements in energy consumption/supply
- [ ] Improvements in international relations
- [x] Other, please specify: Improvement in wireless engineering knowledgement

c. How important is this socio-economic contribution?

- [ ] High social contribution
- [x] Medium social contribution
- [ ] Low social contribution

d. When has/will this social contribution materialised?

- [ ] Already materialised
- [ ] Within three years of project completion
- [ ] Expected in three years or more
- [x] Unknown

Date: 12 August 2008 **Signature:**

UNIVERSITI TEKNOLOGI MALAYSIA
Research Management Centre

PRELIMINARY IP SCREENING & TECHNOLOGY ASSESSMENT FORM

(To be completed by Project Leader submission of Final Report to RMC or whenever IP protection arrangement is required)

1. **PROJECT TITLE IDENTIFICATION** :

ELECTROMAGNETIC BAND GAP STRUCTURE IN MICROWAVE DEVICES

Vote No: **79017**

2. **PROJECT LEADER** :

Name : PROF. MADYA DR. M0HAMAD KAMAL A. RAHIM

Address : JABATAN KEJURUTERAAN RADIO, FAKULTI KEJURUTERAAN ELEKTRIK, UNIVERSITI TEKNOLOGI MALAYSIA, 81310 SKUDAI, JOHOR

Tel : 07 5536088 Fax : - 07-5566272 e-mail : mkamal@fke.utm.my

3. **DIRECT OUTPUT OF PROJECT** *(Please tick where applicable)*

Scientific Research	Applied Research	Product/Process Development
☐ Algorithm	☐ Method/Technique	☐ Product / Component
☐ Structure	■ Demonstration / Prototype	☐ Process
☐ Data		☐ Software
☐ Other, please specify	☐ Other, please specify	☐ Other, please specify
____________	____________	____________
____________	____________	____________
____________	____________	____________

4. **INTELLECTUAL PROPERTY** *(Please tick where applicable)*

☐ Not patentable
■ Patent search required
☐ Patent search completed and clean
☐ Invention remains confidential
☐ No publications pending
☐ No prior claims to the technology

☐ Technology protected by patents
☐ Patent pending
☐ Monograph available
☐ Inventor technology champion
☐ Inventor team player
☐ Industrial partner identified

5. LIST OF EQUIPMENT BOUGHT USING THIS VOT

- Computer

6. STATEMENT OF ACCOUNT

a)	APPROVED FUNDING	RM : 79,298.00
b)	TOTAL SPENDING	RM : 79,297.52
c)	BALANCE	RM : 0.48

7. TECHNICAL DESCRIPTION AND PERSPECTIVE

Please tick an executive summary of the new technology product, process, etc., describing how it works. Include brief analysis that compares it with competitive technology and signals the one that it may replace. Identify potential technology user group and the strategic means for exploitation.

a) Technology Description

This project begins with understanding the concept of the planar structure antenna technologies and the behavior of electromagnetic band gap (EBG) structure. The EBG structures have been used to improve the performance of the radiation pattern and gain of the antennas. In this project the microstrip antenna is being used due to the advantages such as easy and cheap fabrication, light weight, low profile and can easily integrated with microwave circuit. This project involves the design of a new EBG structure incorporated with microwave circuit especially antenna. This project involves the design of a new EBG structure incorporated with various antenna design through simulation and fabrication process. The simulation has been done using microwave office (MWO) and CST simulation software. The fabrication process involves the technique of photo etching. The material used for antenna fabrication is FR4 board which has arelative permittivity 4.7 and loss tangent of 0.019. The simulated and measured result has been compared and analyzed between the antenna with and without EBG structure..

b) Market Potential

Suitable for microstrip antenna design incorporated with EBG in order to improve the gain of the antenna

c) Commercialisation Strategies

This product suitable to enhance the performance of microstrip antennnas. So, for the cormerciallization need some extra work and funding for final packaging of the product.

8. RESEARCH PERFORMANCE EVALUATION

a) FACULTY RESEARCH COORDINATOR

	Excellent	Very Good	Good	Satisfactory	Fair	Weak
Research Status	(✓)	( )	( )	( )	( )	( )
Spending	(✓)	( )	( )	( )	( )	( )
Overall Status	(✓)	( )	( )	( )	( )	( )

Comment/Recommendations :

For a 79k funding, the outputs (academic papers, human resource for partial support of PhD or Master students) is well beyond the normally expected outputs.
Recommendation for further funding under a new research proposal.

PROF. DR. SHAMSUDIN BIN HJ. MOHD AMIN
DEPUTY DEAN (POST GRADUATE & RESEARCH)
FACULTY OF ELECTRICAL ENGINEERING
UNIVERSITI TEKNOLOGI MALAYSIA
81310 UTM, SKUDAI

....
Signature and stamp of
JKPP Chairman

Name : ....

Date : 26/08/08

b) RMC EVALUATION

Research Status	( )	( )	( )	( )	( )	( )
Spending	( )	( )	( )	( )	( )	( )
Overall Status	( )	( )	( )	( )	( )	( )
	Excellent	Very Good	Good	Satisfactory	Fair	Weak

Comments :-

Recommendations :

☐ Needs further research

☐ Patent application recommended

☐ Market without patent

☐ No tangible product. Report to be filed as reference

…………………………………………..

Signature and Stamp of Dean / Deputy Dean
Research Management Centre

Name : ……………………………………………

Date : ……………………………………………

CHAPTER 1

INTRODUCTION

1.1 Introduction

Antenna is one of the important elements in the RF system for receiving or transmitting the radio wave signals from and into the air as the medium. Without proper design of the antenna, the signal generated by the RF system will not be transmitted and no signal can be detected at the receiver. Antenna engineering is a vibrant field which is bursting with activity and is likely to remain so in the foreseeable future. Many types of antenna have been designed to cater with variable application and suitable for their needs. One of the types of antenna is the microstrip antenna. The microstrip antenna has been said to be the most innovative area in the antenna engineering with its low material cost and easy to fabricate which the process can be made inside universities or research institutes.

The idea of microstrip antenna was first presented in year 1950's but it only got serious attention in the 1970's [2]. A microstrip antenna is basically a metallic patch printed on thin, grounded dielectric substrate. The early microstrip patch was originally fed with a coaxial line through the bottom or by coplanar microstrip line.

The latter type of microstrip antenna incorporates feed network and circuitry fabricated on the same substrate [2].

Due to microstrip antennas advantages such as low profile and the capability to be fabricated using the printed circuit technology, antenna developers and researchers can come out with a novel design of antenna in-house which will reduce the cost of its development. Through printed circuit technology, the antenna can be fabricated in mass volume which contributes to cost reduction. The selection of the substrate material could also contribute to cost reduction [4].

1.2 Problem Statement

In the microstrip antenna design, the main problem to be faced is the propagation of surface wave on the substrate. The propagating of surface wave will reduce the efficiency of the antenna. This is due to the increasing of the side and back radiation. The front radiation is decreasing and the antenna gain is decreasing. In the array design, another problem occurred. Mutual coupling effect will occur when more than one element placed near each other. This problem occurs in the E-plane direction of the microstrip antenna. This project introduce an EBG structure reduce the effect of surface wave and mutual coupling. The radiation pattern and the return loss of the antenna have been obtained by simulation and measurement. The antenna properties such as HPBW, co-polar, cross-polar and gain in both antennas with and without EBG structure will be investigated in both simulation and measurement.

1.3 Objectives

The main objective of this project is to design and develop Electromagnetic band gap for microstrip antenna application. Next, the behavior and properties of EBG structure will be investigated by simulation and measurement. The performance of microstrip array antenna will be compared for integration with and without EBG structure.

1.4 Scope of Project

This project focuses on the development of the antenna to meet the satisfied performance that can be used in WLAN system.

The first part of the project is to study the concept of microstrip patch antenna, microstrip array antenna, microstrip antenna with various types of feeding technique and electromagnetic band gap (EBG) structure.

In the second part of the project, the performance of the EBG structure, microstrip array antenna with and without EBG structure will be investigated by performing numerical simulation using microwave office Software (MWO) and CST. The antenna will be designed to operate at frequency of 2.4 GHz. The band gap characteristic of EBG structure must cover the bandwidth of the microstrip array antenna to improve the performance.

The third part is doing the fabrication of the antenna after obtaining the optimum result from simulation. The photo etching techniques is used because this technique is easy to be done in our microwave lab. There are thirteen structures that have been successfully fabricated. The structures fabricated are 2 by 2 and 2 by 1 microstrip array antenna with and without EBG structure respectively, 3 x 3 Slotted patch EBG structure, 3 by 3 cross patch EBG structure, single patch microstrip antenna by using various feed design, antenna array incorporated with EBG as an artificial magnetic conductor, and the last one is the UWB antenna with and without the band rejection.

The forth part of the project is by doing the measurement of the antenna properties. The value of S_{11} and S_{21} of the antenna and EBG structure respectively has been measured by using Marconi Instruments. The radiation pattern of the antenna has been measured by using anechoic chamber, Gigahertz signal generator, and Agilent network analyzer.

Lastly, the performances of the antenna with and without EBG structure will be compared in term of simulation and measurement.

1.5 Project Background

EBG structure recently is developed rapidly due to its unique properties to suppress the propagation of surface wave in microstrip antenna. EBG structure is also known as a high impedance surface due to its ability to suppress the propagation of surface wave at the certain operational frequency. This structure is also has ability to block the effect of mutual coupling effect in array application. Due to its unique properties defined by the structure itself, this project is done to see the ability of the EBG structure to improve the performance of microstrip array antenna especially in term of radiation pattern and gain. The 3 by 3 Slotted patch EBG structure has been designed and this EBG structure is also designed with integration to the microstrip array antenna. Other than that, various types of EBG have been discussed in this project such as cross patch EBG, Sierspinski Gasket, and mushroom like EBG structure. This EBG structure has been incorporated with various types of microstrip antenna to investigate the performances.

1.6 Organisation of Thesis

This thesis consists of five chapters describing all the work done in the project. The thesis organization is generally described as follows.

The first chapter explains the introduction of the project. Scope of the project background and the problem statements has been described in this chapter. This chapter sets the works flow according to the objectives and the scope of project.

Chapter two discusses the theory of microstrip antenna and the equation needed to design the microstrip elements. This chapter explains the basic parameter of microstrip antenna, different types of microstrip antenna and different feeding technique of microstrip antenne. The method of analysis is also explained for the simulation software.

Chapter three describes the steps in designing the microstrip array antenna, EBG structure and the combination of the EBG structure to the microstrip antenna. The design starts from calculation and followed by simulation, fabrication and the measurement. Some modification of the antenna has been done.

Result and analysis are presented in chapter four. The performance of all antennas that has been designed were made between simulation and measurement

The last chapter concludes the project with some future suggestion to improve the design of the antenna and EBG structure.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Antenna is a device used for radiating and receiving an electromagnetic wave in free space [1]. The antenna seems to be an interface between transmission lines and free space. Antenna is divided into two categories that are passive antenna and active antenna. Passive antenna is the reciprocal devices. It can be used whether for transmitting or receiving the information signal. Active antenna is not the reciprocal devices. The simple antenna is like the isotropic antenna where it can radiate signal for all direction but it is not practical built because the practical antenna is a half wave dipole antenna. Antennas can be categorized into 9 types which are [2]:

i. Active integrated antennas
ii. Antenna arrays (including smart antennas)
iii. Dielectric antennas (such as dielectric resonant antennas)
iv. Microstrip antennas (such as patches)
v. Lens antennas (sphere)
vi. Wire antennas (such as dipoles and loops)
vii. Aperture antennas (such as pyramidal horns)

viii. Reflector antennas (such as parabolic dish antennas)

ix. Leaky wave antennas

2.2 Antenna properties

When dealing with RF antenna, some important concept should be learn to design a good antenna performance. There are polarization, radiation pattern, half power beam width (HPBW), gain, voltage standing wave ratio (VSWR), efficiency and bandwidth [3].

Polarization is the physical orientation of the antenna in a horizontal or vertical position. Horizontal Polarization mean the electric field is parallel to the ground while vertical Polarization mean the electric field is perpendicular to the ground. Antenna is not being able to communicate effectively with each other if the polarized is not in the same way [3].

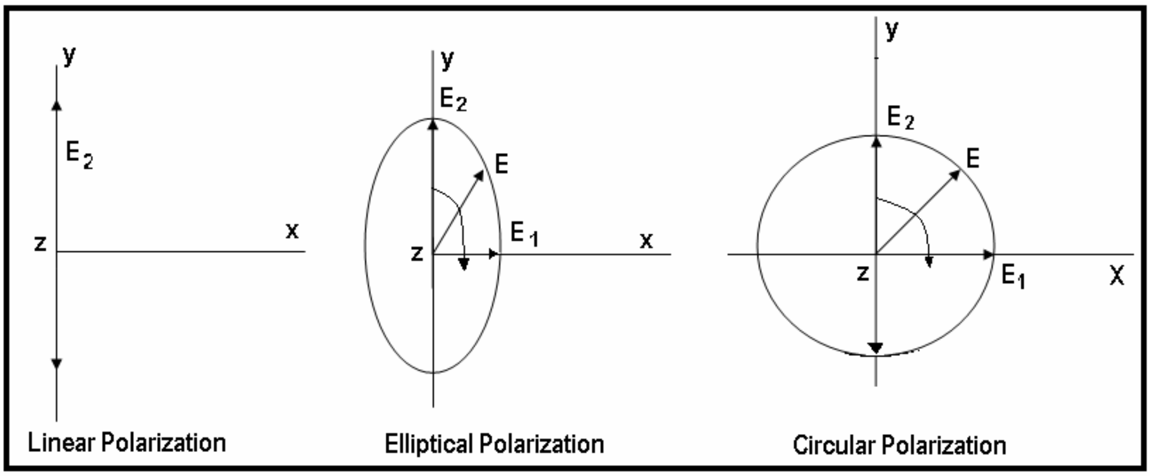


Figure 2.1: Orientation of the radiated wave's electrical field

Radiation pattern provides information which describes how an antenna directs the energy it radiates and it is determined in the far field region. The information is presented in the form of a polar plot for both horizontal (azimuth) and vertical (zenith or evaluation) sweeps. There are four quantitative aspects will be define in radiation pattern such as 3 dB beam width, directivity, side lobe levels and front to back ratio. The radiation pattern could be divided into main lobes, side lobes and back lobes [3].

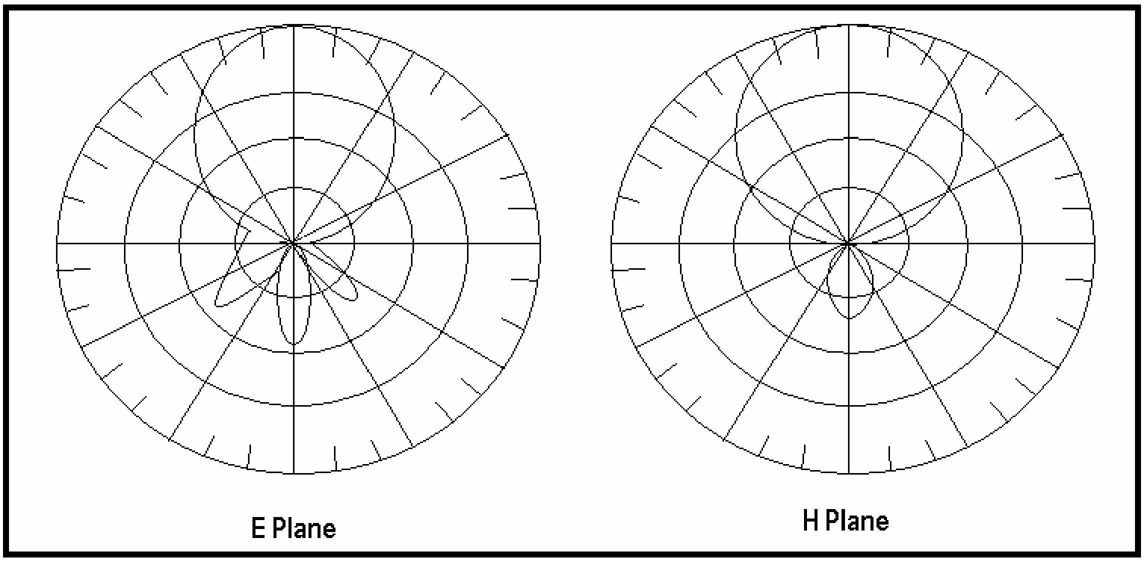


Figure 2.2: 2D radiation pattern

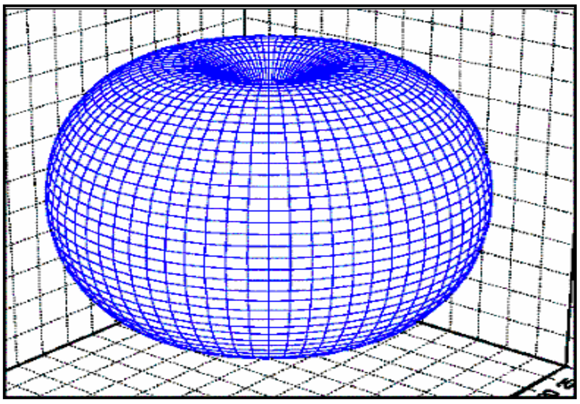


Figure 2.3: 3D radiation pattern

Beam width is a measure of the angular spread of the radiated energy or of the angular spread from which energy can readily be received the “width” of the RF signal beam that the antenna transmits. There are two type of beam width where both are measure in degrees. Firstly is the horizontal beam width which means it is perpendicular to the earth surface and another one is vertical beam width where it is parallel to earth surface. By controlling the width of the beam, the gain of antenna can be increased or decreased. By narrowing the beam width, the gain will increase and it is also creating sectors at the same time [3].

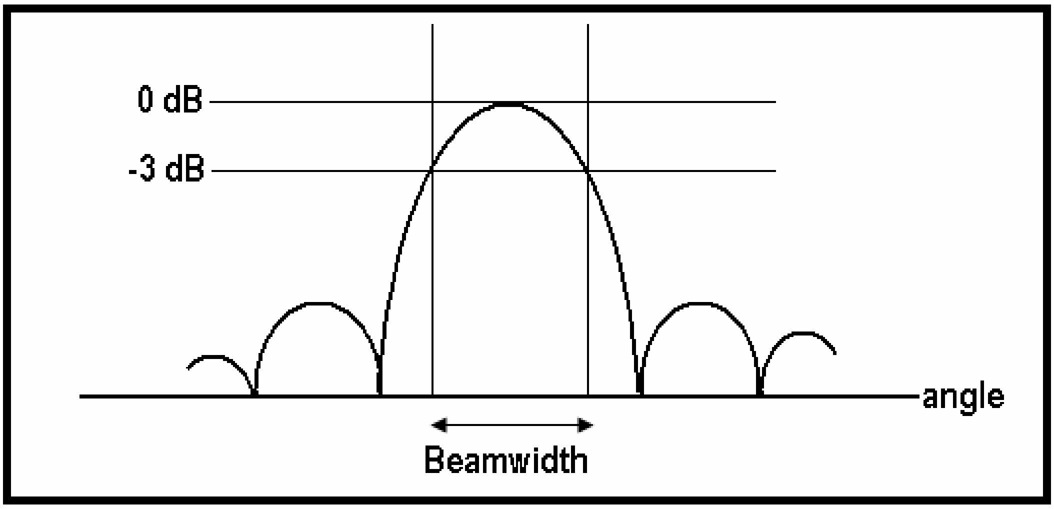


Figure 2.4: Beamwidth

The gain of the antenna can be described as how far the signal can travel through the distance. When the antenna has a higher gain it does not increase the power but the shape of the radiation field will lengthen the distance of the propagated wave. The higher the gain, the farther the wave will travel concentrating its output wave more tightly [4]. The gain of an antenna must equal to its directivity if the antenna 100% in all efficient. Normally there are two types of reference antenna can be used to determine the antenna gain. Firstly is the isotropic antenna where the gain is given in dBi and secondly is the half wave dipole antenna where the gain is given in dBd. The relationship between dBi and dBd is given by [4];

$$\text{dBi} = \text{dBd} + 2.15 \text{ dB} \tag{2.1}$$

For all types of antenna, the gain can be determined by;

$$G = \frac{4\pi A_e}{\lambda^2} \tag{2.2}$$

Where, A_e = Effective aperture, related to the size of the antenna

Bandwidth refers to the range of frequency that the antenna will radiate efficiently where the antenna meets a certain set of specification performance criteria. When antenna power drop to half (3 dB), the upper and lower extremities of these frequency have been reached and the antenna no longer perform satisfactorily. The formula relates the bandwidth for the graph showed at figure 2.5 is given by [3];

$$BW = \frac{(f_2 - f_1)}{\sqrt{(f_2 + f_1)}} \text{ x } 100\% \tag{2.3}$$

The bandwidth is measured for return loss value below -10 dB

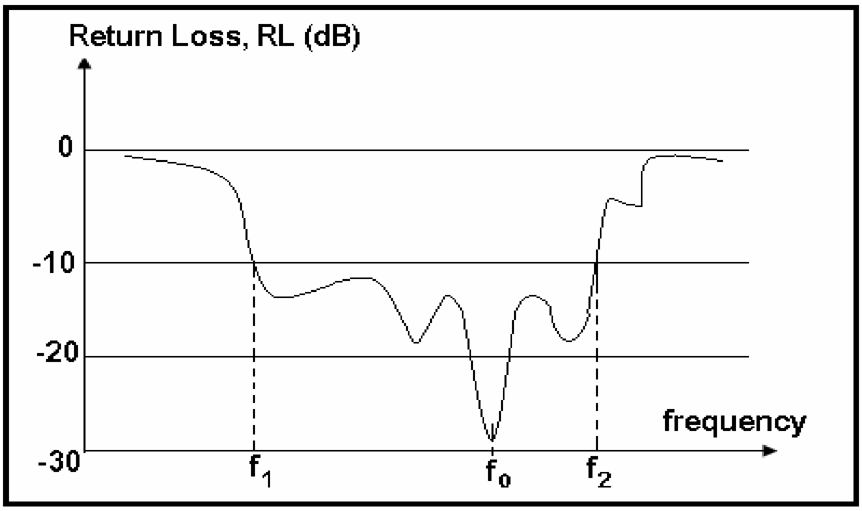


Figure 2.5: Graph of Return Loss vs frequency

Return Loss can be defined as;

$$R_L = -20 \log \left|\Gamma\right| \text{ dB} \tag{2.4}$$

2.3 Microstrip antenna

Among all these types of antennas, microstrip antenna has been one of the most variation in terms of feeding methods, shapes and architectures. Concept of microstrip radiators was proposed by Deschamps firstly in 1953 [5]. While in 1955, a pattern was issued in France in the names of Gutton and Baissinot. Next in 1970s, development was accelerated by the availability of good substrates, attractive thermal and mechanical properties and improved photolithographic techniques and better theoretical models [4].

The first practical antenna was developed by Howell and Munson. After a few years, an extensive research and development of microstrip antenna and array structure had been done to overcome the advantages of the single patch microstrip antenna [4].

Microstrip antenna can be defined as a structure that has a conducting patch printed on a grounded microwave substrate. The microstrip antenna technology is recently developed due to the advantages especially to their low profile structure. The structure is compact and attractive with has light weight, low volume and thin configurations which can be conformal. It surely has a low scattering cross section. When seeing to their linear and circular polarization, it is possible with simple feed. Feed lines and matching networks can be fabricated simultaneously with the antenna structure. By using this structure, dual frequency and dual band polarization antennas can be easily achieved with no cavity backing is required. This antenna structure can be easily integrated with other microwave integrated circuits [5].

Microstrip antenna has many advantages. This type of antenna can be made conformal to any surface. This allows the microstrip antenna suitable to be used for any wireless application for its ability to be concealed into the body of any device. This structure is low profile. As mentioned before, its ability to be easily concealed made microstrip antenna a low profile without sacrificing its aesthetic value [5-6].

Next, easy and cheap fabrication technique can be used. Microstrip antenna can be fabricated using printed circuit technique (photolithographic). The photolithographic technique offers accurate dimension to be print out on the dielectric board [5].

This antenna can be made with low cost. With photolithographic process, fabrication can be done the same as a photocopy machine because the mask of the design can be reused as many times as possible. The cost for making the mask is also cheap [5].

The fabrication into linear or planar arrays is also easy to be achieved. Array structure requires incorporation of many passive elements. The fabrication requires accuracy despite of the complexity of the array organisation. The photolithography technique can handle this situation easily because the design is printed out and transferred to the dielectric board like a copier [6].

Microstrip antenna is also easy for integration with microwave integrated circuit. Integration with microwave device can be realised because of the structure of the microstrip is also similar to a circuit board and the easiness to create a matching network for any microwave devices [6].

Although microstrip antenna possesses many advantages, it also has disadvantages. Microstrip antenna has narrow bandwidth. Usually for rectangular microstrip antenna, the bandwidth is below 5%. It is also has low gain approximately 6 dB. Then most of the microstrip antenna radiates into half space. Extraneous radiation from feed and junctions are also happened [6].

For high performance arrays complex feed structures are required. Polarization is difficult to achieve [7]. Large ohmic loss happened in the feed structure of arrays. Next, low power handling capability is also the problem in designing microstrip antenna. Excitation of surface wave occurs and reducing the efficiency of the antenna and increasing the power loses. Low efficiency of the antenna is due to surface wave effect. This antenna has limited power capacity and tolerance problems [8].

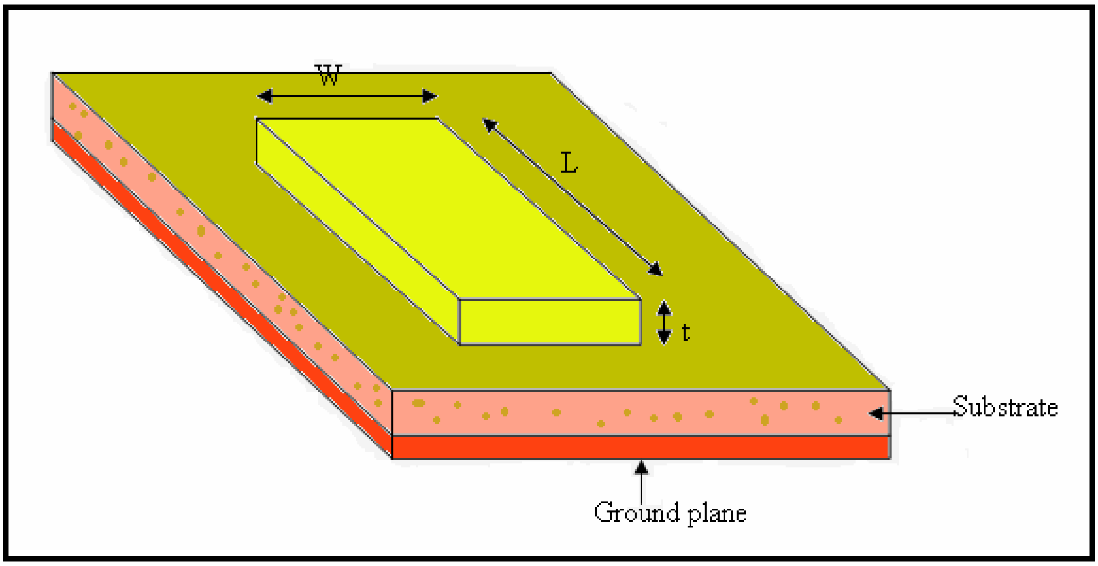


Figure 2.6: Microstrip patch antenna structure

Although the microstrip antenna has a lot of advantages, from time to time so many researches have been done to overcome these problems to satisfy the increasingly stringent systems requirements nowadays.

2.3.1 Improvements in Microstrip Antenna Design

Due to the several advantages of the microstrip antenna, many researches have tried to overcome as many disadvantages of a basic microstrip antenna as they can to improve the performance of the antenna. There are several methods are used to achieve the purpose. Recently, various shape of the microstrip antenna has been used such as slot patch antenna, H-shape, ring, triangle, U-shape and W-shape [9]. Several feeding methods also are used such as coaxial probe, transmission line, gap-couple, and inset feed [10-11]. Instead of using single element microstrip antenna, the arrays structure is also introduce especially to increase the gain of the antenna [8]. Scaling factors technique and integration with active devices are also introduced in the microstrip antenna design [11].

Base on the introduction of various shape of microstrip antenna, some parameters of the antenna can be enhanced such as enhanced bandwidth, increase gain, circular polarization and improve the efficiency [12]. The common shapes that are used for microstrip antenna design are rectangular, square, triangle, circle and hexagon. Shapes that are similar to letters can also be used for the microstrip antenna such as the letter O, H, F, W and E [11].

The proximity and the aperture-coupled feed are two examples of the feeding techniques that are claimed to be improving the bandwidth of the microstrip antenna. Base on the experiment, about 13% bandwidth can be achieved instead of using rectangular patch structure [11]. Even though this technique could produce a wide bandwidth, the modelling of the design cannot be done properly in the simulation software when involving array design such as the log periodic antenna [8].

Scaling technique can also be use to design a wide band or selective band antenna. While using the array technique, the directivity and the gain of the antenna can be increased and improved [11]. Microstrip array has been widely used in military for radar application, in air field and for satellite communication [8].

2.3.2 Feeding Techniques

There are five feeding techniques that can be used when design the microstrip antenna. There are coaxial probe / probe coupling, microstrip feed, proximity (Electromagnetically) coupled microstrip antenna, aperture couple microstrip antenna and coplanar waveguide feed. In this project, the coaxial probe and inset feed are used [11].

Coaxial probe is a coupling of power through a probe. A typical microstrip antenna is using N type coaxial connector. The coaxial connector is attached to the back side of the printed circuit board and the coaxial centre conductor after passing through substrate is soldered to the patch metallization. The location of feed point is determined for the given mode so that the best impedance match is achieved [11].

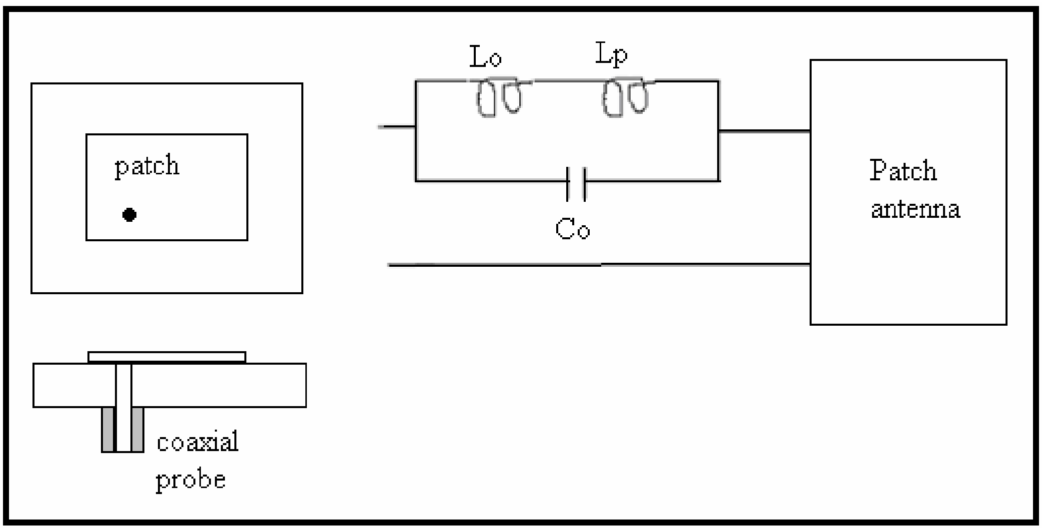


Figure 2.7: Coaxial probe

Microstrip feed is the excitation of the microstrip antenna by a microstrip line on the same substrate to be a natural choice because the patch can be considered an extension of the microstrip line and both can be fabricated simultaneously. The coupling between the microstrip line and the patch could be in the form of edge coupling or gap between them [11].

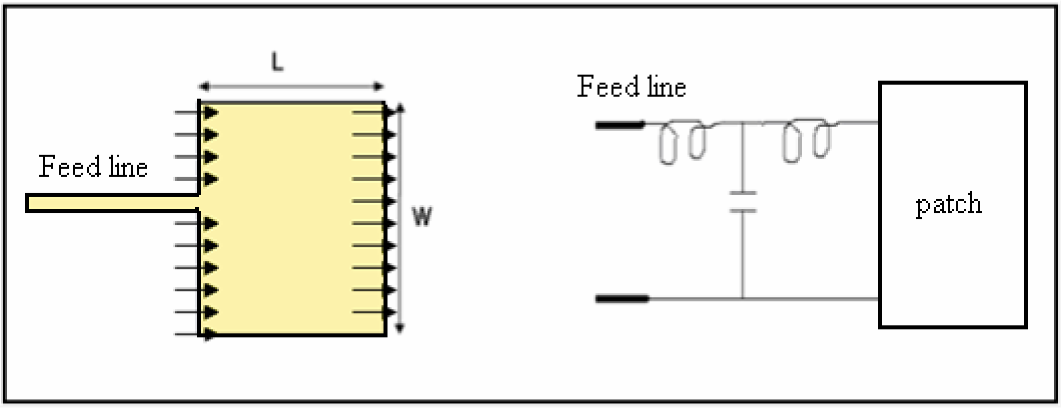


Figure 2.8: Microstrip feed at the radiating edge

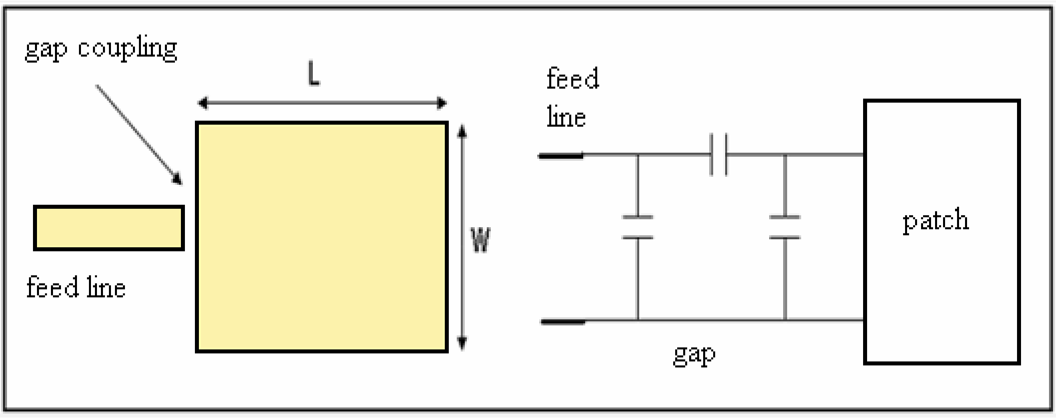


Figure 2.9: Gap – coupled microstrip feed

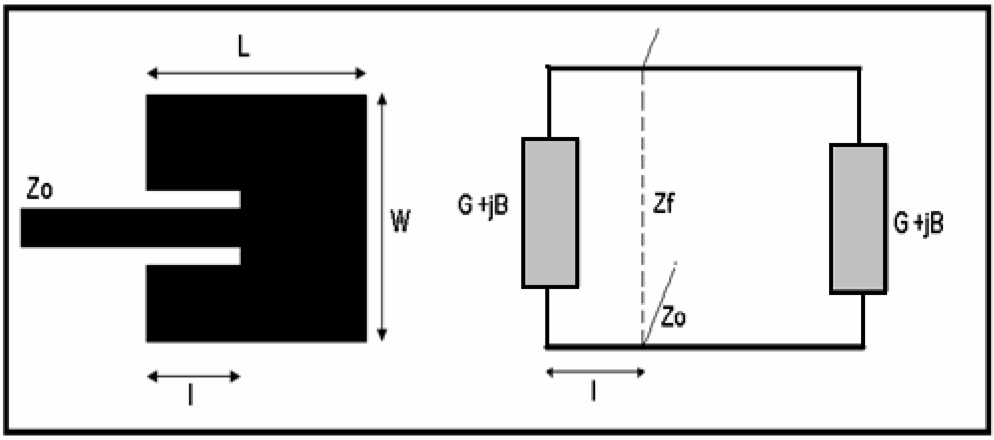


Figure 2.10: Inset Feed

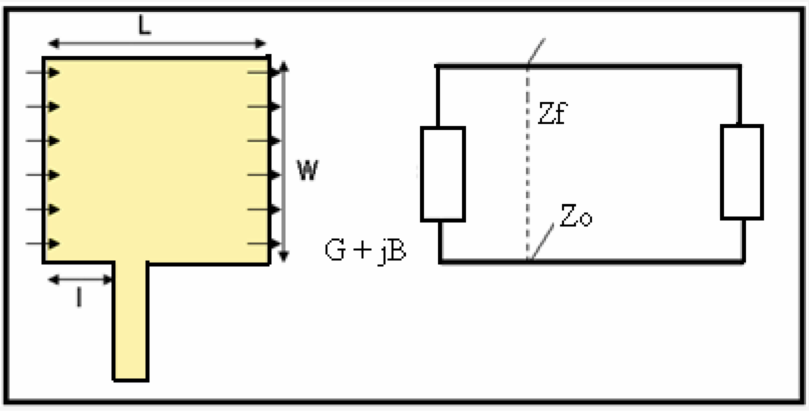


Figure 2.11: Non radiating edge

2.3.3 Microstrip line

Microstrip line is a conductor of width W printed on a thin grounded dielectric substrate of thickness d and relative permittivity ε_r. The geometry of the microstrip line is shown below [2].

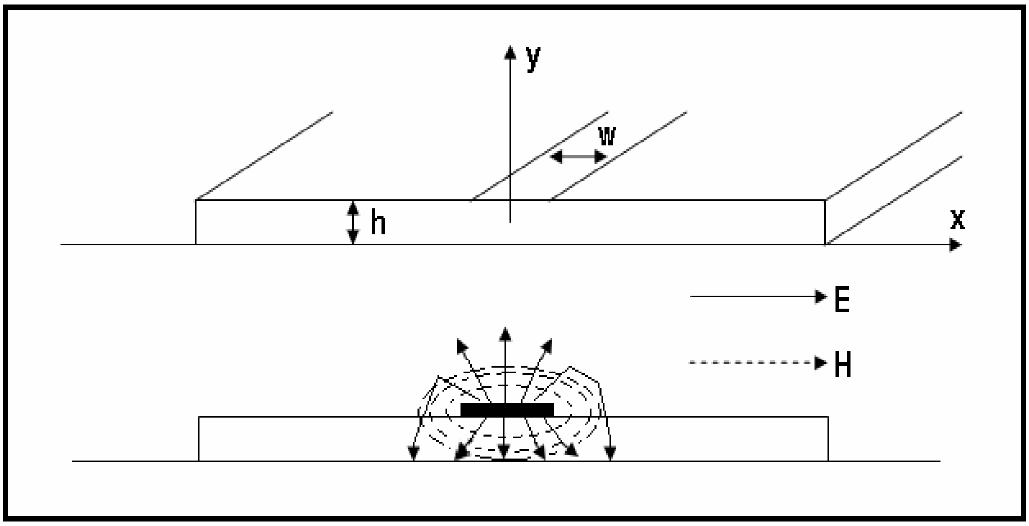


Figure 2.12: Microstrip Line

The effective dielectric constant of a microstrip line is given by [2];

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[\frac{1}{\sqrt{1 + 12h/w}}\right] \tag{2.5}$$

The characteristic impedance Z_0 can be calculated as;

$$Z_o = \begin{cases} \dfrac{60}{\sqrt{\varepsilon_{eff}}}\ln\left[\dfrac{8h}{w} + \dfrac{w}{4h}\right] & \text{for } w/h \le 1 \quad (2.6) \\ \\ \dfrac{120\pi}{\sqrt{\varepsilon_{eff}}\left\{\dfrac{w}{h} + 1.393 + 0.667\ln\left(\dfrac{w}{h} + 1.444\right)\right\}} & \text{for } w/h \ge 1 \quad (2.7) \end{cases}$$

Instead of using the analysis formula as above, the synthesis formula are available for finding w/h and ε_{eff} if Z_o and ε_r are known. The synthesis formula is given by;

$$\frac{w}{h} = \begin{cases} \dfrac{8e^{A}}{e^{2A}-2} & w/h < 2 \quad (2.8) \\[2ex] \dfrac{2}{\pi}\left[B-1-\ln(2B-1)+\dfrac{\varepsilon_r-1}{2\varepsilon_r}\left\{\ln(B-1)+0.39-\dfrac{0.61}{\varepsilon_r}\right\}\right] & w/h > 2 \quad (2.9) \end{cases}$$

$$\mathrm{A} = \frac{Z_o}{60}\sqrt{\frac{\varepsilon_r+1}{2}}+\frac{\varepsilon_r-1}{\varepsilon_r+1}\left[0.23+\frac{0.11}{\varepsilon_r}\right] \quad (2.10)$$

$$\mathrm{B} = \frac{377\pi}{2Z_o\sqrt{\varepsilon_r}} \quad (2.11)$$

$$\mathrm{L} = \frac{\phi(\pi/180)}{\sqrt{\varepsilon_{eff}}\,k_o} \quad (2.12)$$

$$k_o = \frac{2\pi f}{c} \quad (2.13)$$

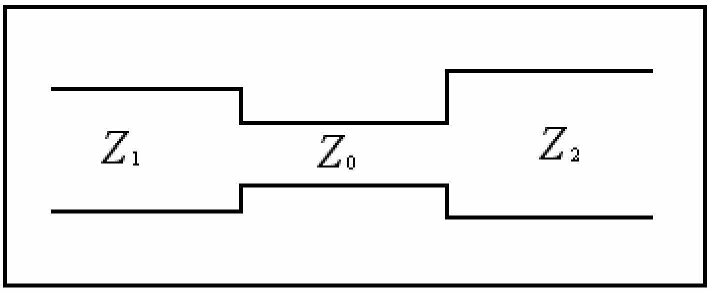


Figure 2.13: Matching technique in transmission line

Referring to the above figure, it shows the matching technique in the transmission line. The matching impedance Z_o can be calculated by using the formula 2.14 [2].

$$Z_o = \sqrt{(Z_1 Z_2)} \tag{2.14}$$

2.3.4 Rectangular design of microstrip antenna

The figure below shows the microstrip diagram of rectangular shape of microstrip patch antenna and the equivalent circuit. The arrows show how the current flow through the patch and the ground plane [6].

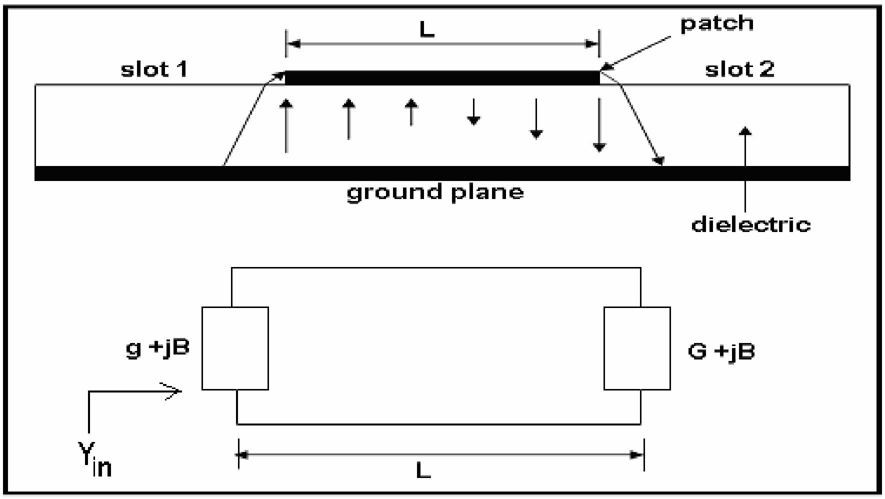


Figure 2.14: Microstrip diagram and equivalent circuit

The patch dimension L can be written as [6];

$$\mathrm{L} = \frac{c}{2f\sqrt{\varepsilon_{eff}}} - 2\,\Delta l \tag{2.15}$$

$$\Delta L = 0.412h \frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \tag{2.16}$$

$$\varepsilon_{reff} = \left(\frac{\varepsilon_r + 1}{2}\right) + \left[\left(\frac{\varepsilon_r - 1}{2}\right)\left[1 + 12\frac{h}{W}\right]^{-0.5}\right] \tag{2.17}$$

Where:

f = Operating frequency

ε_r = Permittivity of the dielectric

ε_{reff} = Effective permittivity of the dielectric

W = Patch's width

L = Patch's length

h = Thickness of the dielectric

The W is not the critical value but can be selected as;

$$\mathrm{W} = \frac{c}{2f}\left[\frac{\varepsilon_r + 1}{2}\right]^{1/2} \tag{2.18}$$

The input admittance at the radiating edge is given by;

$$Y_{in} = Y_{slot} + Y_o \frac{Y_{slot} + jY_O \tan\beta\left(L + \Delta l\right)}{Y_o + jY_{slot} \tan\beta\left(L + 2\Delta l\right)} \tag{2.19}$$

At resonance, $Y_{in} = 2\mathrm{G}$ (2.20)

Based on Harrington, the conductance, G for parallel radiator is given by;

$$\mathrm{G} = \frac{\pi W}{\eta\lambda_o}\left[1 - \frac{\left(kh\right)^2}{24}\right] \tag{2.21}$$

$$k = \frac{2\pi f}{c} \tag{2.22}$$

$$\eta = 120\pi \tag{2.23}$$

2.3.5 Inset feed impedance

The type of feeding technique that will be used is the inset feed technique. It is one of the easiest feeding techniques and it is also easy to control the input impedance of the antenna. From figure 2.14, the input impedance level of the patch can be control by adjusting the length of the inset. The calculation of the inset fed is shown in the equations 2.24 which show the resonant input resistance for the microstrip patches [7].

$$R_{in}(L = \ell) = \frac{1}{2(G_1 \pm G_{12})}\cos^2\left(\frac{\pi \ell}{L}\right) \tag{2.24}$$

L is the length of the patch, ℓ is the length of the inset, G_1 is the conductance of the microstrip radiator and G_{12} is the mutual conductance between the two slots. The conductance of the radiator is calculated using equation 2.25. I_1 is the current excited into the microstrip patch.

$$G_1 = \frac{I_1}{120\pi^2} \tag{2.25}$$

$$I_1 = \int_0^{\pi} \left[\frac{\sin\left(\frac{k_0 w}{2}\cos\theta\right)}{\cos\theta} \right]^2 \sin^3\theta \quad d\theta \tag{2.26}$$

The mutual conductance of the two slots (both sides of the feed) can be calculated using equation 2.27.

$$G_{12} = \frac{1}{120\pi^2}\int_0^{\pi}\left[\frac{\sin\left(\frac{k_0 w}{2}\cos\theta\right)}{\cos\theta}\right]^2 J_0(k_0 L\sin\theta)\sin^3\theta \quad d\theta \qquad (2.27)$$

The equations above need tedious effort to be calculated. The calculations for finding the inset length can be simplified as shown in the equation below. This equation is valid for ε_r from 2 to 10. Using the equation below helps to ease the calculation for the inset length of the microstrip antenna [5].

$$\ell = 10^{-4}\begin{pmatrix} 0.001699\varepsilon_r^{\ 7} + 0.13761\varepsilon_r^{\ 6} - 6.1783\varepsilon_r^{\ 5} + 93.187\varepsilon_r^{\ 4} - \\ 682.69\varepsilon_r^{\ 3} + 2561.9\varepsilon_r^{\ 2} - 4043\varepsilon_r + 6697 \end{pmatrix}\frac{L}{2} \qquad (2.28)$$

where:

ε_r = Permittivity of the dielectric

L = Length of the microstrip patch

2.4 Microstrip antenna array

Microstrip array antenna can be defined as the structure that has a repeated element printed on a grounded microwave substrate [7]. This structure designed to improve the performance of the single patch microstrip antenna. Generally, all the repeating elements in array are fed by using transmission line technique.

Microstrip array antenna has some advantages compared to the rectangular patch microstrip antenna. Below are some advantages of the array structure [7]:

- High gain (depend to the number of elements)
- High cross isolation
- Dual band and multi band antenna can easily design using array structure

This structure also has the disadvantages like below [7]:

- Low efficiency due to high loss mainly in feeding network
- Larger size
- Higher cost
- Narrow bandwidth (by using optimization, the bandwidth can be increase)

There are various types of antenna can be design by using array technique such as dual band microstrip antenna, multiband microstrip antenna and ultra wide band antenna [13]. Below are the figures of some application of array structure:

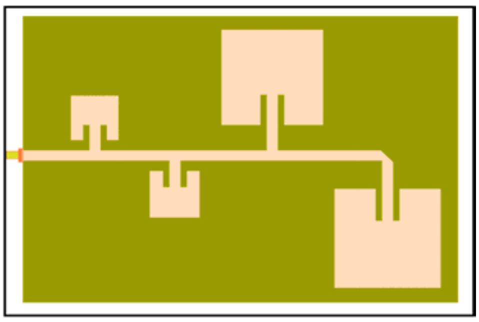


Figure 2.15: dual band microstrip antenna

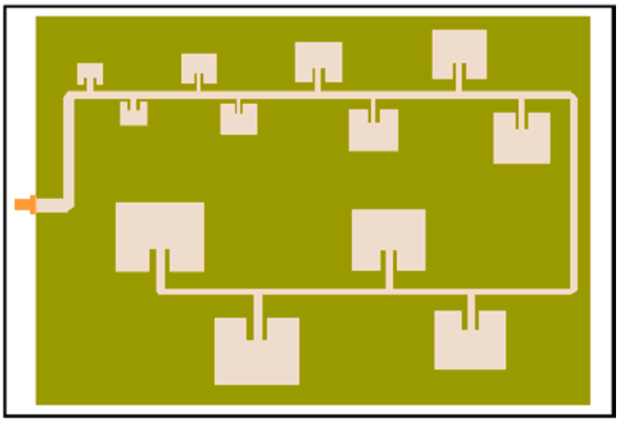


Figure 2.16: Ultra wideband antenna

For the above figure, inset feed technique is used as a feeding technique for all elements in array. To minimum the losses at the transmission lines, quarter wave length transformer matching technique is used together with power divider. By using power divider, the supply current can be divided equally to each patch means that each patch can radiates power equally. Referring to the above figures, the usage of power divider is not needed.

2.5 Electromagnetic Band Gap (EBG) structure

In recent years, there has been growing interest in utilizing electromagnetic band-gap (EBG) structures in the electromagnetic and antenna community. The EBG terminology has been suggested based on the photonic band-gap (PBG) phenomena in optics that are realized by periodical structures. There are diverse forms of EBG structures design such as EBG structures integrated with active device and multilayer EBG structures [14].

Electromagnetic Band Gap (EBG) always referred as photonic band gap (PBG) surface or high impedance surface [15]. This structure is compact which has good potential to build low profile and high efficiency antenna surface. The main advantage of EBG structure is their ability to suppress the surface wave current. The generation of surface waves decreases the antenna efficiency and degrades the antenna pattern. Furthermore, it increases the mutual coupling of the antenna array which causes the blind angle of a scanning array. The feature of surface-wave suppression helps to improve antenna’s performance such as increasing the antenna gain and less power wasted when reducing backward direction [16].

There are two types of EBG structure to be discussed. Firstly is Perforated dielectric and the second one is Metallodielectric structures. Perforated dielectric is defined as effectively suppress unwanted substrate mode commonly exist in microstrip antenna. This structure designed by drill periodic holes on dielectric subtracts to introduce another dielectric but in practical, this structure is difficult to implement. Metallodielectric structure is exhibits an attractive reflection phase future where the reflected field change continuously fro 180 degrees to -180 degrees versus frequency. It was allow a low profile wire antenna to radiate efficiently with enhance bandwidth, radiation pattern, gain, reduce back radiation and reduce size lobe [17].

EBG structure can be design by various shapes and every shape will have different frequency band gap. Something special of the EBG structure is it can be designed which has a characteristic whether it is inductive or more capacitive. The principle of operation of EBG structure will be discussed later.

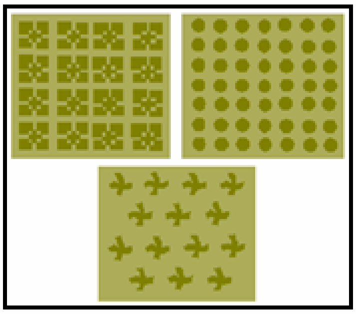


Figure 2.17: various types of EBG structure

2.5.1 Surface wave current

Surface wave are excited on microstrip antenna when the substrate $\epsilon_r > 1$. Besides end fire radiation, surface wave give rise to coupling between various elements of an array. Surface wave are launched into the substrate at an elevation angle θ lying between $\pi / 2$ and $\sin^{-1} (1/\sqrt{\epsilon_r})$. These waves are incident on the ground plane at this angle shown, get the reflected from there, then meet the dielectric-air interface, which also reflect them. Following this zig-zag path, they finally reach the boundaries of the microstrip structure where they are reflected back and diffracted by the edges giving rise to end-fire radiation [5].

On other way in the boundary, if there is any other antenna in proximity, the surface wave can become coupled into it. Surface waves will decay as $1/\sqrt{r}$ so that coupling also decreases away from the point of excitation. Surface wave are TM and TE modes of the substrate. These modes are characterized by waves attenuating in the transverse direction (normal to the antenna plane) and having a real propagation constant above the cut-off frequency. The phase velocity of the surface waves is strongly dependent on the substrate parameters h and ϵ_r. Figure 2.18 shows the propagation of the surface wave in microstrip antenna [5].

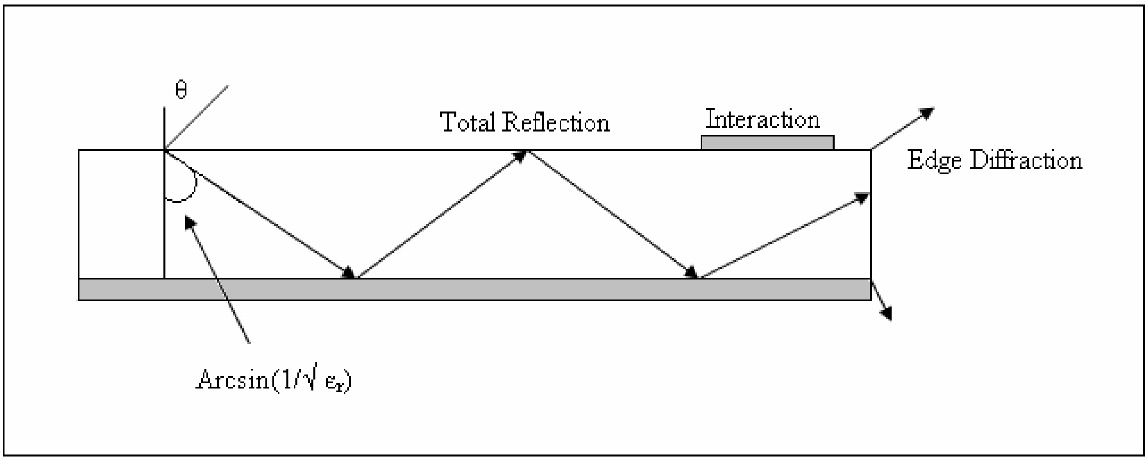


Figure 2.18: Propagation of surface waves in substrate of patch antenna

Surface wave propagation is a serious problem in microstrip antennas. Surface waves reduce antenna efficiency and gain, limit bandwidth, increase end-fire radiation, increase cross-polarization levels, and limit the applicable frequency range of microstrip antennas [18].

Two solutions to the surface wave problem are available now. One of the approaches is based on the micromachining technology in which part of the substrate beneath the radiating element is removed to realize a low efficiency dielectric constant environment for the antenna. In this case the power loss through surface wave excitation is reduced and coupling of power to the space wave enhanced. The second technique relies on photonics bandgap (PBG) engineering. In this case, the substrate is periodically loaded so that the surface wave dispersion diagram presents a forbidden frequency range (stopband or bandgap) about the antenna operating frequency. Because the surface waves cannot propagate along the substrate, an increase amount of radiating power couples to the space waves. Also, other surface wave coupling effects like mutual coupling between array elements and interference with onboard systems are now absent. The figure below shows the blocking of propagation surface wave on waveguide by using EBG (PBG) structure [19].

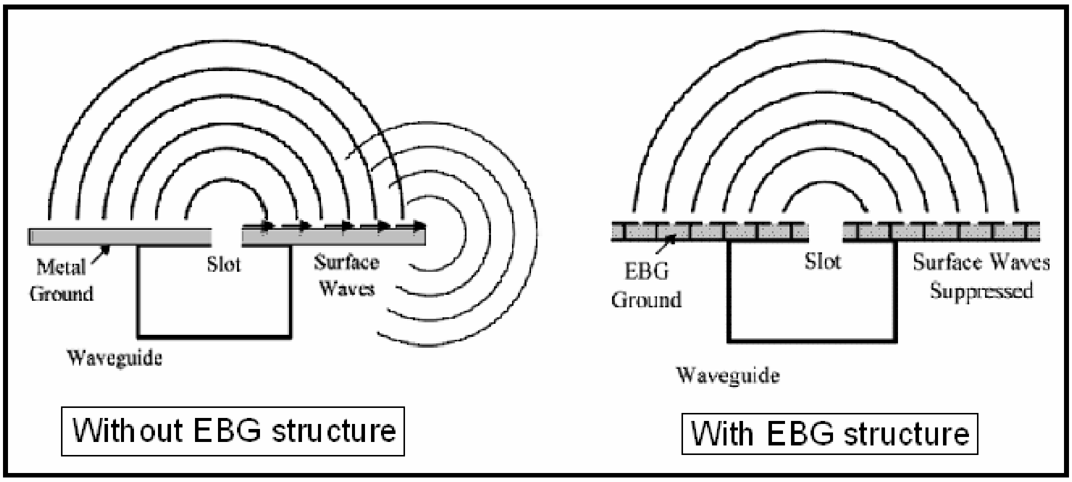


Figure 2.19: The blocking of propagation surface wave by EBG structure [20]

Photonics bandgap materials are new class of periodic dielectrics, which are the photonics analogs of semiconductors. Electromagnetic waves behave in photonics substrates as electrons behave in semiconductors. Various type of periodic loading of substrates has been studied to realize the PBG nature of the substrate. Early attempts involved drilling a periodic pattern of holes in the substrate or etching a periodic pattern of circle in the ground plane. Next, a periodic pattern of the metallic pads was shorted to the ground plane with vias. Recently, a new loading pattern has been studied. This type of planar or 2-D loading is simple to realize (no via are necessary) and is compatible with standard monolithic microwaves integrated circuit fabrication technology [19].

The transmission coefficient of a PBG substrate is characterized by a bandgap or stopband region. The transmission and reflection coefficient of a microstrip line in PBG substrate with circles etched in the ground plane are shown like figure 2.20.

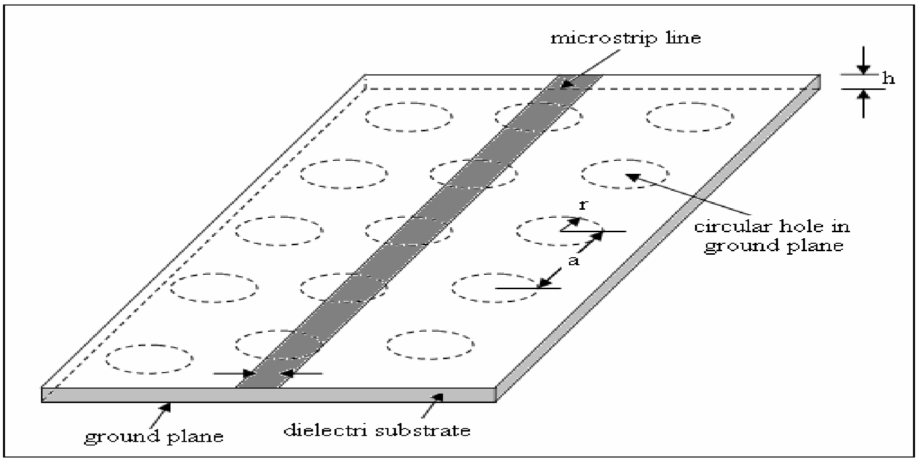


Figure 2.20: Square lattice of etched circles in the ground plane

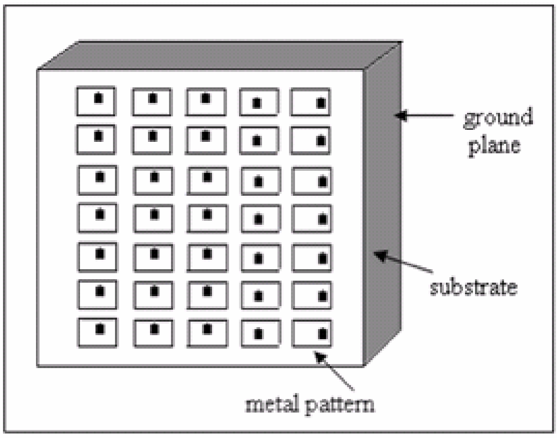


Figure 2.21: Square lattice of small metal pads with grounding vias in the center

2.5.2 Principle of Electromagnetic Band Gap (EBG) structure

The basic design of EBG structure is shown in figure 2.22 known as mushroom like EBG structure. This structure has frequency range where the surface impedance is very high. The equivalent LC circuit acts as a two-dimensional electric filter in this range of frequency to block the flow of the surface waves. The central frequency of the band gap is shown in equation 2.29. The inductor L results from the current flowing through the vias, and the capacitor C due to the gap effect between the adjacent patches. Thus, the approach to increase the inductance or capacitance will naturally result in the decrease of band-gap position [21].

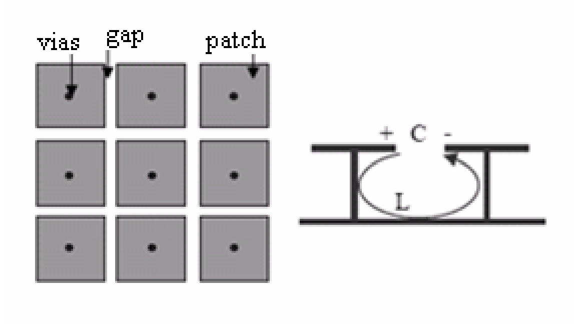


Figure 2.22: 2D EBG structure [21].

Central frequency of the band gap is given by;

$$f_c = 1/\left(2\pi\sqrt{LC}\right) \tag{2.29}$$

Where;

$$L = \mu_o h \tag{2.30}$$

$$C = W\varepsilon o \frac{(\varepsilon r+1)}{\pi} \cosh^{-1}\left(\frac{2W+g}{g}\right) \tag{2.31}$$

The bandwidth of the electromagnetic band gap is given by;

$$BW = \frac{1}{\eta}\sqrt{\frac{L}{C}} \quad . \tag{2.32}$$

2.5.3 Spiral Electromagnetic Band Gap (EBG) structure

The schematic of the proposed spiral EBG structure is shown in Figure 2.23(a). Gray parts in the figure represent the metallic periodic structure which is etched on a dielectric substrate. Each element of this EBG lattice consists of a square metal patch with a spiral branch inserted inside, as shown in Figure 2.23(b). The patch is connected to the solid lower ground plane by a metal plated via [20].

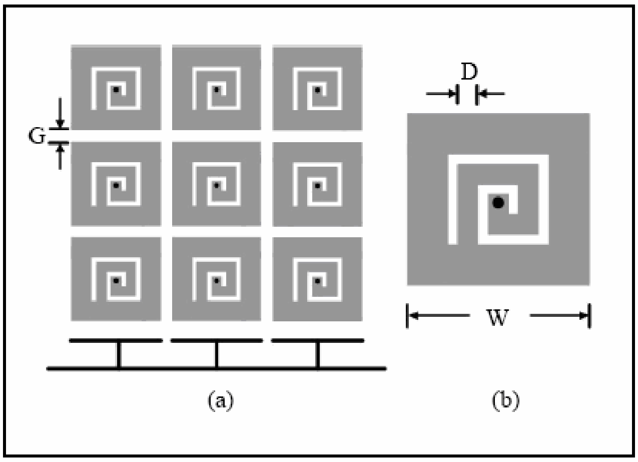


Figure 2.23: (a) Spiral EBG structure. (b) Details of one unit of the structure [20]

A 3 by 3 spiral EBG structure as above have been fabricated by the researchers before. The array is built on 1mm thick substrate with the relative permittivity of 2.2. The length of the square patch (W) is 6 mm. The width of the spiral branch (D) is 0.6 mm. The distance between the adjacent patches (G) is 0.4 mm. The period of the lattice is W + G = 6.4 mm.

The method of suspended microstrip is applied to measure the band-gap characterization of the EBG structure, as shown in Figure 2.24. The measured and simulated results are shown in Figure 2.25. A distinctive stop-band has been observed with the central frequency of 2.28 GHz. The frequency range with S_{21} below -10 dB extends from 2.07 GHz to 2.34 GHz.

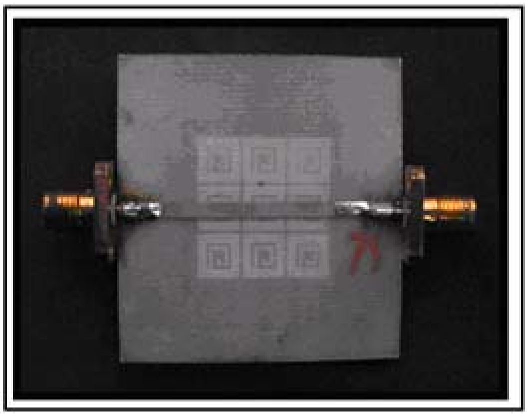


Figure 2.24: Photograph of the 3 by 3 Spiral EBG with suspended microstrip [20]

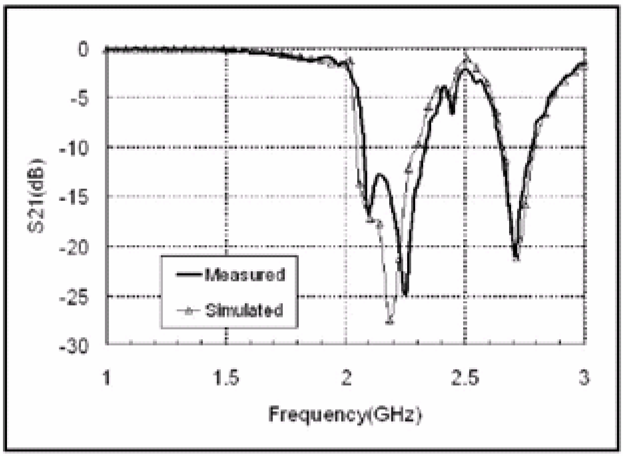


Figure 2.25: Measured and simulated S_{21} of the 3 by 3 Spiral EBG structures [20]

2.5.4 Compactness in EBG structure

Compactness is always important in wireless communications. Microstrip patch antennas offer an attractive solution to compact and low-cost design of modern wireless communication systems. The major setbacks of a patch antenna on a high dielectric constant substrate are its low efficiency due to surface wave loss and inherently narrow bandwidth. Frequency-selective surface have currently attracted considerable attention due to growing interest in utilizing EBG structures [22].

EBG structures are considered to be a key technology to improve patch antenna performances. In practical applications, patch antennas are surrounded properly by planar EBG lattice [23], as shown in Figure 2.26. However, the EBG lattice significantly enlarges the area needed, resulting difficulties in practical applications.

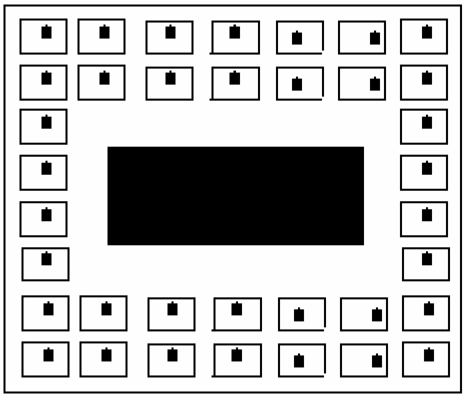


Figure 2.26: A rectangular patch surrounded by EBG structure

2.5.5 Stack EBG structure

In order to suppress the surface wave, EBG lattice is typically placed around the patch antenna in coplanar position. However, such placement significantly enlarges the area needed and runs counter to the principle of compact design in wireless communication circuits. Researches have verified that EBG structure can still exhibit band-gap feature beneath suspended microstrip [24].

A stacked EBG utilization accommodating with patch antenna will be discussed in this section, as shown in Figure 2.27. One layer of EBG lattice is inserted beneath the patch antenna. The surface wave will be coupled to the EBG lattice and forced to radiate. Such structure has the winning feature of compactness [24].

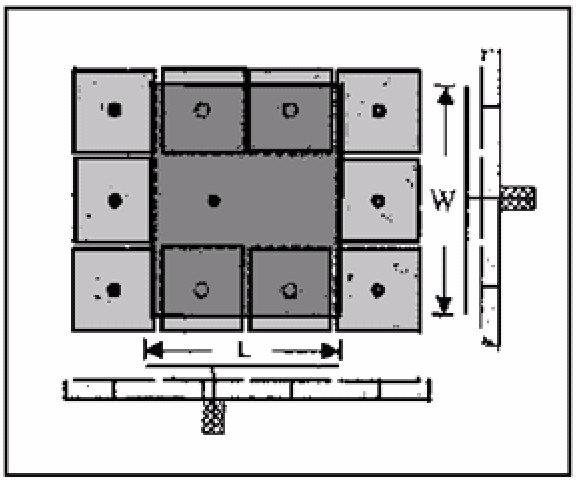


Figure 2.27: Stacked EBG structure [24]

The proposed patch has been fabricated on a finite size ground plane with dimensions of 60 mm x 40 mm. The thickness of the substrate is 1.59 mm with a relative permittivity of 3.2. Mushroom-like EBG structure is used in this case. The patch size is 8 mm and the distance between the edges of the adjacent patches is 0.2 mm. The radius of the vias is 0.6 mm. the patch is probe-fed and has dimensions of L = 16.5 mm, W = 21 mm. The distance between the EBG surface and the patch is 0.5 mm. Foamed plastic could be used as supporting material [24].

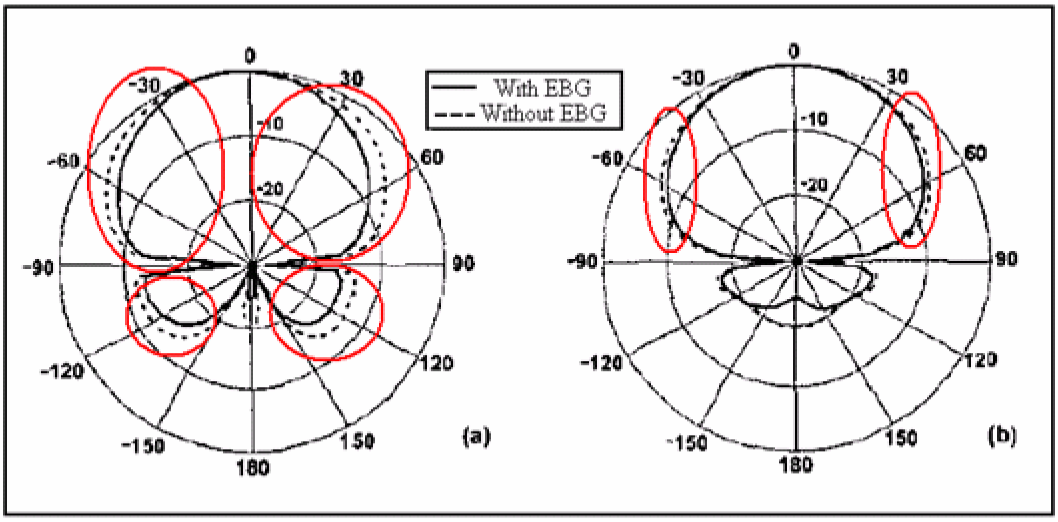


Figure 2.28: Radiation patterns of the patch antenna with and without EBG
(a) E-plane (b) H-plane [24]

From the radiation pattern shown in figure 2.28, the patch antenna with EBG structure has lower side lobe and back lobe compared to the patch antenna without EBG structure especially in E-Plane direction. The antenna with EBG structure seemed has narrower beam width. So, the EBG structure helps the microstrip patch antenna to be more directional. The red circle on the figure shows the difference of radiation pattern characteristic for both structures. The conclusion can be made referring to the research is the EBG structure can improve the radiation pattern of the microstrip antenna design [24].

2.5.6 Fork like EBG structure

Miniaturize is very important to antenna design. By reducing the antenna size, it can also reduce the fabrication cost. In EBG design also miniaturization is very important since the EBG structure will be use periodically together with antenna design. To overcome this problem, a researcher in [24] proposed the fork-like EBG structure as shown in figure 2.29. Based on the general formula for calculating the

EBG dimension, typically for operating at lower frequency the size of EBG structure must be large so it will enlarge the overall size and difficult to applied in practical in term of cost increment. By using the fork like EBG structure, the overall of EBG size is 40% smaller compared to mushroom EBG structure operating at same frequency. The band gap frequency is shown in figure 2.30. The fork like EBG structure has winning the size reduction for EBG design and had good S_{21} value but it still operating at single frequency band.

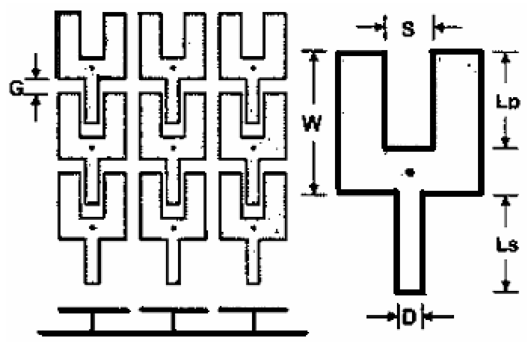


Figure 2.29: Configuration of fork-like EBG structure [24].

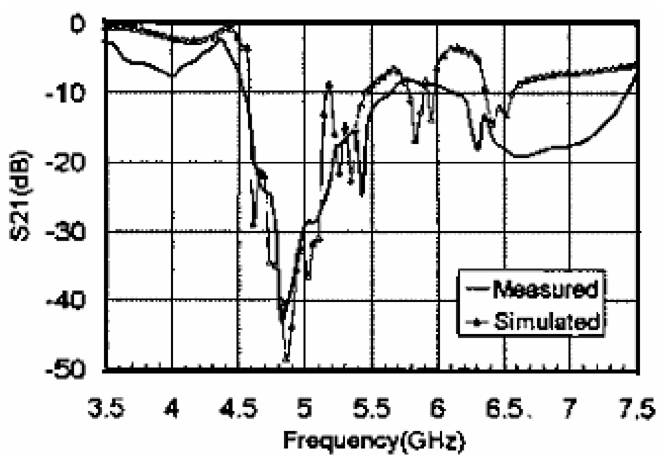


Figure 2.30: The S_{21} result for fork-like EBG structure [].

2.5.7 Hexagonal shape EBG structure

The mushroom like EBG structure has been extensively used in antenna design. But, the researcher in [25] proposed new shape of EBG structure known as hexagonal shape EBG structure. Figure 2.31 shows the hexagonal shape EBG structure that has been designed and fabricated by Dan Sievenpiper in [25]. The structure is used as ground plane for horizontal wire antenna. In figure 2.32, the comparison for the antenna performances has been made between wire antenna on metal ground plane and hexagonal shape EBG structure. The measured return loss and radiation pattern is shown in figure 2.33 and figure 2.34.

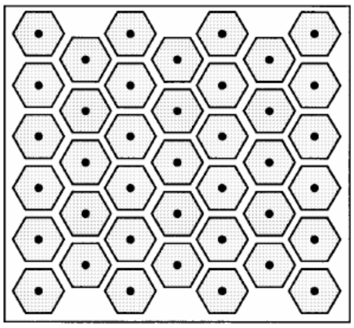
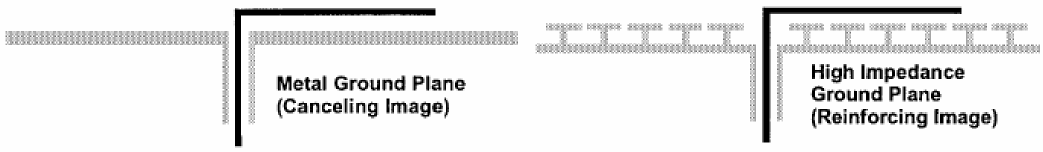


Figure 2.31: Hexagonal shape EBG structure [25]



(a) (b)

Figure 2.32: Horizontal wire antenna. [25]

(a) on metal ground plane (b) on hexagonal shape EBG structure

Figure 2.33 shows the result of the return loss for horizontal wire antenna on hexagonal shape EBG structure and horizontal wire antenna on metal ground plane. The signal transmitted to the horizontal wire antenna on the flat metal ground plane is almost reflect back to the system and cannot be radiated effectively. From figure 2.33, the return loss value for horizontal wire antenna on hexagonal shape EBG structure has better return loss in both E-plane and H-plane where the value is almost below -10 dB in wide frequency ranges. The radiation pattern is also improved with higher front radiation and the back radiation is smaller. The radiation pattern for horizontal wire antenna on EBG structure is smooth with improvement of the characteristic as mentioned before.

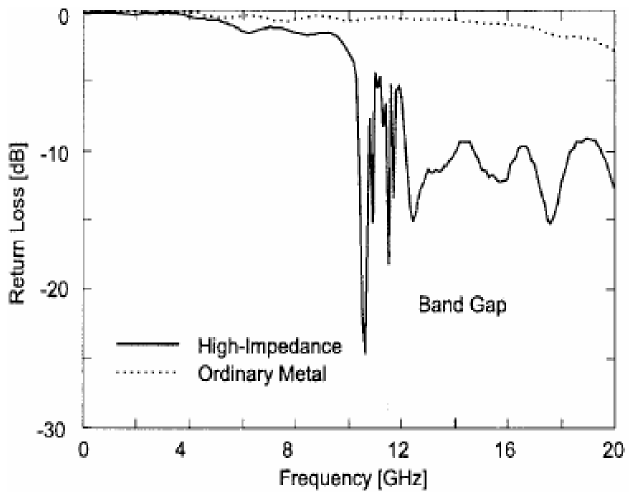
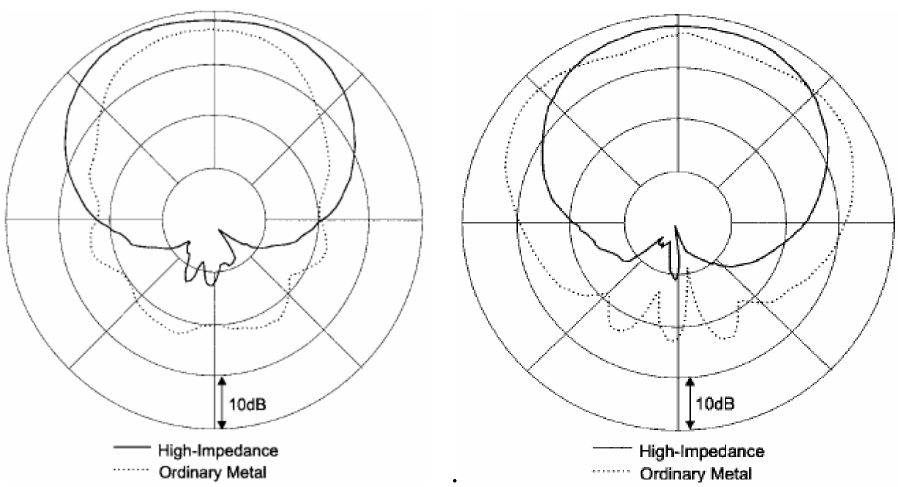


Figure 2.33: Measured return loss []



(a) (b)

Figure 2.34: Measured radiation pattern for both cases [25]

(a) E-plane direction (b)H-Plane direction

2.6 Summary

The basic theory of microstrip antenna has been presented including all the properties such as the feeding method, radiation pattern, gain and all parameters related to the structure. The concept of microstrip array antenna is also discussed. The different structures of Electromagnetic Band Gap (EBG) form previous work have also been discussed in term of the characteristic of the EBG structures.

METHODOLOGY

3.1 Project Methodology

The methodology of this project starts by understanding of the microstrip antenna technology. This includes the properties study of the antenna such as operating frequency, radiation pattern, polarization and antenna gain. The related literature reviews are carried out from reference books and IEEE publish paper. The antenna designs started by calculating the dimensions of single patch microstrip antenna operate at frequency (2.4 GHz). The simulation has been done by using Microwave Office and CST. The fabrication process is started after the optimization result from the simulation. The measurement and simulation result has been compared in term of Return Loss (S_{11}), radiation pattern and gain of the antenna. For the EBG structure, the value of transmission loss (S_{21}) has been measured to obtain the band gap frequency around 2.4 GHz.

3.2 Flow Chart of Design Methodology

Figure 3.0 shows the design methodology of the project

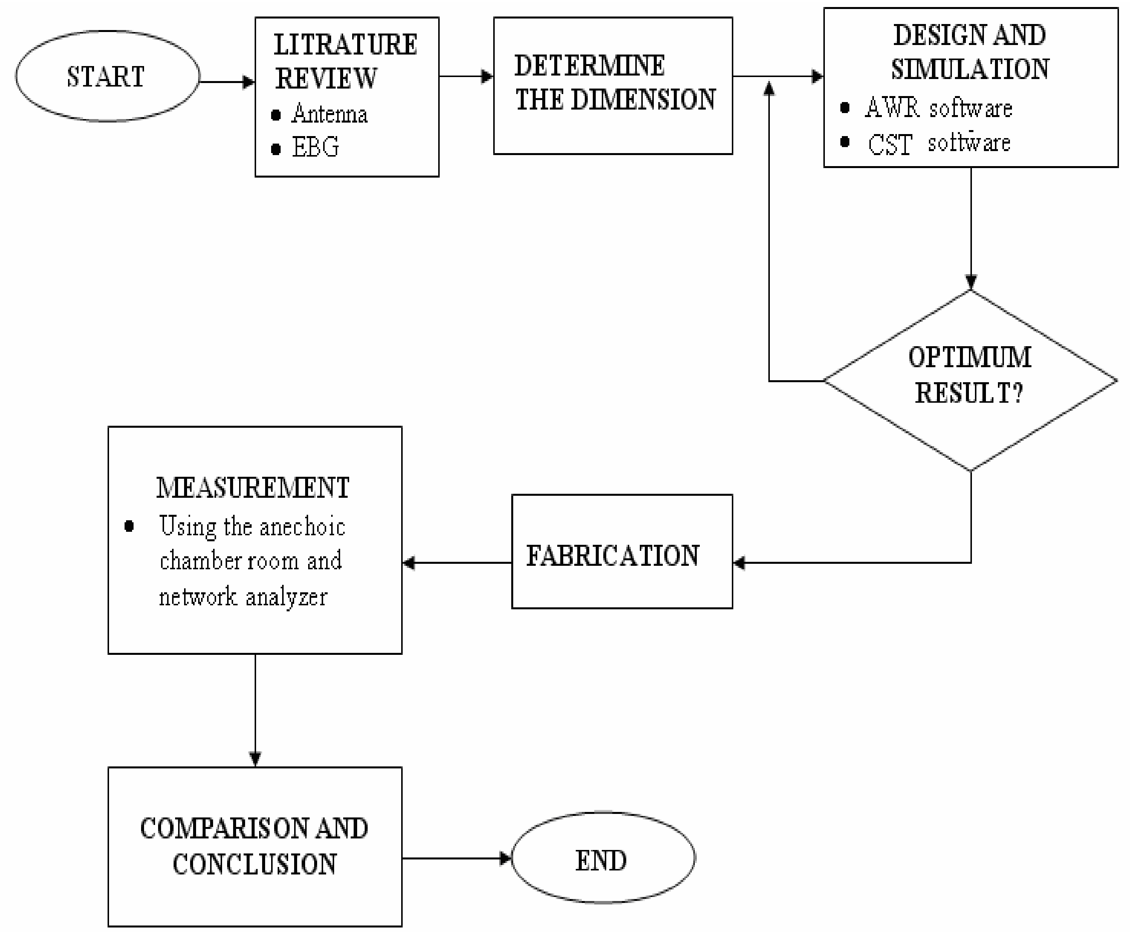


Figure 3.0 Flow chart of the project

3.2.1 Literature review of the antenna

According to the above flow chart, firstly literature review of the antenna will be found out especially to the relation topic for this research. In this case, there are three main topics to be studied. First is about the microstrip antenna. The properties of the antenna are studied such as the return loss, antenna gain and radiation pattern. The basic concepts of the microstrip antenna are learned such as the structure, the operation and the design technique. Secondly is about the concept of the microstrip array antenna. The advantages and disadvantages of this structure and the design technique to be used are found out. Thirdly is about the Electromagnetic band gap structure (EBG). The reasons by choosing the EBG structure and the method to design the structure are found out. This part has already discussed deeply in chapter 2.

3.2.2 Determine the antenna dimension

All the dimensions of the antenna are calculated base on the formulas discussed in chapter 2. There are 3 sections of the design in this project. First is to design the microstrip array antenna where 2 by 1 and 2 by 2 structures will be designed. Secondly is to design the EBG structure which can cover the bandwidth of the operational frequency of the microstrip array antenna. Because there is no specific formula created to calculate the size of the EBG structure to get the band gap characteristic at certain operational frequency, the parametric study will be used. Thirdly is to integrate the EBG structure with the array structure to compare the performance of the array structure with and without EBG structure.

Firstly is the rectangular design for elements in microstrip array antenna. Refer to the figure 3.1, by using the formula given in chapter 2 with the value of dielectric constant, ε_r = 4.6, operational frequency = 2.4 GHz and the substrate thickness, h = 1.6 mm, the parameters are W = 37.3 mm, L = 28.8 mm and l = 10 mm.

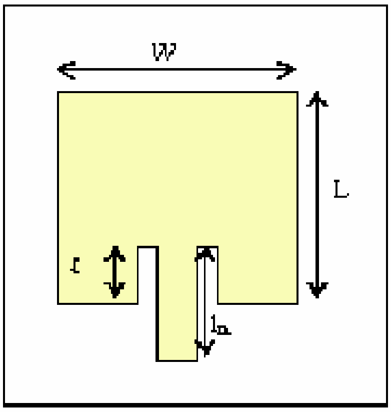


Figure 3.1: Inset feed for rectangular design

Secondly is the transmission line design. Quarter wave length transformer matching technique will be used together with power divider to optimum the power transfer to all elements in array. The impedance of the antenna design is 50 Ω due to the impedance of the connector. All the values in figure 3.2 are calculated using formulas in chapter 2. The table 3.1 shows the value of the parameters in figure 3.2. The overall size of 2 by 1 microstrip antenna array is 131 mm x 71 mm and for 2 by 2 microstrip array antenna is 131 mm by 151 mm.

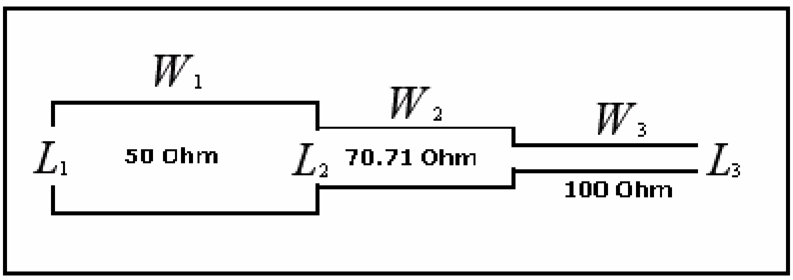


Figure 3.2: Quarter wave length matching technique

Table 3.1: parameters of transmission lines

Impedance	$Z_0 = 70.71\ \Omega$	$Z_1 = 50\ \Omega$	$Z_2 = 100\ \Omega$
W (mm)	1.56	2.96	0.67
L (mm)	17.22	16.81	17.66

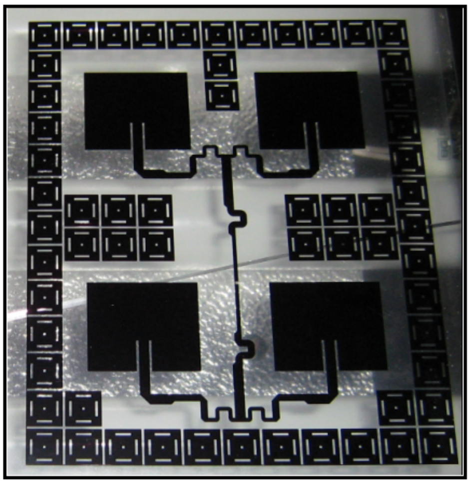


Figure 3.3: Layout design of 2 by 2 microstrip array antenna with EBG structure.

Thirdly is to design the electromagnetic band gap (EBG) structure which can cover the operational frequency of the microstrip array antenna has been designed. Slotted patch EBG structure has been chosen due to the compact size and the ability of tuning the band gap frequency by adjusting the slotted size. By using the parametric study based on the simulation, all the parameters of the EBG structure shown in figure 3.4 are like listed in table 3.2 as below.

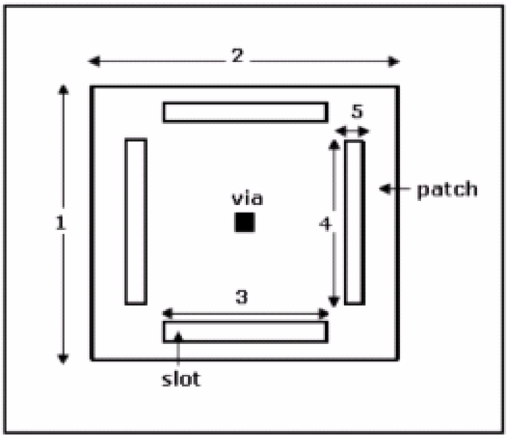


Figure 3.4: Slotted patch EBG structure

Table 3.2: parameters of slotted patch EBG structure

parameter	Size (mm)
1	11
2	11
3	5
4	5
5	1

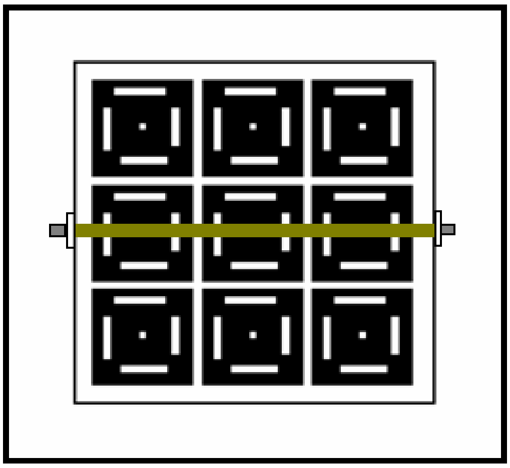


Figure 3.5: Layout design of 3 by 3 slotted patch EBG structure

The figure 3.5 shows the layout of 3 by 3 slotted patch EBG structure. The gaps between the patches are 1mm. The transmission line size used is 50 mm x 3 mm. the overall size of EBG structure is 50 mm x 50 mm. The band gap frequency is determined using microwave office software.

3.2.3 Design and simulation

When all the dimension of the antenna had been investigated, the design and simulation process can be done. In this project, the microwave office (2D EM simulator) and CST (3D EM simulator) have been used for the simulation of th structure.

Figure 3.6: Microwave office software

This microwave office software (WMO) is very useful. It is also user friendly where this software is easy to be learned and used. By using this software, the design process can be done regularly to see to get an optimum result. This software helps to reduce the fabrication's cost because only the antenna with the best performance will be fabricated

First the parameters for the microstrip array antennas are calculated by using the equation before and applied to the schematic diagram. After that from the schematic diagram, the layouts of these antennas were generated. The designs can also being done through the layout diagram without using the schematic diagram. After setting all parameters in the software, run the simulation.

From the simulation process, the performance of the antenna is depending on the value of return loss (S_{11}), bandwidth, radiation pattern, and antenna gain. This values need to be analyzed before doing the fabrication. From this research, the value of return loss should be much lower than -10 dB. This value is choosing as assumption that only 10% of the powers transmitted are reflected back or loss.

For the EBG structures, the value of S_{21} is measured to see the band gap frequency of this structure. The value of S_{21} chosen must be less than -20 for the band gap frequency to ensure that all the surface wave signal radiates in this frequency band gap cannot propagate on this structure. So, the surface wave can be eliminated.

3.2.4 Fabrication process

In the fabrication process, the first process involved is the photo etching technique. The substrate has been used is FR4 board. This board is a double layer board. Overall thickness of the structure is 1.6mm. The thickness of the conductor (copper) is 0.035mm. The epsilon relative, Er is 4.6 and tangent loss is 0.019.

Figure 3.7: FR4 board

In the photo etching technique process first, the cover of the photo resist microstrip board is being removed. After that, the transparent mask is used to the antenna layout area. Lastly, mask and microstrip board are exposed to ultra violet (UV) light where mask is transparent, the layer were not expose to UV light become polymerized or soluble (hard). The region which not soluble at layer 1 is removed by an acid call *developer.* This process must be done in the dark room.Next, the region of layer 2 which not exposed by layer 1 is removed by using certain chemical acid.

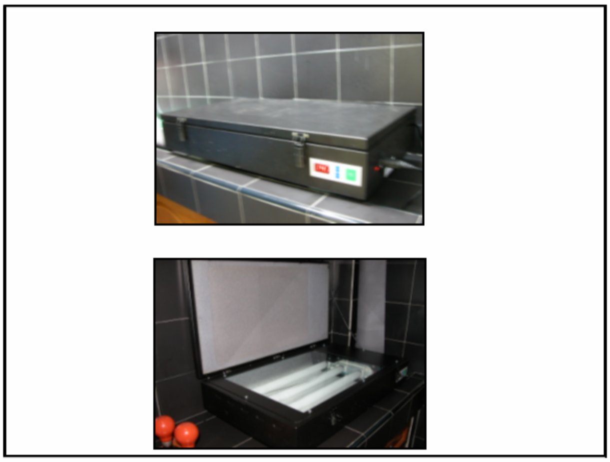


Figure 3.8: UV- light generator

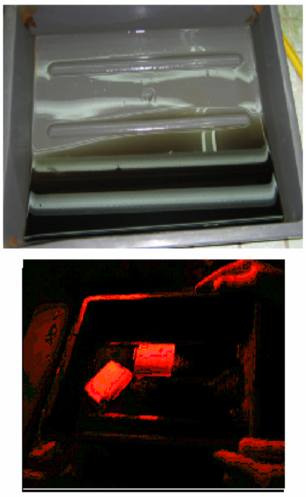


Figure 3.9: Acid / developer (to remove first layer)

Figure 3.10: Chemical acid (to remove second layer)

The second process in the fabrication is the soldering process. This process only can be done after the etching process has finish. In this process, a port or feeder, a small drill with the diameter of 1 mm and a solder will be used. The soldering process actually is to connect the port or feeder to the antenna. A small drill which has the diameter as mentioned above is used to drill a hole with the approximate diameter of 1 mm. This hole is used to put the feeder. After that, the feeder will be soldered together with the antenna.

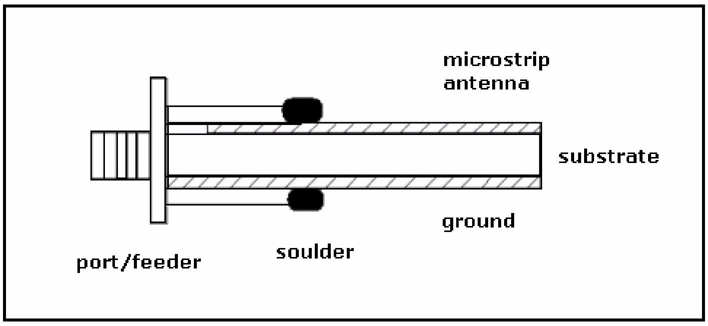


Figure 3.11: Port / feeder

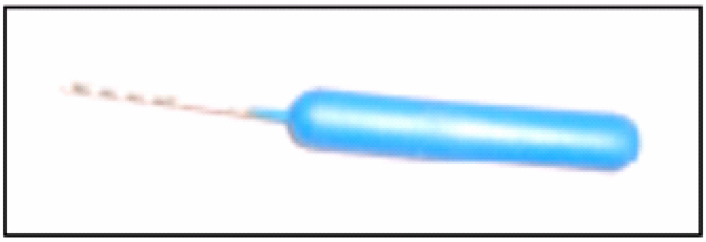


Figure 3.12: small drill

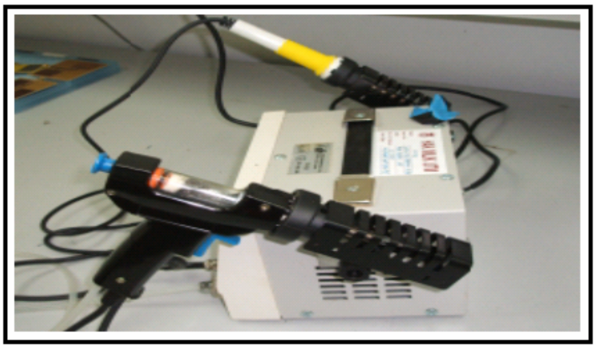


Figure 3.13: soldier

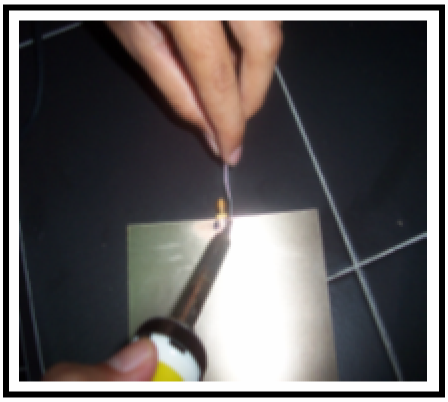


Figure 3.14: Soldering technique for soldering the port / feeder to microstrip board.

Fabrication of the EBG structure is difficult compared to the general microstrip antenna. After the second layer of the substrate has been removed, move to the soldering process. But, for EBG structure, each elements of EBG structure is drilled. Refer figure 3.15.

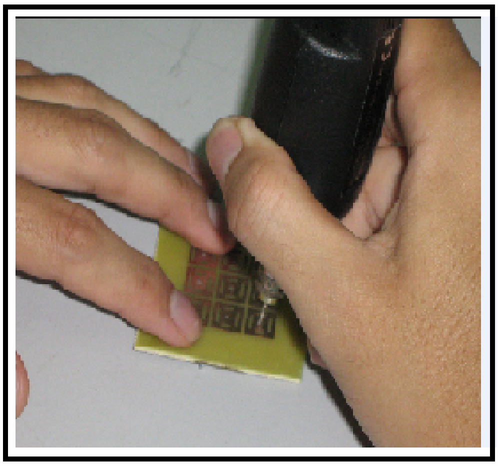


Figure 3.15: Drilling hole at EBG structure

After drilling a hole at all EBG structures, put via at each holes to connect the patch EBG to the ground as shown in figure 3.16 below.

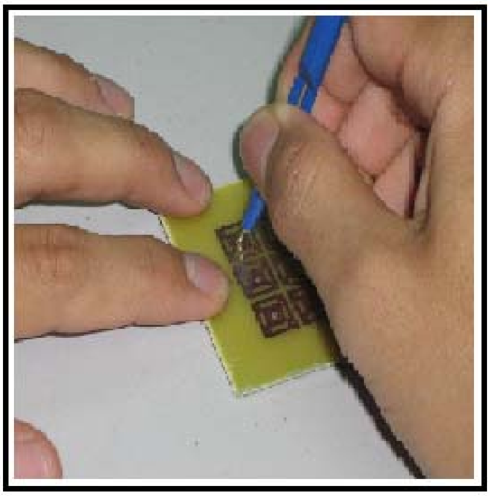


Figure 3.16: Connecting EBG structure to ground plane with via.

Next, use a pressing device to compress all vias in each hole. It can make the vias stable in the hole and not loose. The technique shows in figure 3.17.

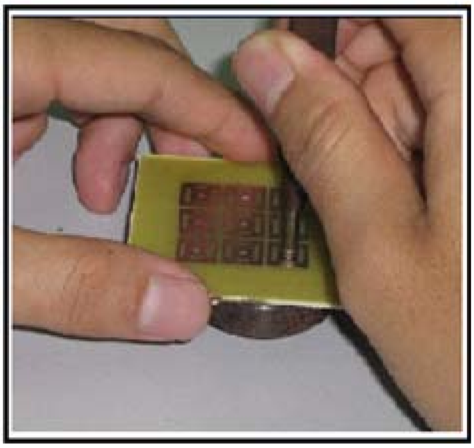


Figure 3.17: Compressing the vias.

After finish the compressing step for the vias, use a multimeter to check that all EBG structures are connected to the ground. The multimeter will give a reading means that the EBG structure is grounded. If the EBG structure is not grounded, solder the vias with the patches to make it connected.

Figure 3.18: Checking the connection of vias to the ground plane.

The last fabrication process for EBG structure is by fixing a transmission line on an FR4 board which has dielectric constant 4.6 and thickness 0.5 mm. The transmission line is soldering together with two connectors for input and output. Next, the second FR4 board is attached on the EBG structure as shown in figure 3.19.

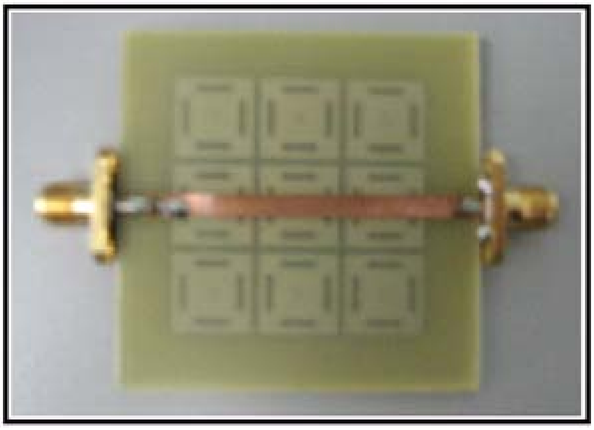


Figure 3.19: The 3 by 3 slotted patch EBG structure.

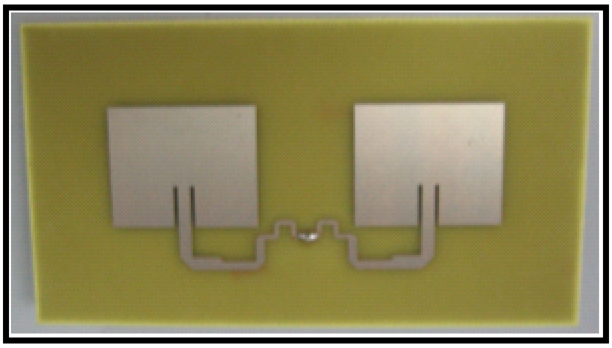


Figure 3.20: 2 by 1 microstrip antenna array.

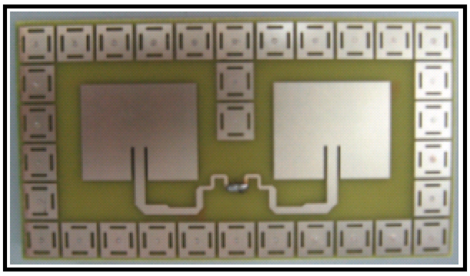


Figure 3.21: 2 by 1 microstrip antenna array with EBG structures.

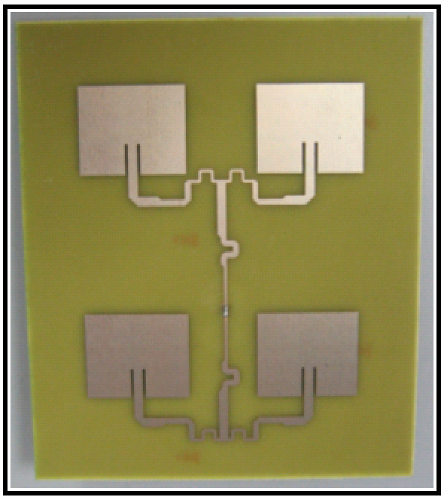


Figure 3.22: 2 by 2 microstrip antenna array.

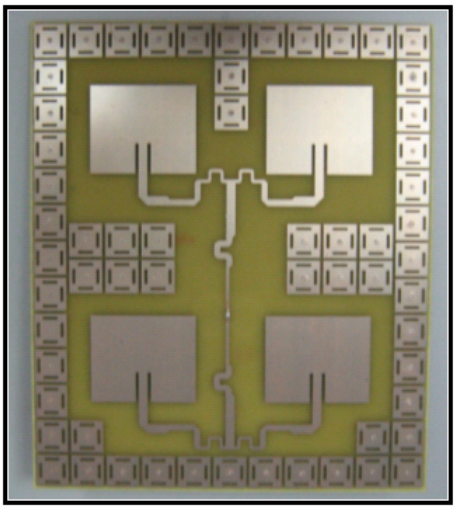
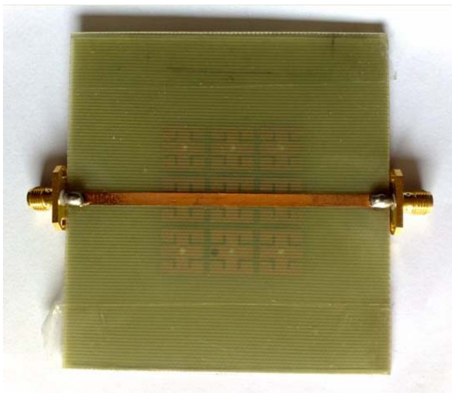


Figure 3.23: 2 by 2 microstrip antenna array with EBG structures.



Picture 3.24: The 3 by 3 Cross patch EBG structure.

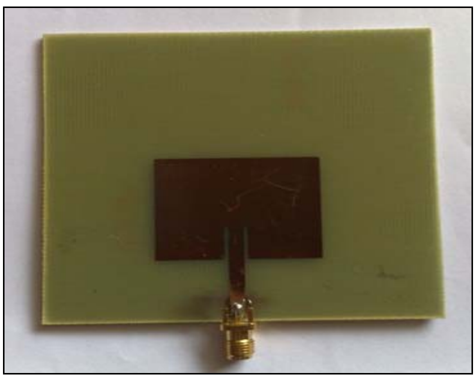
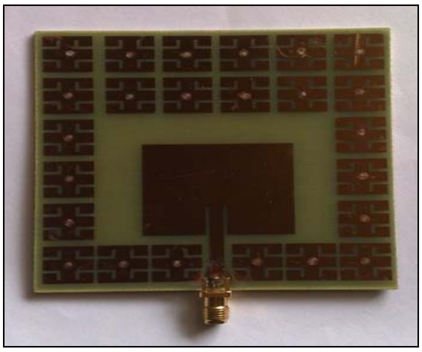
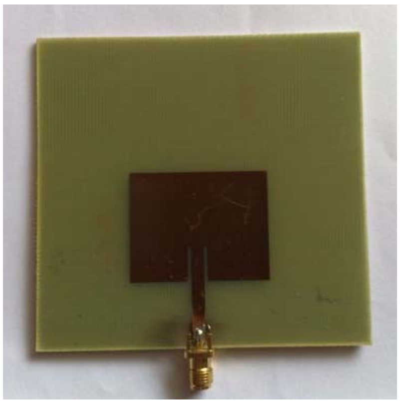


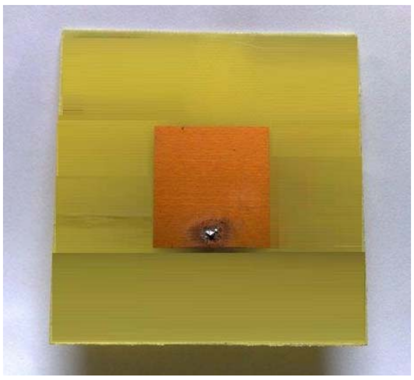
Figure 3.25: Fabrication of single rectangular patch antenna.



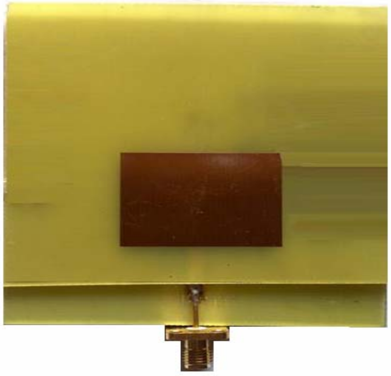
Picture 3.26: Fabrication of single rectangular patch antenna incorporated with EBG structure.



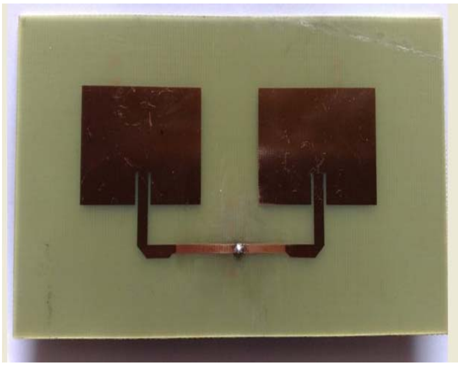
Picture 3.27: Fabrication of integrated EBG structure with two layer single rectangular patch (inset feed) antenna.



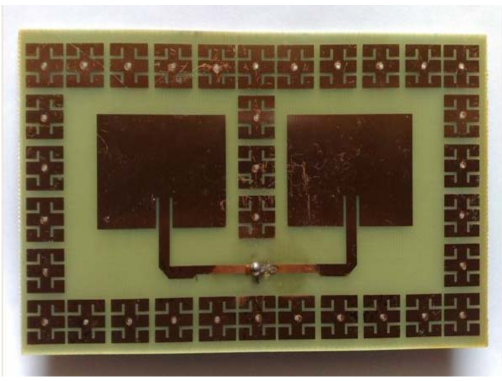
Picture 3.28: Fabrication of integrated EBG structure with two layer single rectangular patch (coaxial cable feed) antenna.



Picture 3.29: Fabrication of integrated EBG structure with two layer single rectangular patch (proximity feed) antenna.



Picture 3.30: Fabrication of 2 by 1 patch antenna array.



Picture 3.31: Fabrication of integrated EBG structure with 2 by 1 patch antenna array

3.2.5 Measurement process

The measurement is the last process to be done. The measurement process has been done to investigate the performance of the antenna fabricated. The data of antenna properties such as return loss, transmission loss, radiation pattern and bandwidth are analyzed and investigated. Then the result will be compared to the simulation result. The characteristic of the antenna from simulation and measurement can be seen. This result can be used for references to analysis for solve any possible problem about the antenna.

There are two equipment has been used to implement this process. There are Network Analyzer and Anechoic Chamber. The anechoic chamber room is divided into two rooms. One room is called as antenna analysis room contains the device such as an Agilent spectrum analyzer, positioner, a rotator and a Gigahertz signal generator to generate signal to horn antenna. Another one room located the anechoic chamber device such as absorbers, horn antenna and antenna under test. The absorbers are used to absorb the unwanted signal to reduce the reflected signal. It can increase the efficiency of the measurement process. The antenna under test (AUT) will be placed at the rotator. The positioner will control the rotator to rotate the tested antenna from 0 degrees to 180 degrees. The received signal of the antenna will be measured by the spectrum analyzer at different angle in the term of signal to noise ratio. This measurement is done to see the radiation pattern of the antenna. To use these device, the experience user is needed to guide inexperience user to use these device because it can make hazardous effect by higher frequency and quite expensive.

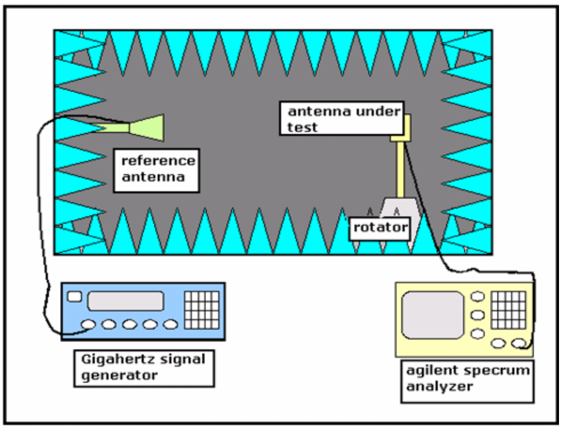


Figure 3.32: Anechoic chamber

Referring to the figure 3.32, it shows all the connection of the devices for anechoic chamber. The Gigahertz signal generator is connected to the reference antenna (horn antenna). The rotator are connected to the antenna under test (AUT)

The network analyzer (figure 3.33) is using to monitoring the return loss and the bandwidth of the fabricated antenna. From that the value of return loss and bandwidth can be measured and the decision can be made whether the value is same from the expected requirement. Floppy drive or USB port is also can be used from this device to save the data collected.

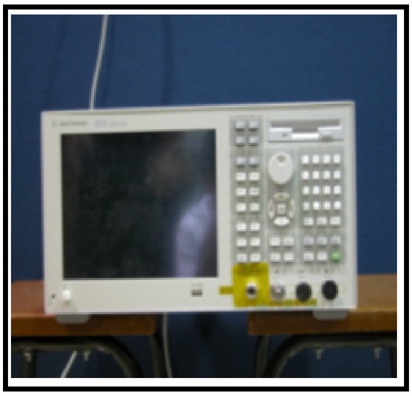


Figure 3.33: Network analyzer

3.3 Summary

This chapter discusses the methodology of this project deeply. Firstly, the designs of the microstrip array antenna and EBG structure are discussed. All the parameters determined by using appropriate formulas in chapter 2 except for EBG structure where the parametric study has been used. The type of software use and the procedures to use the software is also given. Next, the tools and the steps to do the fabrication process are also discussed. Lastly, the measurement equipments and the procedures to do the measurement are discussed. The next chapter will shows the results from the simulations and measurements of the microstrip array antenna and EBG structures.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The results of microstrip array antenna designs such as the return loss and the radiation pattern can be obtained by using the microwave office software. For the EBG structure, the result for transmission loss, S_{21} is also can be obtained by microwave office software. The results for the antenna simulation does not accurately give similar result as measured. This is because the simulation only considers the perfect condition for the material but in practical it is otherwise. Based on the simulations and measurements that haves been done, the operating frequency of the antenna fabricated are shifting to the higher frequency. There are two probabilities which affect the result. First is imperfection in the fabrication process and secondly the properties of the substrate used have some tolerance.

4.2 Electromagnetic Band Gap (EBG) structure

The performance of the EBG structure has been designed will be shown by simulation and measurement. The value of S_{21} or well known as transmission coefficients will show the band gap frequency of the EBG structure. This value will be investigated in both simulation and measurement. Typically, the gap band frequency measured less than -20 dB referring the value of S_{21}.

The reason for the value of S_{21} must be chosen less than -20 dB for the band gap frequency to ensure that the entire surface wave signal radiates in this frequency band gap cannot propagate on EBG structure. So, the surface wave can be suppressed.

4.2.1 3 by 3 Slotted patch EBG structure

Figure 4.1 shows the value of S_{21} in both simulation and measurement. From the graph, the simulation result shows that the band gap frequency of the 3 by 3 slotted EBG structure from the simulation is from 1.975 GHz to 2.639 GHz. The bandwidth of the band gap measured for the value of S_{21} below -20 dB is 29.08%.

Due to the excellent result from the simulation, the 3 by 3 slotted EBG structure was fabricated based on the etching technique discussed in chapter 3. After the fabrication process, the transmission loss was measured using Marconi network analyzer. The band gap frequency measured is from 2.25 GHz to 2.60 GHz. The bandwidth of the band gap is 14.47%. Although the bandwidth of the EBG structure is reduced compared to the simulation, this bandwidth is large enough to cover the bandwidth of the fabricated microstrip antenna array. The bandwidth of the microstrip antenna is discussed in the next chapter.

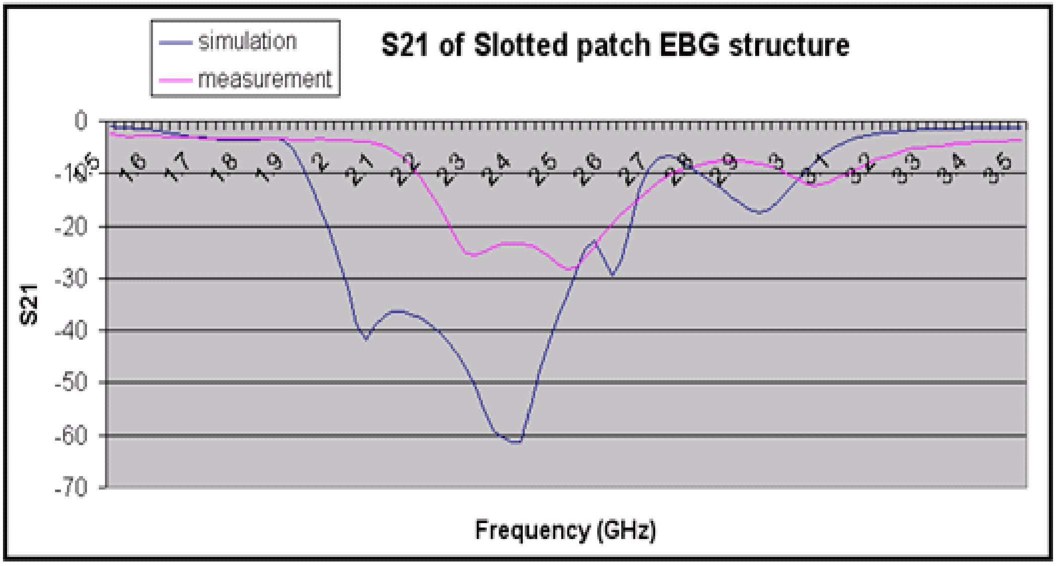


Figure 4.1: S_{21} value for 3 by 3 Slotted patch EBG structure.

4.2.2 3 by 3 Cross patch EBG structure

Figure 4.2 shows the value of S21 in both simulation and measurement. From the graph, the simulation result shows that the band gap frequency of the 3 by 3 Cross EBG structure from the simulation is from 1.935 GHz to 2.507 GHz. The bandwidth of the band gap measured for the value of S21 below -20 dB is 25.9%. Due to the excellent result from the simulation, the 3 by 3 Cross EBG structure was fabricated based on the etching technique discussed in this chapter.

After the fabrication process, the transmission loss was measured using Marconi network analyzer. The band gap frequency measured is from 2.26 GHz to 2.57 GHz. The bandwidth of the band gap is 12.86 %. Although the bandwidth of the

EBG structure is reduced compared to the simulation, this bandwidth is large enough to cover the bandwidth of the fabricated microstrip antenna.

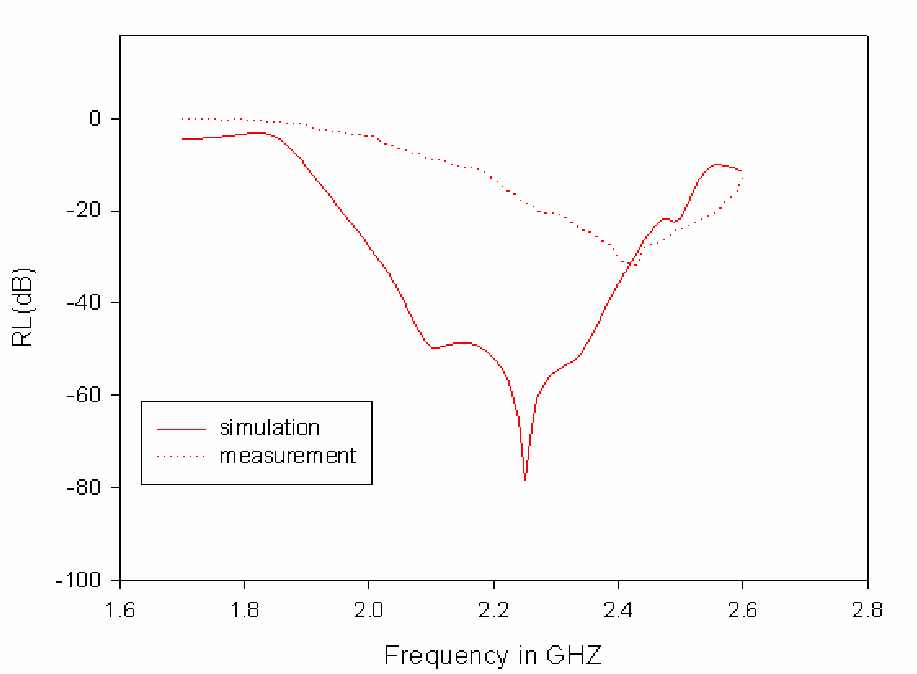


Figure 4.2: S_{21} value for 3 by 3 Cross patch EBG structure

4.3 Microstrip antenna

In this project, UWB antenna, single element microstrip patch antenna (single and double layer), 2 by 1 and 2 by 2 microstrip antenna array was designed and fabricated. Each of the antenna is designed in two forms. One form with EBG and another one is the structure without EBG. The comparison between the performance of the antenna with and without EBG structure was investigated in both simulation and measurement. The results obtained were compared for the same antenna. The value of the input return loss (S_{11}), the radiation pattern, half power beamwidth (HPBW) and the gain of the antenna were compared. These results determine the performance of each antenna developed.

4.4 Return loss, operational frequency, and bandwidth comparison

4.4.1 2 by 1 microstrip antenna array

Referring to the figure 4.2 below, from the simulation, the 2 by 1 microstrip antenna array shows the resonant frequency exactly at 2.4 GHz with a return loss -17.77 dB. The operational frequency of the antenna is 2.3669 GHz to 2.4222 GHz measured at a return loss value below -10 dB. The bandwidth is about 2.30%.

From the measurement result, the resonant frequency shift to the higher frequency to 2.42 GHz. The return loss value at the resonant frequency increased to -17.657 dB. The operating frequency of the antenna shift from 2.39 GHz to 2.45 GHz. The bandwidth is 2.48%, 0.18% wider compared to the simulation process.

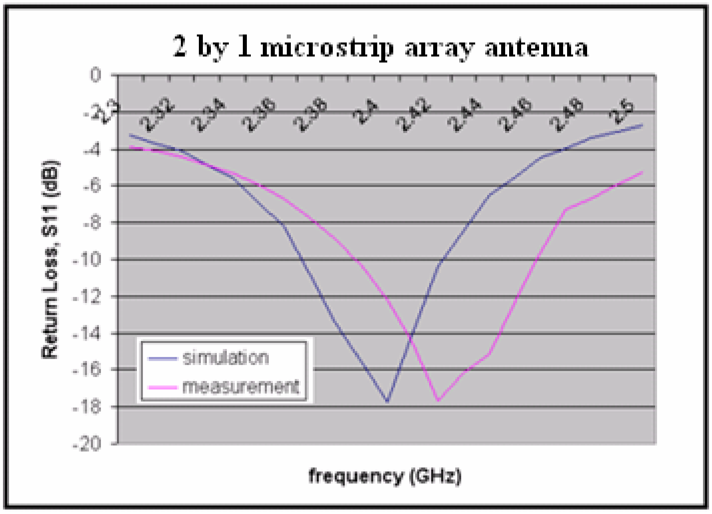


Figure 4.3: Return loss for the 2 by 1 microstrip antenna array (without EBG structure).

4.4.2 2 by 1 microstrip antenna array (with EBG structure)

Referring to the figure 4.3 below, from simulation, the 2 by 1 microstrip antenna array with EBG structure shows the resonant frequency exactly at 2.4 GHz with a return loss -17.29 dB. The return loss value for the 2 by 1 microstrip antenna array with EBG structure increased about 0.48 dB compared to the microstrip antenna array without EBG. The operational frequency of the antenna is 2.367 GHz to 2.4213 GHz measured at the return loss value below -10 dB. The bandwidth is 2.27%.

From the measured result, the resonant frequency shift to the higher frequency to 2.44 GHz. The frequency increases about 0.04 GHz compared to the simulated result. The return loss value at the resonant frequency increased to -15.19 dB. The operating frequency of the antenna shift from 2.39 GHz to 2.47 GHz. The bandwidth is 3.27%, 1% wider compared to the simulated process.

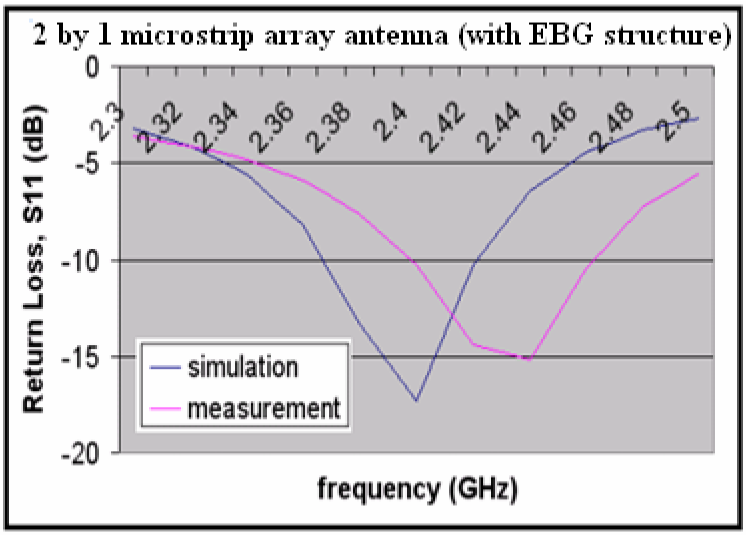


Figure 4.4: The Return loss for 2 by 1 microstrip antenna array (with EBG structure).

4.4.3 Comparison of simulation of 2 by 1 microstrip antenna array (with and without EBG structure)

Figure 4.4 below shows the simulated result for both 2 by 1 microstrip antenna array with and without EBG structure. The graph shows that both results are almost the same. This is because the size of the antenna is small and the total EBG lattice used is small and do not give the big effect to the original antenna structures. There are only 32 EBG lattice are place around the original antenna structures.

The value of return loss, bandwidth, and operational frequency are already discussed in 4.3. The conclusions from the simulation process are the value of return loss for the microstrip antenna array with EBG structure is increase and the bandwidth is decrease but the difference is still small.

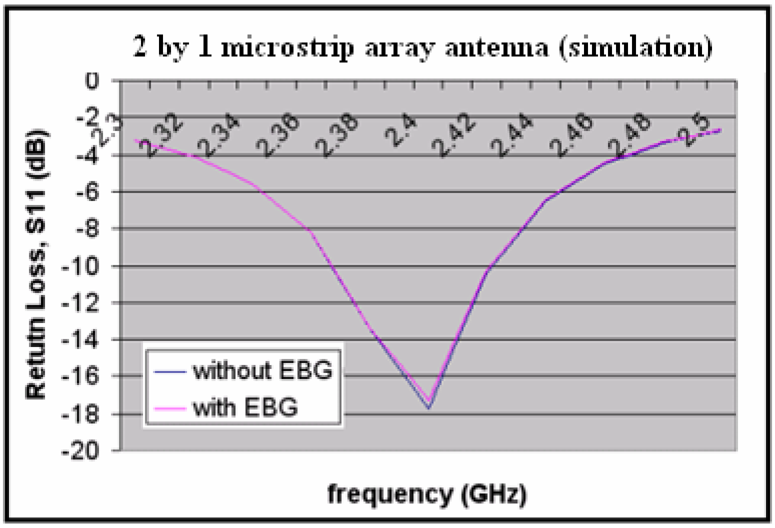


Figure 4.5: Simulation result of S_{11} for 2 by 1 microstrip antenna array

4.4.4 Comparison of measurement of 2 by 1 microstrip antenna array (with and without EBG structure)

Figure 4.5 below shows the measured result for both structure of 2 by 1 microstrip antenna array with and without EBG structure. The graph shows that the operation frequency of the EBG structure has shift to the higher frequency.

By looking at the bandwidth of the antenna with EBG structure, the bandwidth is wider compared to the antenna without EBG structure. From measured result, the 2 by 1 microstrip antenna array has 2.48% bandwidth, but by integrates the 2 by 1 microstrip antenna array with EBG structure, the bandwidth increase to 3.27%. The bandwidth is 0.79% higher when integrated with EBG structure. The operational frequency shifts to a higher frequency for the antenna with EBG structure.

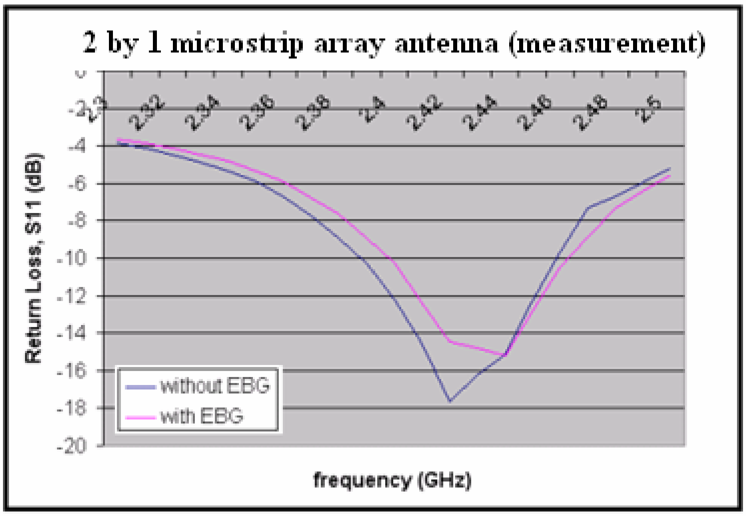


Figure 4.6: Measurement result of S_{11} for 2 by 1 microstrip antenna array

4.4.5 2 by 2 microstrip antenna array

Referring to the figure 4.6 below, from the simulated result, the 2 by 2 microstrip antenna array shows that the resonant frequency radiates at 2.4 GHz with a return loss -16.08 dB. The operational frequency of the antenna is 2.3442 GHz to 2.4323 GHz measured at the return loss value below -10 dB. The bandwidth is 3.69%.

From the measurement result, the resonant frequency shifts to the higher frequency at 2.43 GHz. The return loss at the resonant frequency reduced to -27.3 dB, 11.22 dB better compared to the simulation result. The operational frequency of the antenna shifts from 2.38 GHz to 2.48 GHz. The bandwidth is 4.12%, 0.43% wider compared to the simulation process.

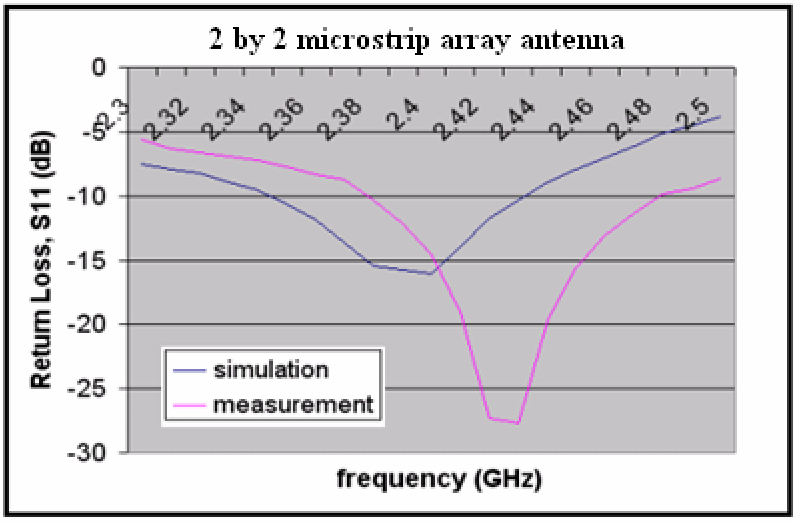


Figure 4.7: Return loss for the 2 by 2 microstrip antenna array.

4.4.6 2 by 2 microstrip antenna array (with EBG structure)

Referring to the figure 4.7, for simulated result, the 2 by 2 microstrip antenna array with EBG structure shows the resonant frequency shift to a lower frequency at 2.36 GHz with a return loss -20.71 dB. The operational frequency of the antenna shifts to a lower frequency starting from 2.3314 GHz to 2.3964 GHz. The bandwidth is 2.75%.

From the measured result, the resonant frequency shifts to the higher frequency at 2.43 GHz. The frequency increase about 0.07 GHz compared to the simulation result. The return loss value at the resonant frequency is decreasing to -24.8 dB, 4.09 dB less compared to the simulated result. The operational frequency of the antenna shifts from 2.38 GHz to 2.49 GHz. The bandwidth is 4.52%, 1.77% wider compared to the simulation process.

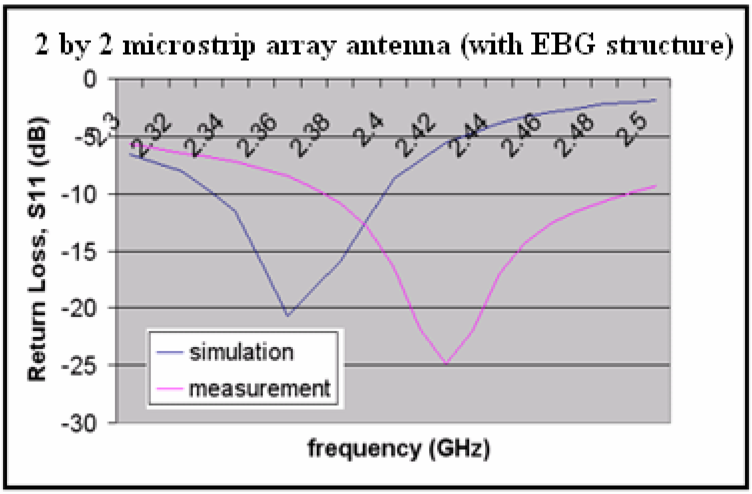


Figure 4.8: Return loss for the 2 by 2 microstrip antenna array (with EBG structure).

4.4.7 Comparison from simulated result of 2 by 2 microstrip antenna array (with and without EBG structure)

Figure 4.8 shows the simulated results for both structure of 2 by 2 microstrip antenna array with and without EBG structures. The graph also shows that 2 by 2 microstrip antenna array with and without EBG structure have different performance compared to the 2 by 1 microstrip antenna array with and without EBG structure. Due to the large number of EBG structures placed around the original antenna structure, it will give a big effect to the original antenna structures. There are 60 EBG lattices are placed around the original antenna structures.

From the simulated result, the resonant frequency shift to a lower frequency at 2.36 GHz. The frequency reduced 0.04 GHz for the antenna with EBG structure compared to the antenna without EBG structure. The return loss value for 2 by 2 microstrip antenna array with EBG structure at the resonant frequency reduced to -20.71 dB compare to the antenna without EBG structure which has return loss value -16.08 at resonant frequency. The return loss value is 4.63 dB less compared to the structure without EBG. The operational frequency of the antenna reduced from 2.3314 GHz to 2.3964 GHz. The bandwidth is 2.75%. The operational frequency for 2 by 2 microstrip antenna array without EBG is 2.3442 GHz to 2.4323 GHz and the bandwidth is 3.69%. The bandwidth reduced about 0.94% compared to the structure without EBG.

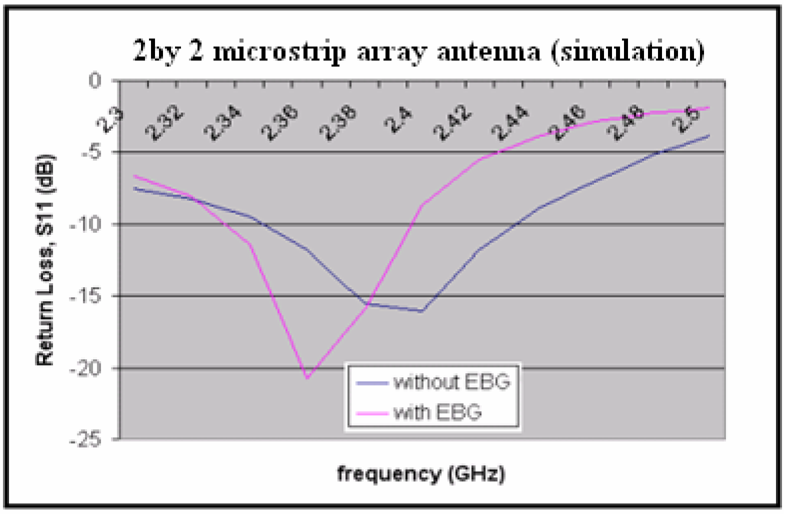


Figure 4.9: Simulation result of S_{11} for 2 by 2 microstrip antenna array

4.4.8 Comparison of measurement of 2 by 2 microstrip antenna array (with and without EBG structure)

Figure 4.9 below shows the measured result for 2 by 2 microstrip antenna array with and without EBG structure. The graph shows that the operation frequency of the EBG structure reduced to a lower frequency. The return loss value of the antenna with EBG structure is increase to -20.71 dB compared to the structure without EBG, -27.3. The total increment is 6.59 dB.

In term of bandwidth, by measurement, the 2 by 2 microstrip antenna array has 4.12% but by integration with EBG structure, the bandwidth increase to 4.52%. The bandwidth is 0.4% higher when integrate the antenna with EBG structure. The operational frequency shifts to lower frequency at 2.36 GHz for the antenna with EBG structure.

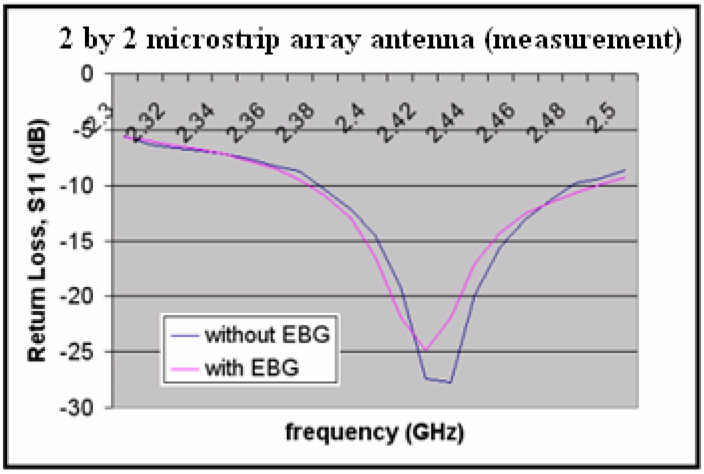


Figure 4.10: Measurement result of S_{11} for 2 by 2 microstrip antenna array

4.5 Radiation pattern comparison

Radiation pattern is the most important part in this project's research. This is because the EBG structure was expected to improve the radiation pattern of the microstrip antenna array by reducing side lobe and back lobe and increase the front lobe. The radiation characteristic of the antenna will be investigated in term of maximum power received, cross isolation, half power beam width (HPBW), side lobe, and back lobe. The reference antenna used is monopole antenna which has maximum power received equal to 24 dBm. HPBW is measured by calculating the angle of the radiated power only at the main lobe that is from the maximum radiated power to half of the maximum radiated power which is -3 dB from the maximum radiated power. Cross isolation is measured by calculating the difference between co polar and cross polar at 0 degree in main lobe.

4.5.1 2 by 1 microstrip antenna array

Figure 4.10 shows the E-plane radiation pattern from measurement with anechoic chamber properties for 2 by 1 microstrip antenna array at a frequency of 2.4 GHz. From the graph, the maximum power receive is -25 dBm, 1 dB less than monopole antenna. The cross isolation is 32 dB. The HPBW is 49 degree (-22 degree to 27 degree)

Figure 4.11 shows the measured result for H-plane radiation pattern for 2 by 1 microstrip antenna array at a frequency of 2.4 GHz. From the graph, the maximum power received is -25 dBm. The cross isolation is 28 dB. The HPBW is 83 degree (-40 degree to 43 degree).

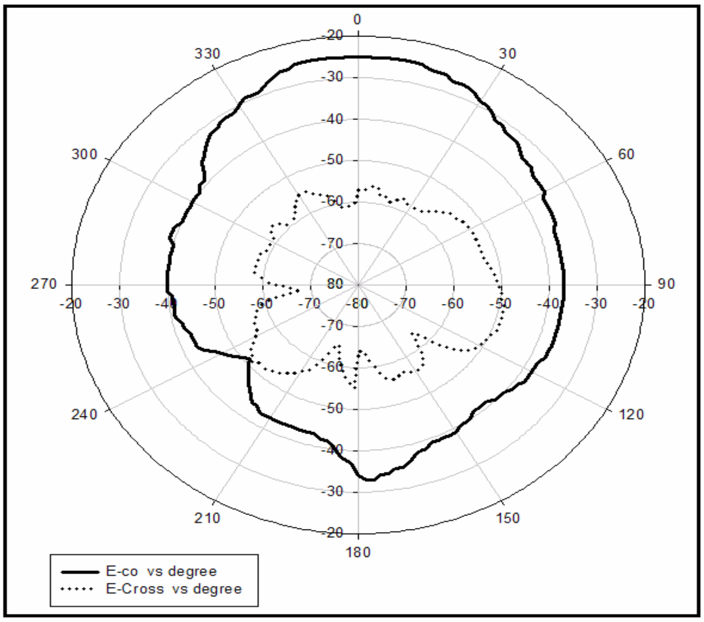


Figure 4.11: Measured E-plane radiation pattern for 2 by 1 microstrip antenna array

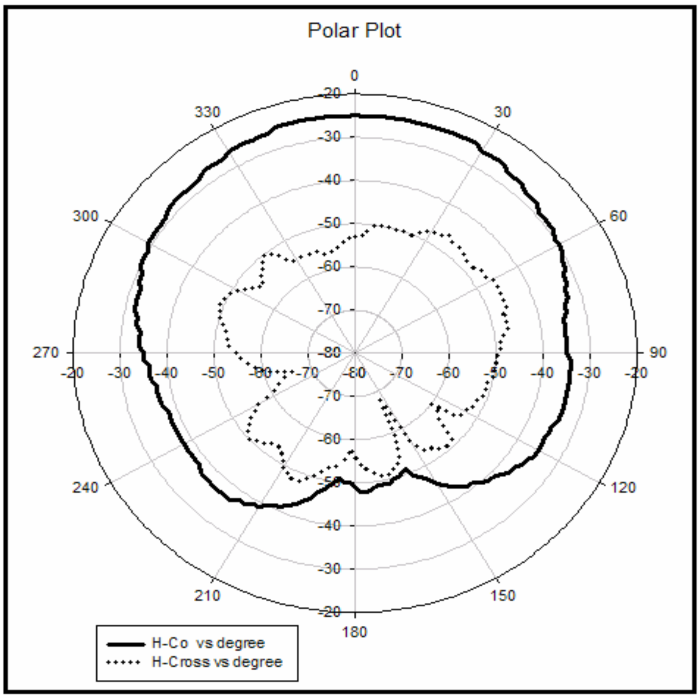


Figure 4.12: Measured H-plane radiation pattern for 2 by 1 microstrip antenna array

4.5.2 2 by 1 microstrip antenna array (with EBG structure)

Figure 4.12 shows the measured E-plane radiation pattern by for 2 by 1 microstrip antenna array with EBG structure at a frequency of 2.4 GHz. From the graph, the maximum power received is -24 dBm, same as monopole antenna. The cross isolation is 32 dB. The HPBW is 39 degree (-20 degree to 19 degree).

Figure 4.13 shows the measured H-plane radiation pattern for 2 by 1 microstrip antenna array with EBG structure at a frequency of 2.4 GHz. From the graph, the maximum power received is -25 dBm, 1 dB less compared to monopole antenna. The cross isolation is 29 dB. The HPBW is 85 degree (-41 degree to 44 degree).

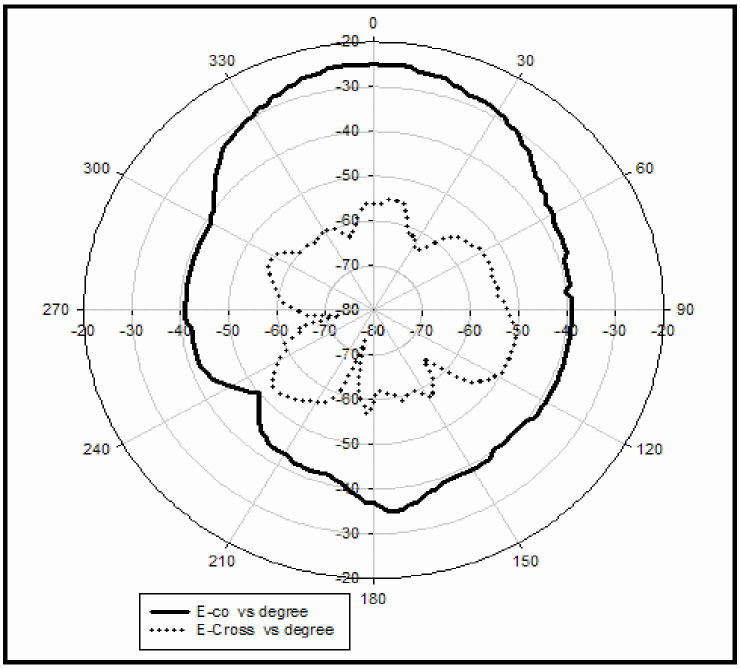


Figure 4.13: Measured E-plane radiation pattern for 2 by 1 microstrip antenna array (with EBG)

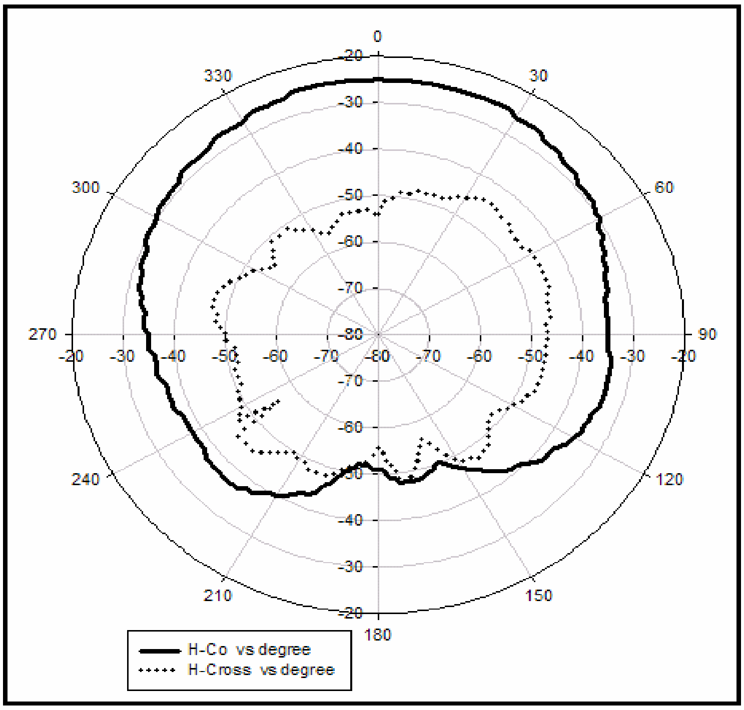


Figure 4.14: Measured H-plane radiation pattern for 2 by 1 microstrip antenna array (with EBG)

4.5.3 2 by 2 microstrip array antenna

Figure 4.14 shows the measured E-plane radiation pattern for 2 by 2 microstrip antenna array at a frequency of 2.4 GHz. From the graph, the maximum power receive is -22 dBm, 2 dB better than monopole antenna. The cross isolation is 33 dB. The HPBW is 56 degree (-27 degree to 29 degree).

Figure 4.15 shows the measured H-plane radiation pattern for 2 by 2 microstrip antenna array at frequency 2.4 GHz. From the graph, the maximum power received is -23 dBm, 1 dB better compared to isotropic antenna. The cross isolation is 33 dB. The HPBW is 47 degree (-24 degree to 23 degree).

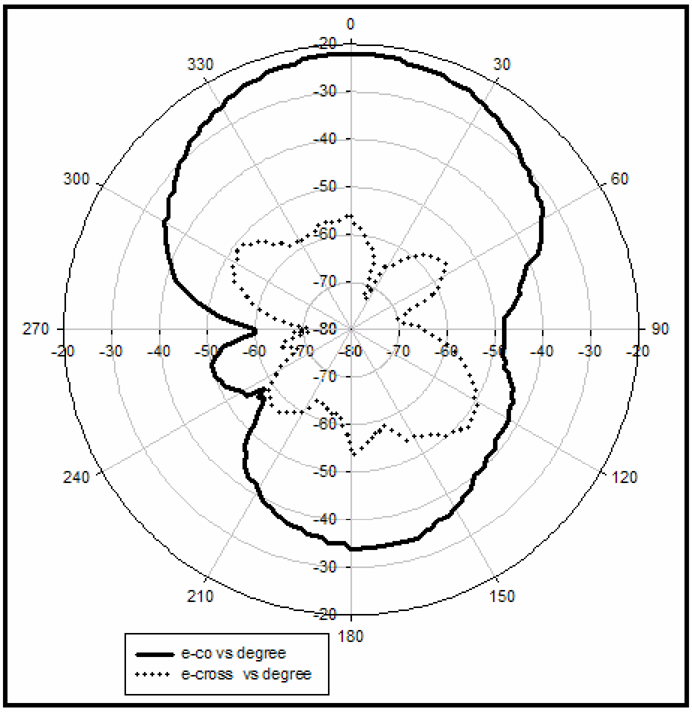


Figure 4.15: Measured E-plane radiation pattern for 2 by 2 microstrip antenna array

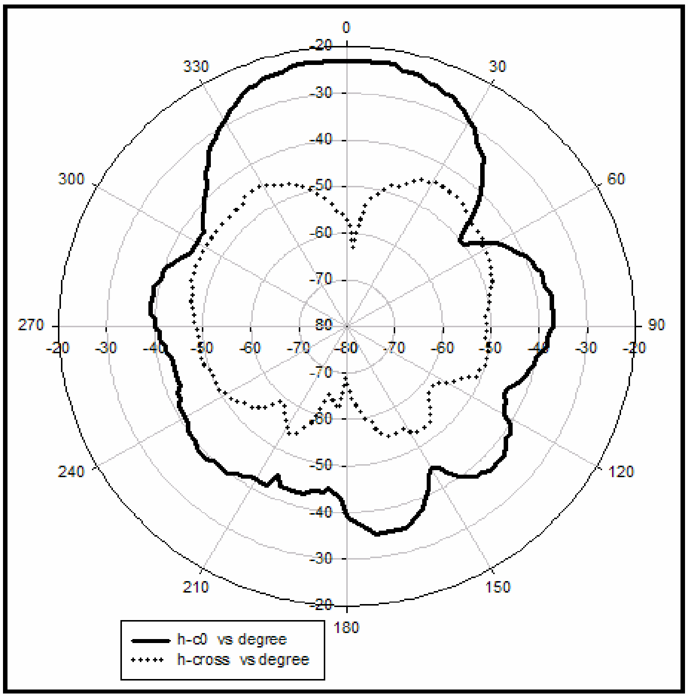


Figure 4.16: H-plane radiation pattern for 2 by 2 microstrip antenna array

4.5.4 2 by 2 microstrip antenna array (with EBG structure)

Figure 4.16 shows the measured E-plane radiation patter for 2 by 2 microstrip antenna array integrated with EBG structure at a frequency of 2.4 GHz. From the graph, the maximum power receive is -21 dBm, 3 dB higher than monopole antenna. The cross isolation is 39 dB. The HPBW is 35 degree (-20 degree to 19 degree).

Figure 4.17 shows the H-plane radiation patter for 2 by 2 microstrip antenna array integrated with EBG structure at a frequency of 2.4 GHz. From the graph, the maximum power receive is -22 dBm, 2 dB higher compared to monopole antenna. The cross isolation is 40 dB. The HPBW is 33 degree (-14 degree to 19 degree).

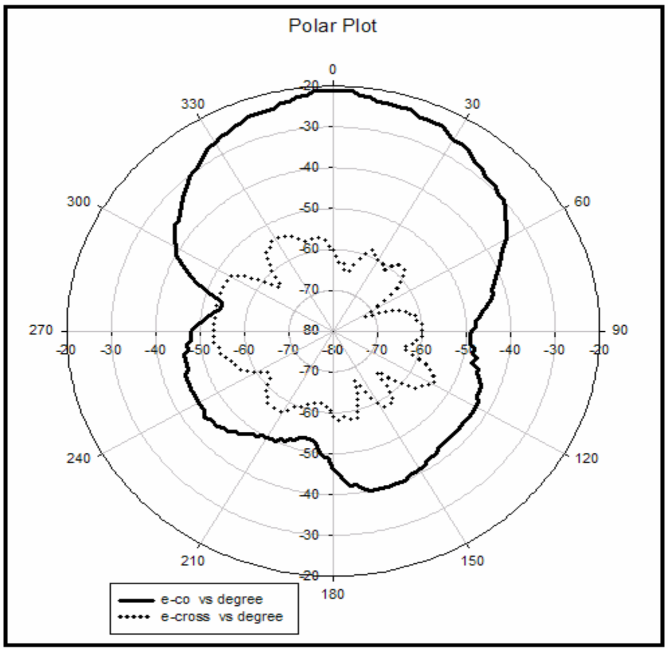


Figure 4.17: Measured E-plane radiation pattern for 2 by 2 microstrip antenna array (with EBG)

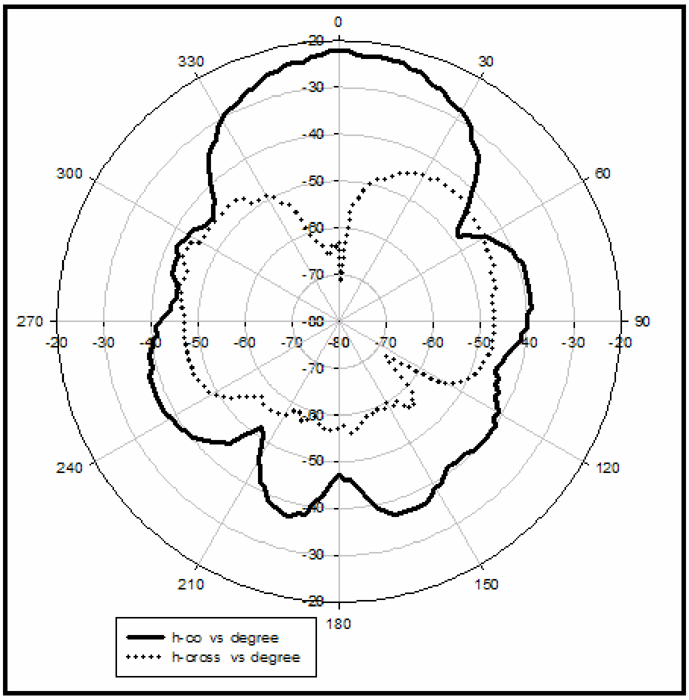


Figure 4.18: Measured H-plane radiation pattern for 2 by 2 microstrip antenna array (with EBG)

4.5.5 2 by 1 microstrip antenna array (with and without EBG structure)

Figure 4.18 shows the comparison of measured E-Co polarization for 2 by 1 microstrip antenna array with and without EBG structure at a frequency of 2.4 GHz. From the graph, the maximum power received is -25 dBm for the antenna without EBG structure. The power received increase to -24 dB for the antenna with EBG structure. The side lobe and back lobe for the 2 by 1 microstrip antenna array with EBG structure is reduced.

Figure 4.19 shows the comparison of measured H-Co polarization for 2 by 1 microstrip antenna array with and without EBG structure at frequency 2.4 GHz. From the graph, the maximum power received in both structures is same at -25 dBm. The side lobe and back lobe for the 2 by 1 microstrip antenna array with EBG structure is reduced.

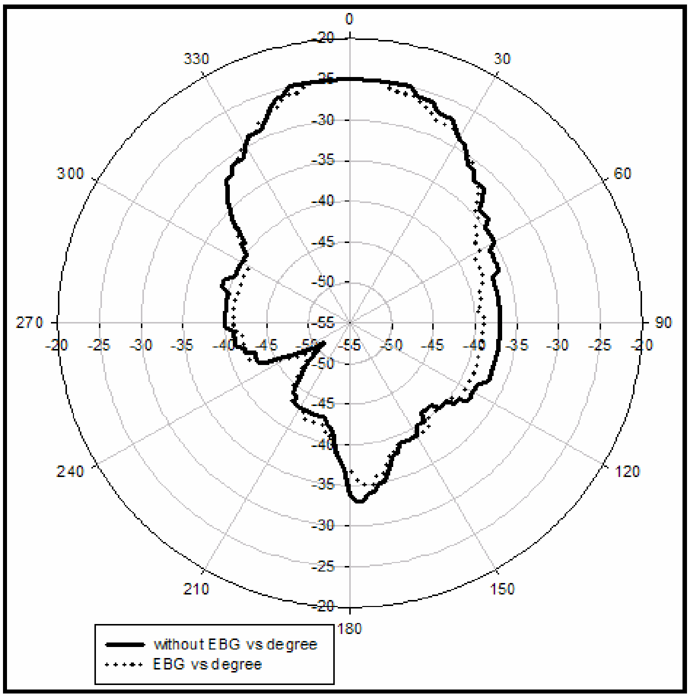


Figure 4.19: Measured E-Co polarization for 2 by 1 microstrip antenna array

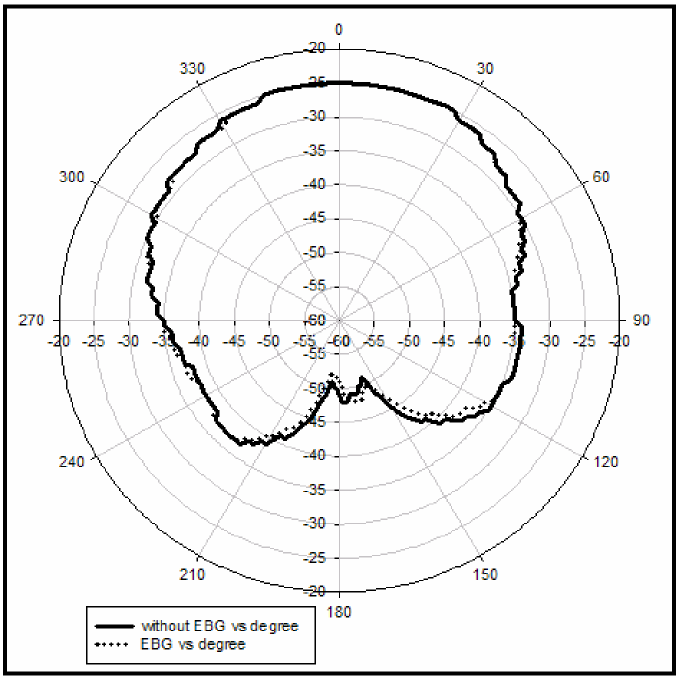


Figure 4.20: Measured H-Co polarization for 2 by 1 microstrip antenna array

4.5.6 2 by 2 microstrip array antenna (with and without EBG structure)

Figure 4.20 shows the comparison of measured E-Co polarization for 2 by 2 microstrip antenna array with and without EBG structure at a frequency of 2.4 GHz. From the graph, the maximum power received is -22 dBm for the antenna without EBG structure. The power received increase to -21 dB for the antenna with EBG structure shows 1 dB increment. The side lobe and back lobe for the 2 by 2 microstrip antenna array with EBG structure is reduced.

Figure 4.21 shows the comparison of measured H-Co polarization for 2 by 2 microstrip antenna array with and without EBG structure at a frequency of 2.4 GHz. From the graph, the maximum power received is -23 dBm for the antenna without EBG structure. The power received increase to -22 dB for the antenna with EBG structure, 1 dB increment noticed. The side lobe and back lobe for the 2 by 2 microstrip antenna array with EBG structure is reduced.

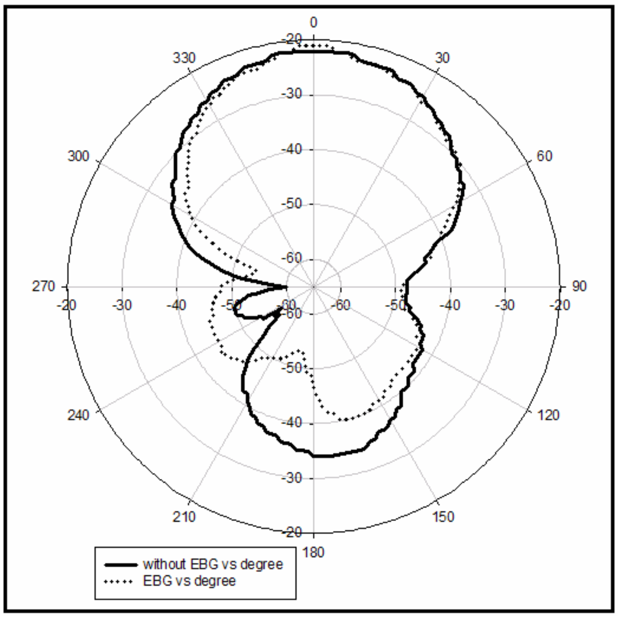


Figure 4.21: Measured E-Co polarization for 2 by 2 microstrip antenna array

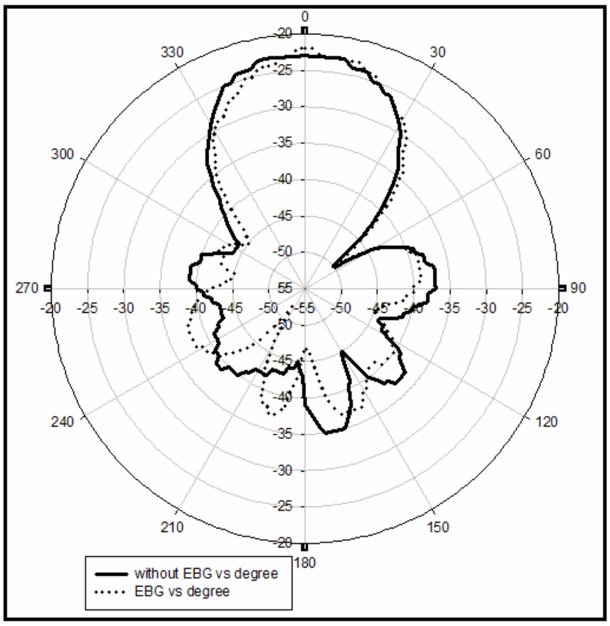


Figure 4.22: Measured H-Co polarization for 2 by 2 microstrip antenna array

4.6 Simulation and measurement result of rectangular single patch antenna design

The return loss results obtained from the Scalar Network Analyzer are plotted in Sigma Plot software. This data is shown in APPENDIX B along with simulation data. Figure 4.23 shows a graph which compares the simulation and measurement return loss results of rectangular single patch antenna.

For the simulation results the resonant frequency exactly at 2.4 GHz with a return loss -13.6 dB. The operational frequency of the antenna is 2.38 GHz to 2.43 GHz measured at a return loss value below -10 dB. The bandwidth is about 2.07%.

From the measurement result, the resonant frequency shift to the higher frequency to 2.45 GHz. The return loss values at the resonant frequency -13.6 dB. The operational frequency of the antenna shifts from 2.384 GHz to 2.491 GHz. The bandwidth is 4.39%.

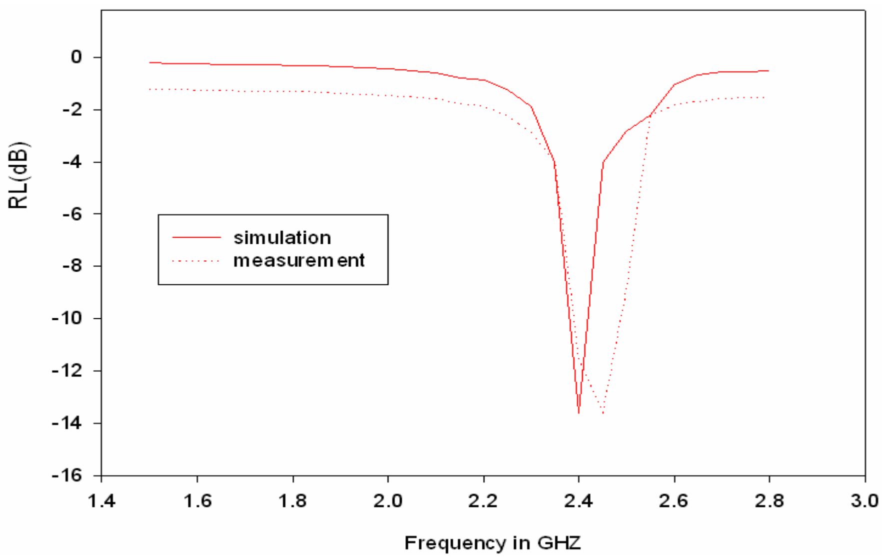


Figure 4.23: Return Loss results for simulation and fabrication

Figure 4.24 shows the measured E-plane radiation pattern for rectangular single patch antenna at a frequency of 2.45 GHz. From the graph, the maximum power receive is -60 dBm. The HPBW is 126 degree (-64 degree to 62 degree).

Figure 4.25 shows the measured H-plane radiation pattern for rectangular single patch antenna at frequency 2.45 GHz. From the graph, the maximum power received is -60 dBm. The HPBW is 122 degree (-62 degree to 66 degree).

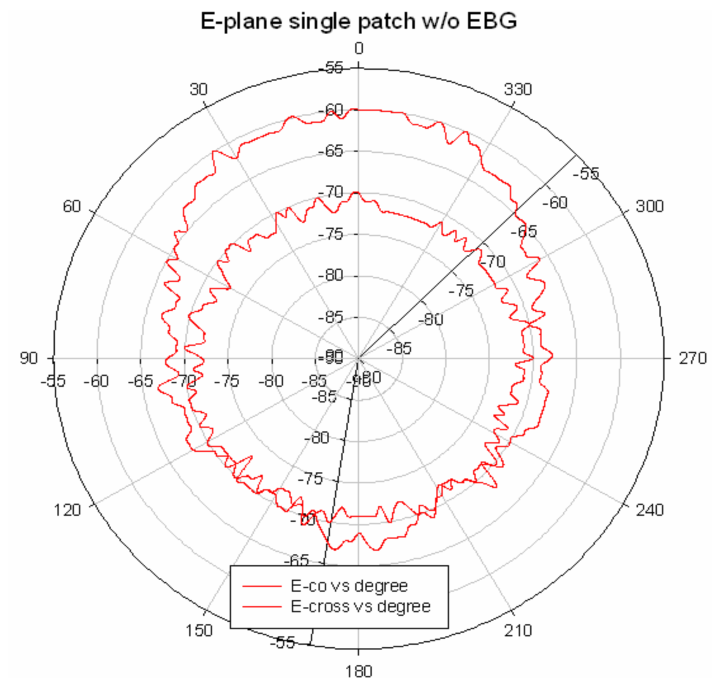


Figure 4.24: Measured E-plane radiation pattern for single patch microstrip antenna

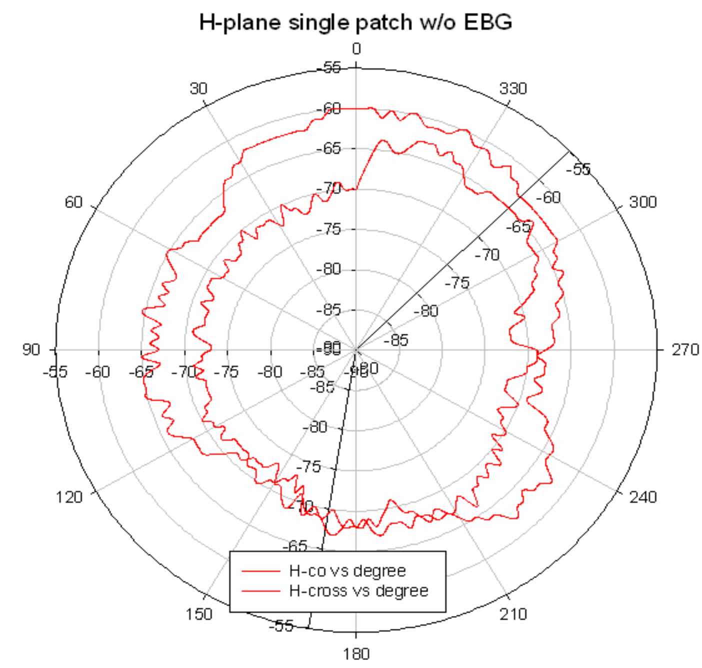


Figure 4.25: Measured E-plane radiation pattern for single patch microstrip antenna

4.7 Simulation and measurement result of rectangular single patch antenna design incorporated with EBG structure.

The return loss results obtained from the Scalar Network Analyzer are plotted in Sigma Plot software. This data is shown in APPENDIX C along with simulation data. Figure 4.26 shows a graph which compares the simulation and measurement return loss results of integrated EBG structure with rectangular single patch antenna.

For the simulation results the resonant frequency exactly at 2.4 GHz with a return loss -22.4 dB. The operational frequency of the antenna is 2.39 GHz to 2.44 GHz measured at a return loss value below -10 dB. The bandwidth is about 2.07%.

From the measurement result, the resonant frequency shift to the higher frequency to 2.45 GHz. The return loss values at the resonant frequency -19.5 dB. The operational frequency of the antenna shifts from 2.39 GHz to 2.48 GHz. The bandwidth is 3.69%.

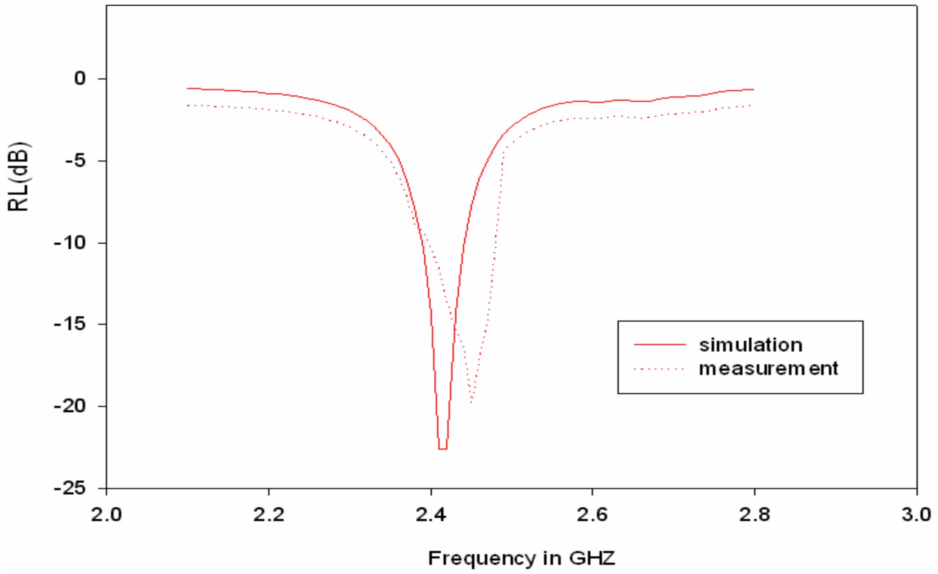


Figure 4.26: Return Loss results for simulation and fabrication

Figure 4.27 shows the measured E-plane radiation pattern for integrated EBG structure with rectangular single patch antenna at a frequency of 2.45 GHz. From the graph, the maximum power receive is -59 dBm. The HPBW is 120 degree (-60 degree to 60 degree).

Figure 4.28 shows the measured H-plane radiation pattern for integrated EBG structure with rectangular single patch antenna at frequency 2.45 GHz. From the graph, the maximum power received is -59 dBm. The HPBW is 120 degree (-60 degree to 60 degree).

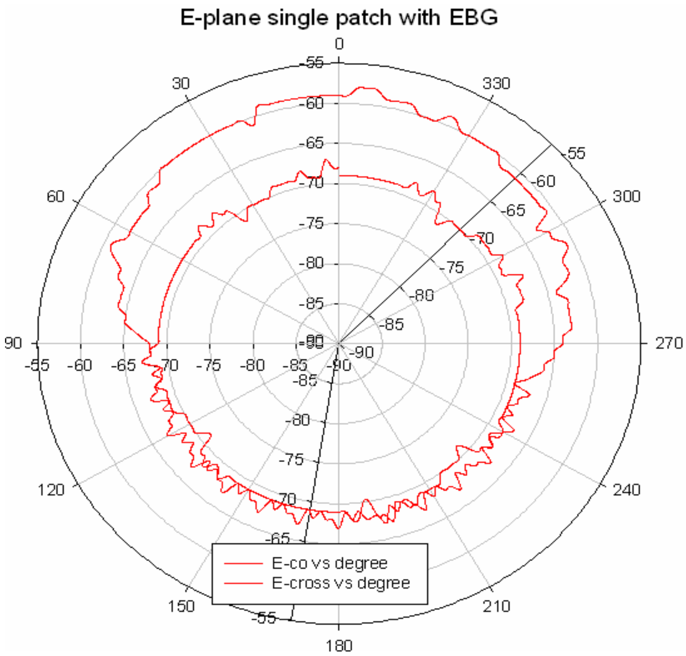


Figure 4.27: Measured E-plane radiation pattern for integrated EBG with single patch microstrip antenna

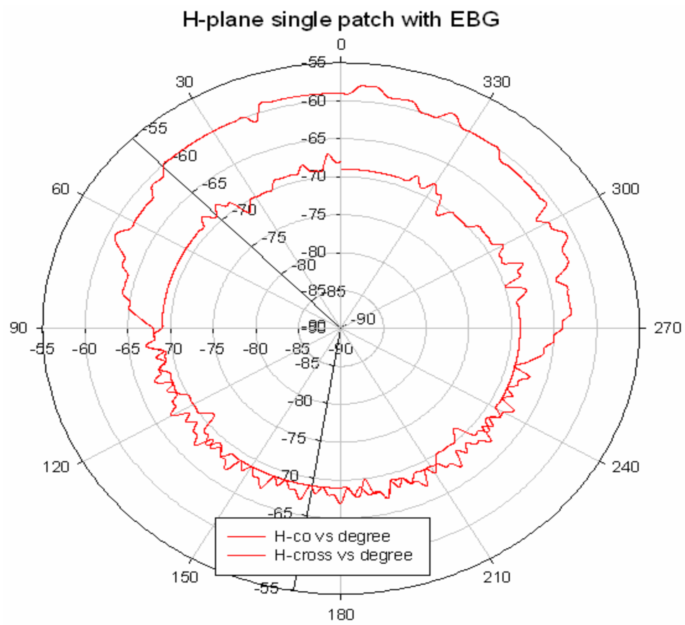


Figure 4.28: Measured H-plane radiation pattern for integrated EBG with single patch microstrip antenna

4.8 Two Layers Rectangular Single Patch (inset feed) Design

Same as in rectangular single patch antenna, the measured results obtained for the return loss from the Scalar Network Analyzer are plotted in Sigma Plot software for two layer rectangular single patch(inset feed) antenna. The date is shown in APPENDIX D along with simulation data. Figure 4.8 shows a graph which compares the simulation and measurement return loss results of two layer rectangular single patch antenna.

For the simulation results the resonant frequency exactly at 2.4 GHz with a return loss -17.3 dB. The operational frequency of the antenna is 2.34 GHz to 2.41 GHz measured at a return loss value below -10 dB. The bandwidth is about 2.947%.

From the measurement result, the resonant frequency a bit shifted to the high frequency at 2.41 GHz. The return loss values at the resonant frequency -14.5 dB. The operational frequency of the antenna shifts from 2.34 GHz to 2.41 GHz. The bandwidth is 2.947%.

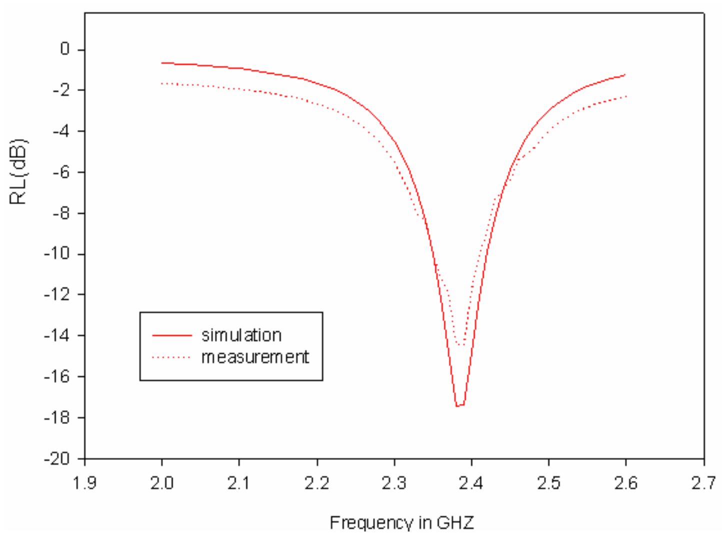


Figure 4.29: Return Loss results for simulation and fabrication.

Figure 4.30 shows the measured E-plane radiation pattern for 2 by 2 microstrip antenna array at a frequency of 2.4 GHz. From the graph, the maximum power receive is -49 dBm. The HPBW is 107.6 degree (-53.8 degree to 53.8 degree).

Figure 4.31 shows the measured H-plane radiation pattern for 2 by 2 microstrip antenna array at frequency 2.4 GHz. From the graph, the maximum power received is -49 dBm. The HPBW is 107.6 degree (-51.6 degree to 56 degree).

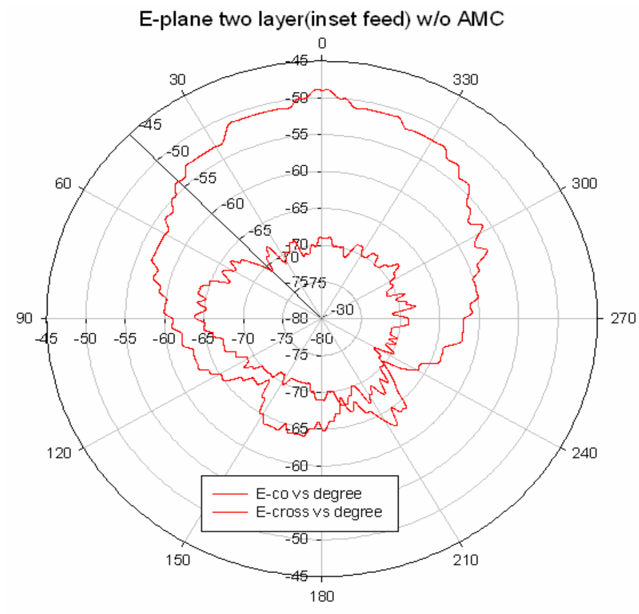


Figure 4.30: Measured E-plane radiation pattern for two layers single patch (inset feed) microstrip antenna

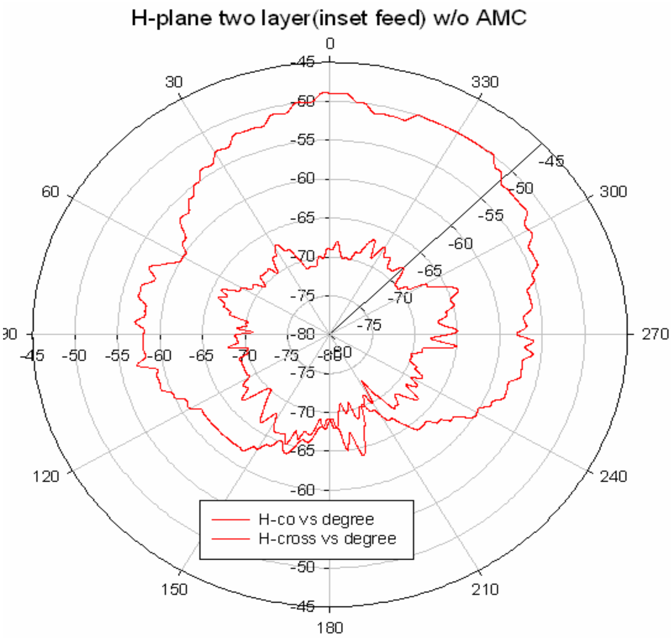


Figure 4.31: Measured H-plane radiation pattern for two layers single patch (inset feed) microstrip antenna

4.9 Two layers single patch (inset feed) design incorporated with EBG structure

Same as in rectangular single patch microstrip antenna, the measured results obtained for the return loss from the Scalar Network Analyzer are plotted in Sigma Plot software for integrated EBG surface with two layer rectangular single microstrip antenna. The date is shown in APPENDIX E along with simulation data. Figure 4.32 shows a graph which compares the simulation and measurement return loss results of integrated EBG surface with two layer rectangular single patch antenna.

For the simulation results of integrated EBG surface with two layer rectangular single patch antenna the resonant frequency has been shifted to the lower frequency at 2.31 GHz with a return loss -20 dB. The operational frequency of the antenna is 2.27 GHz to 2.33 GHz measured at a return loss value below -10 dB. The bandwidth is about 2.608%.

From the measurement result, the resonant frequency has been shifted to the upper frequency at 2.32 GHz. The return loss value is reduced at the resonant frequency - 14.5 dB. The operational frequency of the antenna shifts from 2.27 GHz to 2.35 GHz. The bandwidth is 3.46%

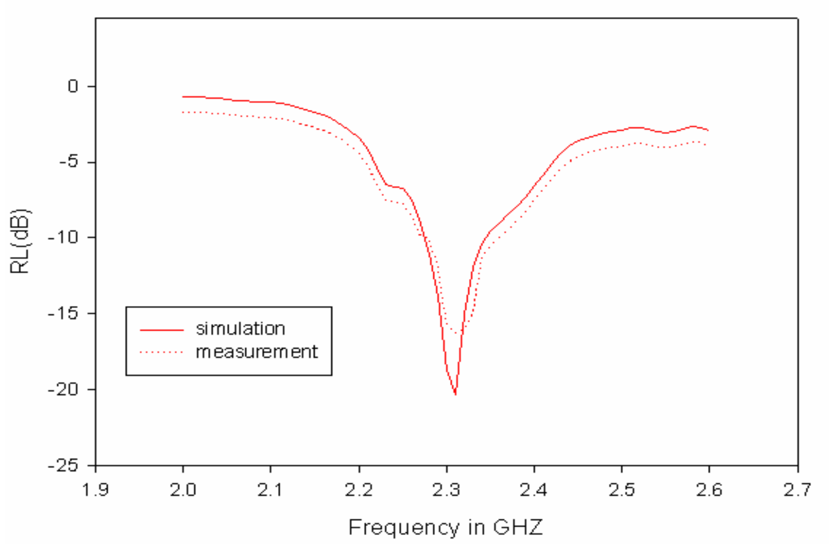


Figure 4.32: Return Loss results for simulation and fabrication

Figure 4.33 shows the measured E-plane radiation pattern for integrated EBG surface with two layer rectangular single patch (inset feed) antenna at a frequency of 2.32 GHz. From the graph, the maximum power receive is -49 dBm. The HPBW is 107.6 degree (-53.8 degree to 53.8 degree).

Figure 4.34 shows the measured H-plane radiation pattern for integrated EBG surface with two layer rectangular single patch (inset feed antenna at frequency 2.34

GHz. From the graph, the maximum power received is -49 dBm. The HPBW is 107.6 degree (-51.6 degree to 56 degree).

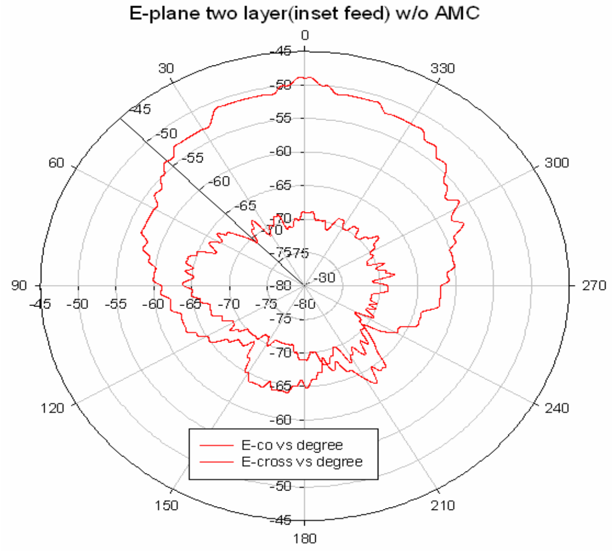


Figure 4.33: Measured E-plane radiation pattern for incorporated of EBG structure with two layers single patch (inset feed) microstrip antenna

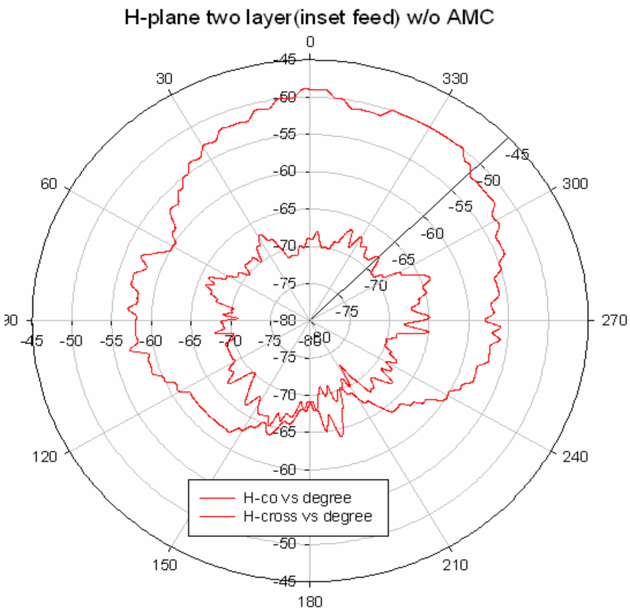


Figure 4.34: Measured H-plane radiation pattern for incorporated of EBG structure with two layers single patch (inset feed) microstrip antenna.

4.10 Two layers single rectangular patch (coaxial cable feed) design

Same as rectangular single patch antenna, the measured results obtained for the return loss from the Scalar Network Analyzer are plotted in Sigma Plot software for two layer rectangular single patch (coaxial cable feed) antenna. The date is shown in APPENDIX F along with simulation data. Figure 4.35 shows a graph which compares the simulation and measurement return loss results of two layer rectangular single patch (coaxial cable feed) antenna.

For the simulation results of two layer rectangular single patch (coaxial cable feed) antenna the resonant frequency exactly at 2.4 GHz with a return loss -28.06 dB. The operational frequency of the antenna is 2.15 GHz to 3.33 GHz measured at a return loss value below -10 dB. The bandwidth is about 44.18%.

From the measurement result, the resonant frequency has been shifted to the higher frequency at 2.5 GHz. The return loss value is reduced at the resonant frequency – 21.41 dB. The operational frequency of the antenna shifts from 2.19 GHz to 3.02 GHz. The bandwidth is 32.27%

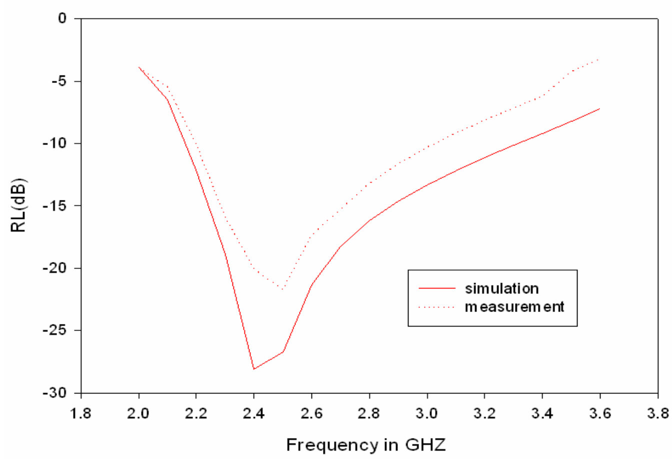


Figure 4.35: Return Loss results for simulation and fabrication

Figure 4.36 shows the measured E-plane radiation pattern for two layer rectangular single patch (coaxial cable feed) antenna at a frequency of 2.5 GHz. From the graph, the maximum power receive is -52 dBm. The HPBW is 110.2 degree (-55.3 degree to 54.9 degree).

Figure 4.37 shows the measured H-plane radiation pattern two layer rectangular single patch (coaxial cable feed) antenna at frequency 2.4 GHz. From the graph, the maximum power received is -52 dBm. The HPBW is 112.5 degree (-56.8 degree to 55.7 degree).

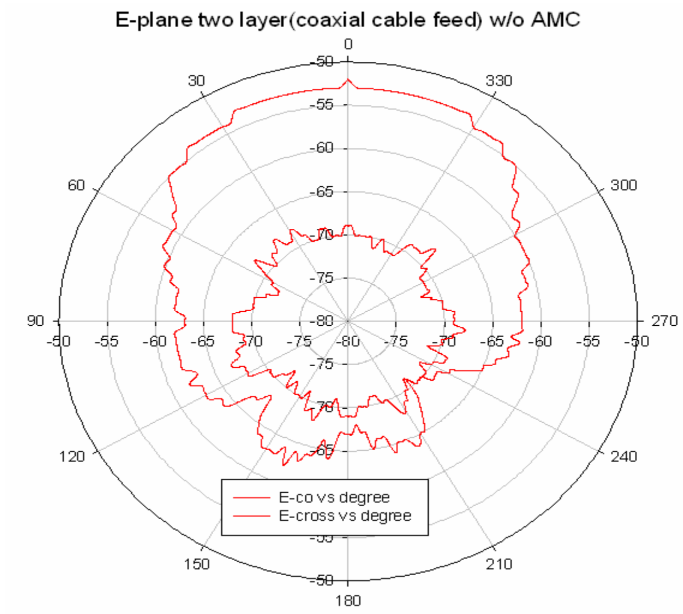


Figure 4.36: Measured E-plane radiation pattern for two layers single patch (coaxial cable feed) microstrip antenna

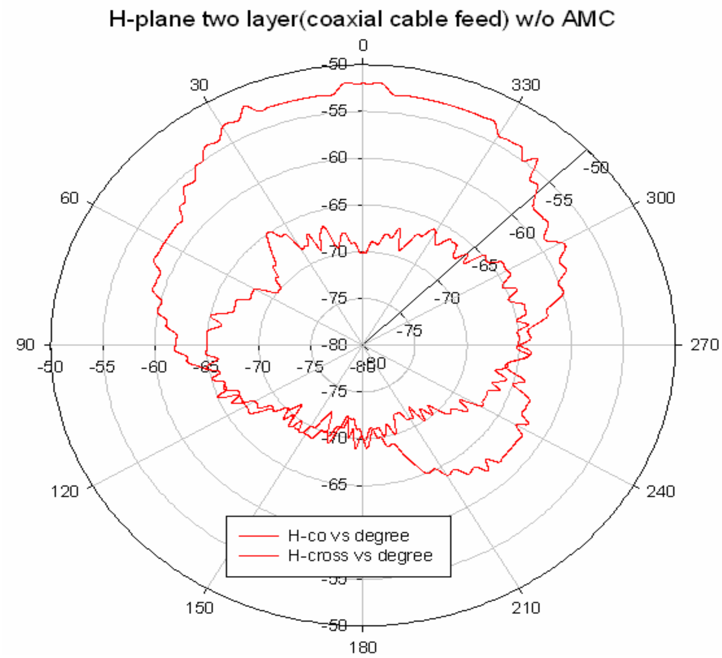


Figure 4.37: Measured H-plane radiation pattern for two layers single patch (coaxial cable feed) microstrip antenna.

4.11 Two Layers Single Rectangular Patch (coaxial cable feed) Design incorporated with EBG structure

Same as rectangular single patch antenna, the measured results obtained for the return loss from the Scalar Network Analyzer are plotted in Sigma Plot software for integrated EBG surface with two layers rectangular single patch (coaxial cable feed) antenna. The date is shown in APPENDIX G along with simulation data. Figure 4.38 shows a graph which compares the simulation and measurement return loss results of integrated EBG surface with two layer rectangular single patch (coaxial cable feed) antenna.

For the simulation results of integrated EBG surface two layer rectangular single patch antenna the resonant frequency has been shifted to the lower frequency at 1.609 GHz with a return loss -31.03 dB. The operational frequency of the antenna is 1.45 GHz to 3 GHz measured at a return loss value below -10 dB. The bandwidth is about 74.31%.

From the measurement result, the resonant frequency has been shifted to the higher frequency at 1.92 GHz. The return loss value is reduced at the resonant frequency – 21.05 dB. The operational frequency of the antenna shifts from 1.47 GHz to 2.88 GHz. The bandwidth is 68.5%

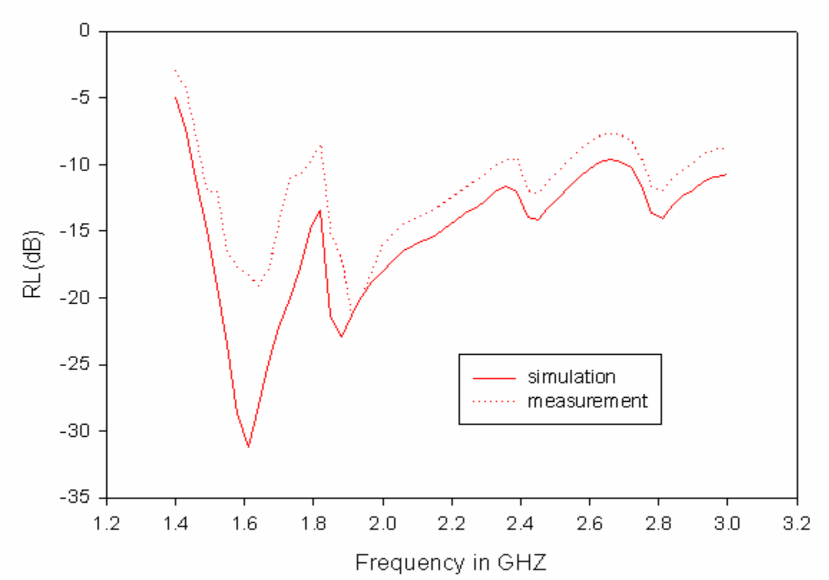


Figure 4.38: Return Loss results for simulation and fabrication

Figure 4.39 shows the measured E-plane radiation patter for integrated EBG surface with two layers rectangular single patch (coaxial cable feed) antenna at frequency of 1.9 GHz. From the graph, the maximum power receive is -34 dBm. The HPBW is 75.9 degree (-37.9 degree to 38 degree).

Figure 4.40 shows the H-plane radiation patter for integrated EBG surface with two layers rectangular single patch (coaxial cable feed) antenna at a frequency of 1.9 GHz. From the graph, the maximum power receive is -34 dBm. The HPBW is 76.8 degree (-35.8 degree to 36 degree).

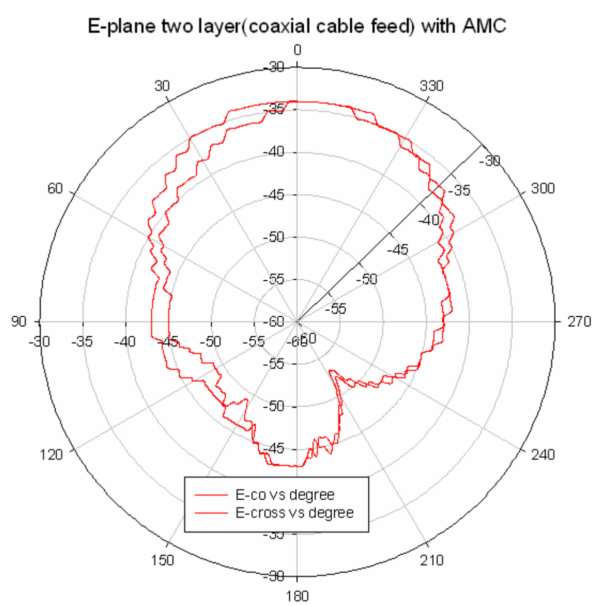


Figure 4.39: Measured E-plane radiation pattern for integrated EBG surface with two layers single patch (coaxial cable feed) antenna

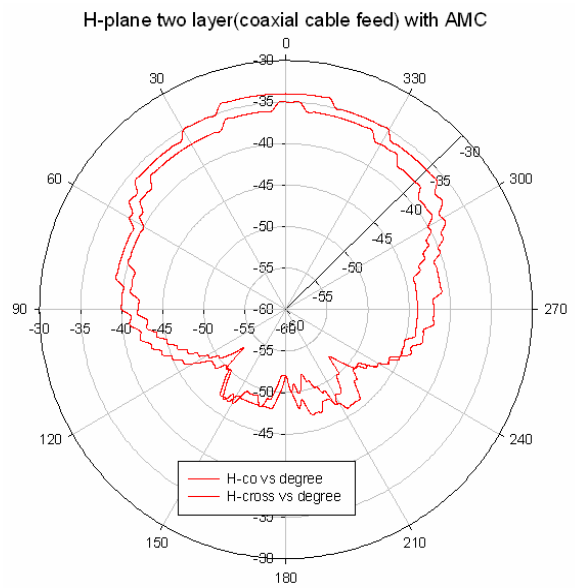


Figure 4.40: Measured E-plane radiation pattern for integrated EBG surface with two layers single patch (coaxial cable feed) antenna

4.12 2 by 1 rectangular microstrip patch array design

Same as rectangular single patch antenna, the measured results obtained for the return loss from the Scalar Network Analyzer are plotted in Sigma Plot software for 2 by 1 rectangular microstrip patch array antenna. The date is shown in APPENDIX M along with simulation data. Figure 4.41 shows a graph which compares the simulation and measurement return loss results of 2 by 1 rectangular microstrip patch array antenna.

For the simulation results of 2 by 1 rectangular microstrip patch array antenna the resonant frequency exactly at 2.4 GHz with a return loss -25 dB. The operational frequency of the antenna is 2.36 GHz to 2.435 GHz measured at a return loss value below -10 dB. The bandwidth is about 3.12%.

From the measurement result, the resonant frequency is a bit shifted to the higher frequency at 2.41 GHz. The return loss value is reduced at the resonant frequency – 21.01 dB. The operational frequency of the antenna shifts from 2.359 GHz to 2.44 GHz. The bandwidth is 3.37%

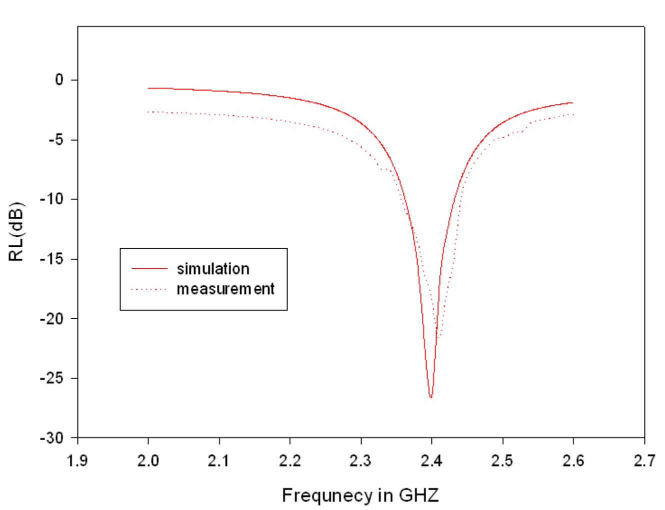


Figure 4.41: Return Loss results for simulation and fabrication

Figure 4.42 shows the E-plane radiation pattern from measurement with anechoic chamber properties for 2 by 1 rectangular microstrip patch array antenna at a frequency of 2.4 GHz. From the graph, the maximum power receive is -49 dBm, 1 dB less than monopole antenna. The HPBW is 114.3 degree (-55 degree to 59.3 degree)

Figure 4.43 shows the measured result for H-plane radiation pattern for 2 by 1 rectangular microstrip patch array antenna at a frequency of 2.4 GHz. From the graph, the maximum power received is -49 dBm. The HPBW is 100.98 degree (-53.5degree to 51.48 degree).

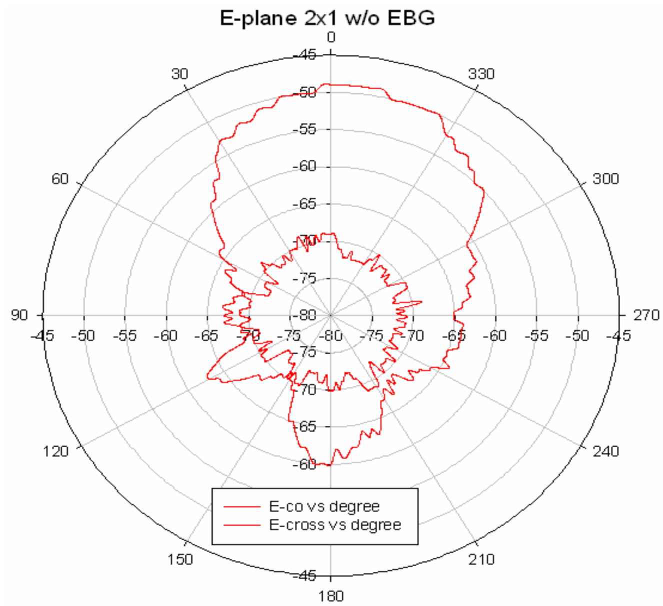


Figure 4.42: Measurement E- plane radiation pattern result of 2 by 1 rectangular microstrip patch array design

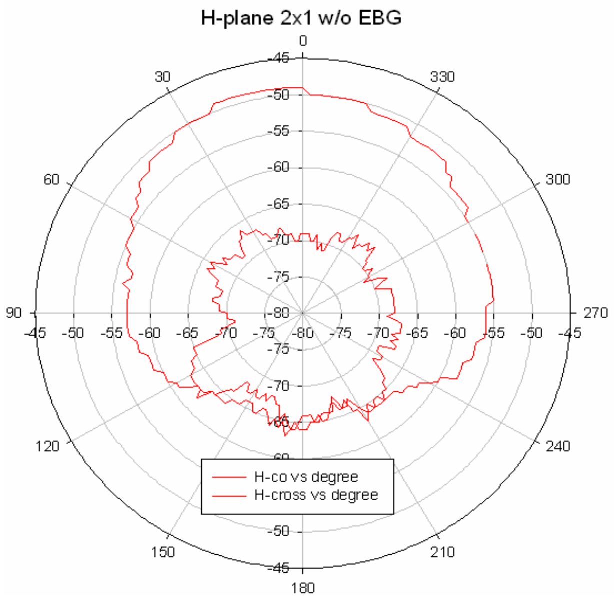


Figure 4.43: H- plane radiation pattern result of 2 by 1 rectangular microstrip patch array design

4.13 2 by 1 rectangular microstrip patch array design incorporated with EBG structure

Same as rectangular single patch antenna, the measured results obtained for the return loss from the Scalar Network Analyzer are plotted in Sigma Plot software for integrated EBG structure with 2 by 1 rectangular microstrip patch array antenna. The date is shown in APPENDIX N along with simulation data. Figure 4.44 shows a graph which compares the simulation and measurement return loss results of integrated EBG structure with 2 by 1 rectangular microstrip patch array antenna.

For the simulation results of integrated EBG structure with 2 by 1 rectangular microstrip patch array antenna the resonant frequency is shifted at 2.42 GHz with a return loss -26.9 dB. The operational frequency of the antenna is 2.37 GHz to 2.45 GHz measured at a return loss value below -10 dB. The bandwidth is about 3.31%.

From the measurement result, the resonant frequency is a bit shifted to the higher frequency at 2.43 GHz. The return loss value is reduced at the resonant frequency –21.2 dB. The operational frequency of the antenna shifts from 2.37GHz to 2.47 GHz. The bandwidth is 4.13%.

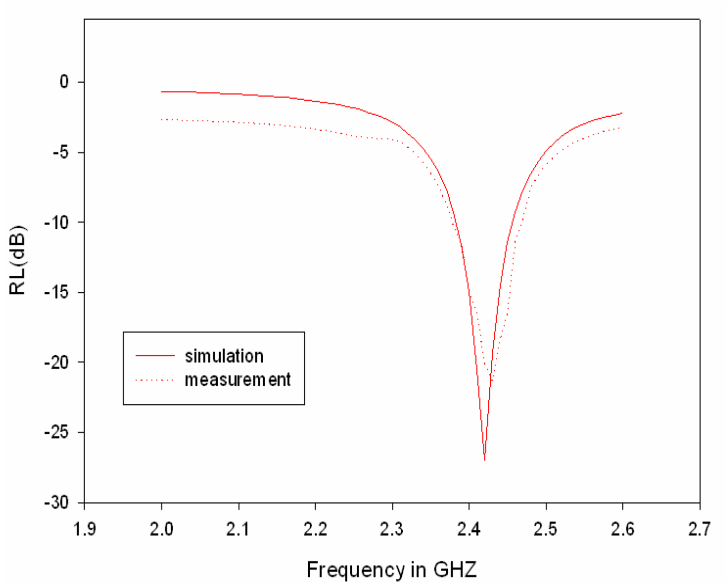


Figure 4.44: Return Loss results for simulation and fabrication

Figure 4.45 shows the measured E-plane radiation pattern by for 2 by 1 microstrip array antenna with EBG structure at a frequency of 2.4 GHz. From the graph, the maximum power received is -47 dBm. The HPBW is 101 degree (-53 degree to 48 degree).

Figure 4.46 shows the measured H-plane radiation pattern for 2 by 1 microstrip array antenna with EBG structure at a frequency of 2.4 GHz. From the graph, the maximum power received is -47 dBm. The HPBW is 97.8 degree (-49.7 degree to 48.1 degree).

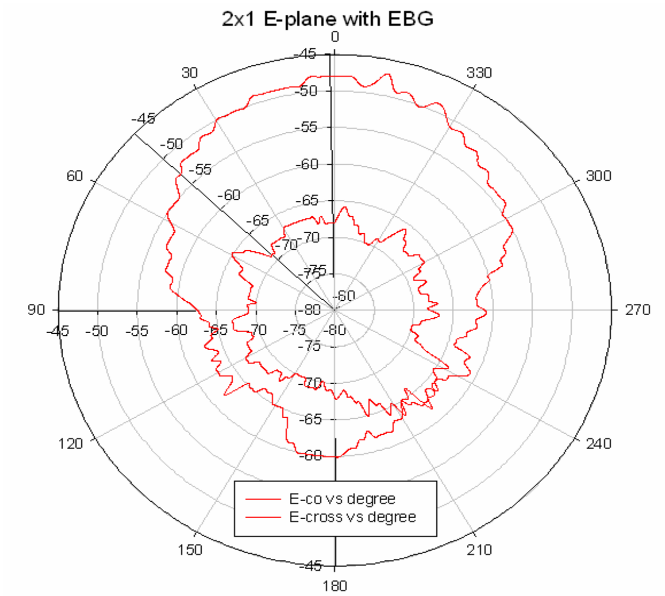


Figure 4.45: Measurement E- plane radiation pattern result of integrated EBG structure with 2 by 1 rectangular microstrip patch array design

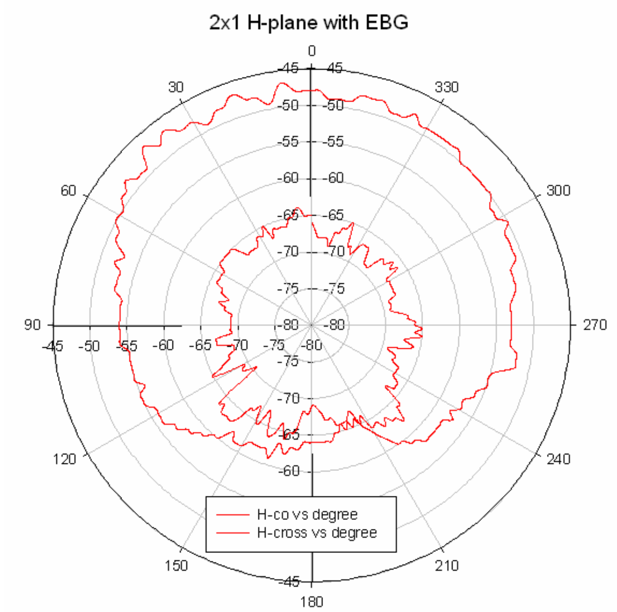


Figure 4.46: H- plane radiation pattern result of integrated EBG structure with 2 by 1 rectangular microstrip patch array design

4.14 Electromagnetic Band gap as band rejected

In this research, one novel application has been found related to the EBG structure. The novel application has been found is the ability of the EBG structure to be used as band rejection in UWB antenna. UWB antenna operates at the range of frequency between 3.1 GHz to 10.6 GHz. Some application used the ranges of frequency within the UWB frequency ranges. If both applications are used together, the interference of the signal will occur due to the same operating frequency. Due to the reason, the concept of band rejection can be applied in this research.

Figure 4.47 shows the UWB antenna with band rejection at higher frequency band. Two patch EBG structure with frequency band gap at high frequency are placed beneath the transmission line of the UWB antenna. In both simulation and measurement result, it can be seen that the UWB antenna with EBG structure as band rejection has successfully reject the frequency band at higher mode.

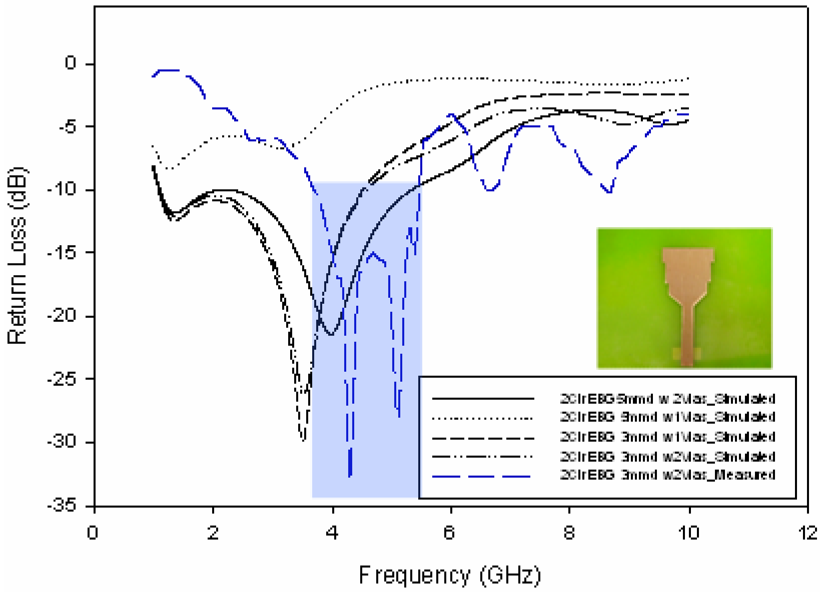


Figure 4.47: The UWB antenna with band rejection in higher frequency.

Figure shows the UWB antenna with band rejection at lower frequency band. A single patch EBG structure with frequency band gap at lower frequency band has been placed beneath the transmission line of the UWB antenna. In both simulation and measurement, it show a good agreement that the lower frequency band of the UWB antenna has been rejected by using the low frequency band gap EBG structure beneath the transmission line of the UWB antenna.

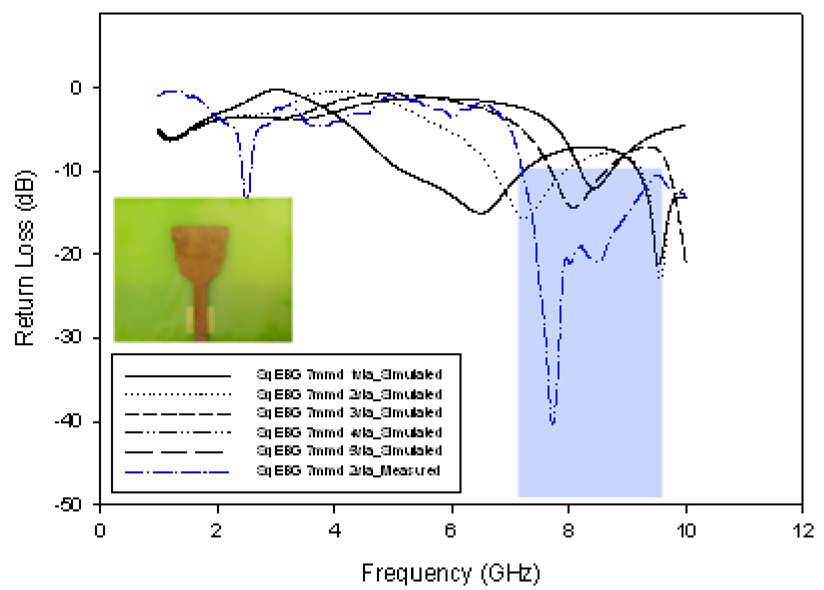


Figure 4.48: The UWB antenna with band rejection in lower frequency.

4.15 UWB Antenna with enhanced impedance bandwidth incorporated with EBG as a Notch structure

Figure 4.49 shows the UWB antenna with enhanced impedance bandwidth incorporated with EBG as a notch structure. Two patch of EBG structure with frequency band gap at 5.8 GHz frequency band has been placed beneath the transmission line of the UWB antenna. From the simulation result, it can be seen that the frequency band of the UWB antenna at 5.8 GHz has been suppressed. From the result in figure 4.50, it can be concluded that by using EBG structure beneath the transmission line, some frequency band of the UWB antenna can be suppressed depending to the frequency band gap of the EBG structure.

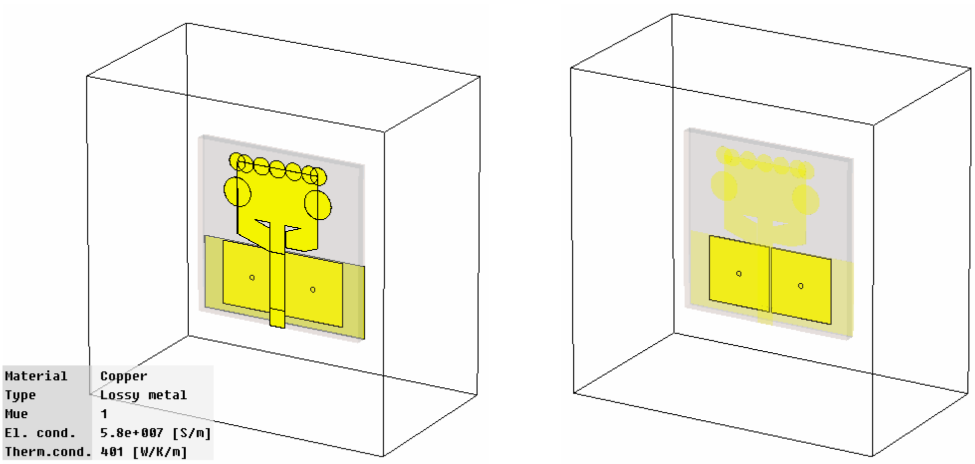


Figure 4.49: UWB antenna with EBG as notch structure.

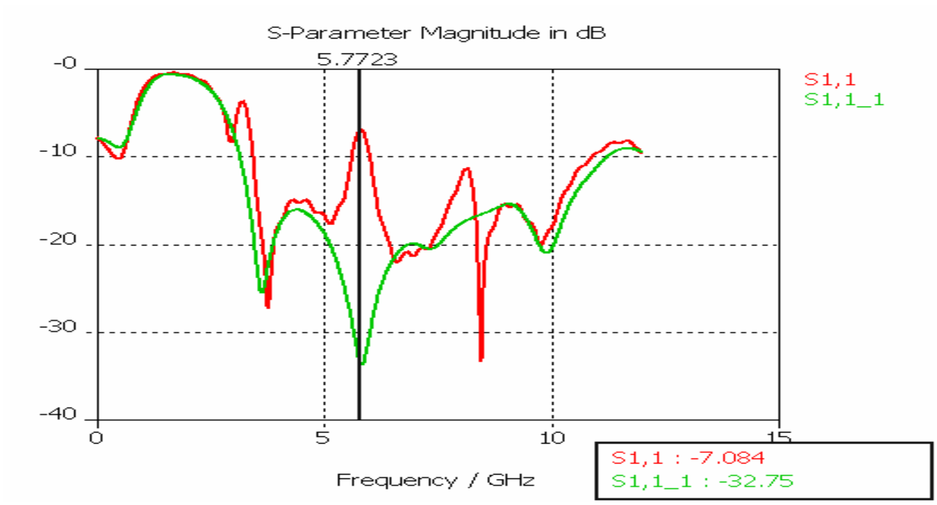
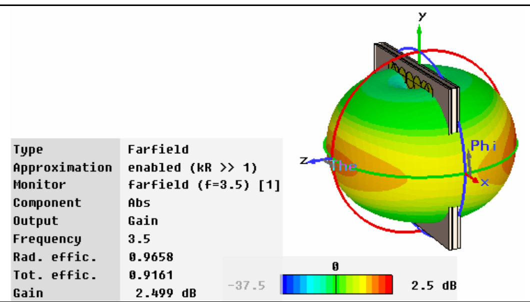
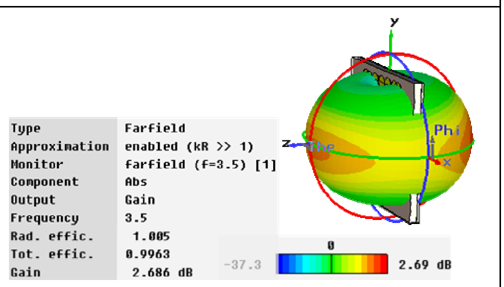


Figure 4.50: The simulation S_{11} of the UWB antenna with and without EBG as notch structure.

Table 4.1: The simulation result of the radiation pattern of UWB antenna with and without EBG as notch structure at differences operating frequency.

frequency	UWB without EBG	UWB with EBG
2.5 GHz		

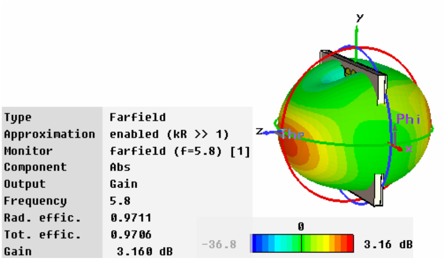
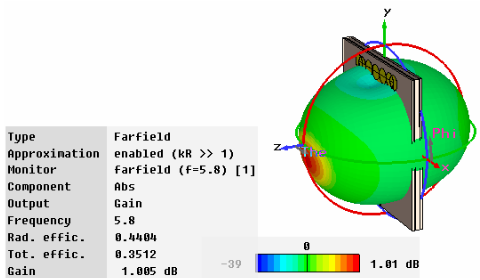
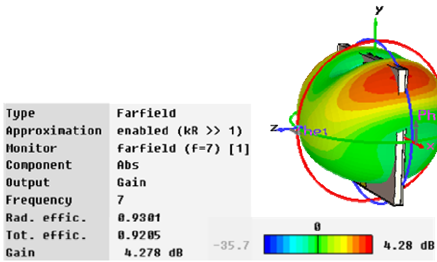
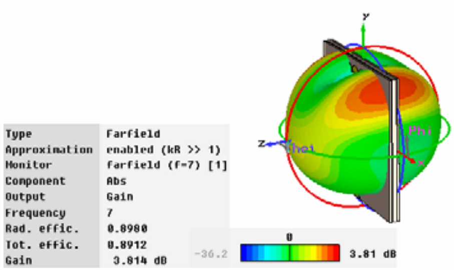
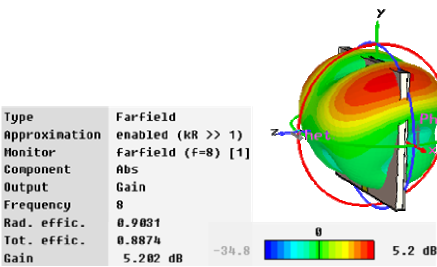
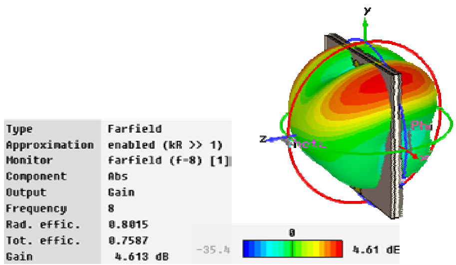
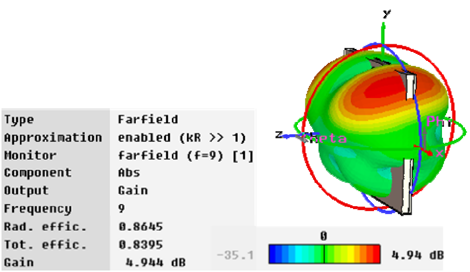
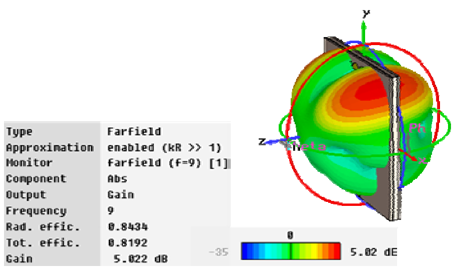
5.8 GHz		
7 GHz		
8 GHz		
9 GHz		

Table 4.1 shows the simulation result of the radiation pattern of UWB antenna with and without EBG as notch structure at differences operating frequency by using CST software. Five frequencies have been selected to do the simulation. The operating frequencies are at 2.5 GHz, 5.8 GHz, 7 GHz, 8 GHz and 9 GHz. From the table, it can be seen that the radiation pattern of the UWB antenna with and without the EBG structure as a notch structure is the same except at 5.8 GHz

frequency. This is because the EBG structure has the frequency band gap at 5.8 GHz frequency band. The radiating signal operates at the ranges of the band gap frequency of the EBG has been suppressed.

4.16 Conclusions

The analysis has been done to study the characteristic of the antenna designed. The measurement results for the microstrip array antenna after fabrication process shows the operational frequency shifts to higher frequency. Suggestion to researches in this field is to design the antenna with the operational frequency a little bit lower compared to the frequency needed because of this shifting property. A 0.03 GHz is suggested to be reduced compared to the targeted operational frequency.

The antenna with EBG structure operates at a lower frequency compared to the antenna without EBG structure. Normally, when design the microstrip antenna operates at lower frequency, the larger size of substrate needed. So, the EBG structure can reduce the size of the antenna and the fabrication cost. Next, the EBG structure can enhance the bandwidth of the original antenna structure.

Table 4.2 and 4.3 show the summaries made from the graph of return loss vs. operational frequency from simulation and measurement. The properties such as return loss, resonant frequency and bandwidth are compared for all cases.

The analysis of radiation patterns is summarized according to the table 4.4 and 4.5 as below. The radiation patterns properties such as maximum power received, cross isolation and HPBW are compared for all cases.

From the table 4.4 and 4.5, power received for the microstrip antennas with EBG structure increase approximately 1 dB. The cross isolation for the microstrip antenna with EBG structure are higher compared to the structure without EBG. The result for HPBW shows that HPBW is narrow for the antennas with EBG structure indicates that the antenna is more directional.

Table 4.2: Summary from Return Loss vs. Frequency Operation (simulation)

structure	Return Loss	Resonant frequency	Bandwidth
2 by1	-17.77 dB	2.40 GHz	2.30 %
2 by 1 (with EBG)	-17.29 dB	2.40 GHz	2.27 %
2 by 2	-16.08 dB	2.40 GHz	3.69 %
2 by 2 (with EBG)	-20.71 dB	2.36 GHz	2.75 %

Table 4.3: Summary from Return Loss vs. Frequency Operation (measurement)

structure	Return Loss	Resonant frequency	Bandwidth
2 by 1	-17.657 dB	2.42 GHz	2.48%
2 by 1 (with EBG)	-15.19 dB	2.44 GHz	3.27 %
2 by 2	-27.30 dB	2.43 GHz	4.12 %
2 by 2 (with EBG)	-24.80 dB	2.43 GHz	4.52 %

Table 4.4: E-plane radiation pattern

structure	P_{in} max (dBm)	Cross isolation (dB)	HPBW (Degree)
2 by 1	-25	32	49
2 by 1 (with EBG)	-24	32	39
2 by 2	-22	33	56
2 by 2 (with EBG)	-21	39	35

Table 4.5: H-plane radiation pattern

structure	P_{in} max (dBm)	Cross isolation (dB)	HPBW (Degree)
2 by 1	-25	28	83
2 by 1 (with EBG)	-25	29	85
2 by 2	-23	33	47
2 by 2 (with EBG)	-22	40	33

Table 4.6: shows the summary of comparison results for all the designs

Type of Design	Rep model	Resonant Freq (GHz)	Return Loss (dB)	Bandwidth (%)	Power (dBm)
3 by 3 Cross patch EBG structure	Simulation Fabrication	2.25 2.42	-76.8 -31.2	25.9 12.86	
Rectangular single patch w/o EBG	Simulation Fabrication	2.4 2.45	-13.6 -13.6	2.07 4.39	E-60 H-60
Rectangular single patch with EBG	Simulation Fabrication	2.4 2.45	-22.4 -19.5	2.07 3.69	E-59 H-59
Two layers Rectangular single patch(inst feed) w/o EBG	Simulation Fabrication	2.4 2.41	-17.3 -14.5	2.94 2.947	E-49 H-49
Two layers Rectangular single patch (inst feed) with EBG	Simulation Fabrication	2.31 2.32	-20 -14.5	2.06 3.46	E-49 H-49
Two layers Rectangular single patch (coaxial feed) w/o EBG	Simulation Fabrication	2.4 2.5	-28.06 -21.4	44.1 32.27	E-52 H-52

Two layers Rectangular single patch (coaxial feed) with EBG	Simulation Fabrication	1.609 1.92	-31.03 -21.05	74.31 68.5	E-34 H-34
2 by 1 patch array w/o EBG	Simulation Fabrication	2.4 2.41	-25 -21.4	3.1 3.37	E-49 H-49
2 by 1 patch array w/o EBG	Simulation Fabrication	2.42 2.43	-26.9 -21.2	3.31 4.13	E-47 H-47

Refer to the table 4.6 the parameters of microstrip antenna can be increased by integrate electromagnetic band gap EBG structure with microstrip antenna.

All the fabricated antenna design show a good return loss more than -10dB. These indicate a good impedance matching is achieved in designing the patches and feeds

The S_{11} comparison graphs show that the resonant frequency has shifted in the magnitude from the designed frequency for all the designs. The root cause of the shift is could be due to the FR4 board, which has ε_r that varies from 4.0 to 4.9.

In practical world, a material which has varying ε_r along a length / width / height, will affect resonant frequency to shift. The other factors affecting etching accuracy such as chemical used, surface finish and metallization thickness also could be the reason for shifting the resonant frequency.

There seem to be a significant difference in the simulation and fabrication values especially for return loss and radiation pattern. Among the possible reasons that could have attributed to this fact is the poor design layout printing on transparency, some impurities in conducting patch, the non-uniformity of fed line width in the fabrication, the difference in length created when the ports are soldered and the possibility that there are may have been errors during the testing process.

4.7 Summary

The analyses of performance for the entire microstrip antenna incorporated with EBG have been presented in this chapter. All the properties such as the bandwidth, return loss, radiation pattern, power received, gain and operational frequency are investigated in this chapter. The radiation pattern characteristic such as the maximum power received, HPBW and cross isolation has been analyzed in this chapter to see the performance of each of the antenna structure.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

The design of the electromagnetic band gap for a frequency of 2.4 GHz has been presented. The utilization of the software involved in the process helps minimized the processing time for the calculation and the simulation of the design. Two types of EBG structure has been fabricated and tested by using vector network analyzer. The EBG structure then has been incorporated with microstrip antenna to see how the antennas perform by introducing this EBG structure.

The integration of the EBG structure with the microstrip array antenna improved the bandwidth and the gain. The radiation pattern of the antenna with EBG in term of the cross isolation, HPBW, side lobe and back lobe are better compared to the niscrostrip array antenna without EBG structure. By using the EBG structure, the surface wave effect and mutual coupling effect are reduced resulting to the improvement of the antenna performance.

As an overall conclusion, all the planned works and the objectives of this project have been successfully implemented and achieved, even though the performance of the antenna designed do not shows a big different after integrated with EBG structure. But, the improvement of the antenna properties such as bandwidth, gain, cross isolation, side lobes, front lobe, and back lobes for the antenna with EBG structure still can be noticed.

5.2 Proposed Future Work

Further works should be carried out in order to improve the performance of the EBG structure. Below are the suggestions for future work:

i. The multi band gap frequency characteristic for EBG structure should be design to cover the multiband antenna.
ii. Miniaturized the EBG structure to achieve the compactness of the antenna design.
iii. Other application of EBG especially in the filter design.
iv. Different structure of EBG in order to improve the performance of the microwave devices

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