DEVELOPMENT OF FABRY PEROT ANTENNA INSPIRED BY PATCH-TYPE FREQUENCY SELECTIVE SURFACE (FSS) FOR X BAND COMMUNICATION

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This thesis submitted in partial fulfillment of the requirements for the award of the Master’s Degree in Electrical Engineering.

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This work is dedicated to my beloved Parents, Siblings
And dear Supervisor
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ABSTRACT

Fabry Perot antenna with Frequency Selective Surface (FSS) has been presented and analyzed in this project. Fabry perot antenna has numerous applications like satellites communication, radar, telecommunications and broadcasting and sensor systems. The proposed antenna structure consist of microstrip patch antenna which is the primary source of radiation, ground plane which acts as a totally reflective surface, and Partially Reflective Surface (PRS) with a distance of half wavelength in between them. The PRS is a dielectric material with a periodically spaced square patches of copper printed on it.

The main advantage of the presented structure is the simultaneous enhancement of both gain and bandwidth. The primary desired design goal is to achieve high gain with a low profile antenna. By increasing the reflection coefficient of PRS, directivity will be improved. The size and the shape of the printed material and the distance of PRS from the source have also a numerous effect on the gain and bandwidth. The antenna was designed to operate at a frequency of around 10 GHz. This proposed structure increased the gain from 9.2 dB up to 14.65 dB and bandwidth improvement of about 1%. To validate the theoretical analysis, the antenna has been designed and simulated using the commercially available software of CST studio.
ABSTRAK

Fabry perot antenna dengan frequency selective surface (FSS) telah digunakan dan dianalisa dalam projek ini. Fabry perot antenna mempunyai banyak aplikasi gunaan seperti komunikasi satelit, radar, telekomunikasi, penyiaran dan system penderia. Struktur antenna yang digunakan dalam projek ini mengandungi microtrip antenna yang digunakan sebagai sumber utama radiasi, tapak pembumi yang bertindak sebagai pemantul permukaan penuh dan pemantul permukaann (PRS) dengan jarak separuh panjang gelombang. PRS adalah bahan nyah elektrik dengan kuprum tercetak diantara ruang segi empat.

Di antara kelebihan struktur yang digunakan adalah peningkatan untuk gain dan jalur lebar secara berterusan. Tujuan utama reka bentuk dipilih kerana untuk mencapai gain yang tinggi dengan antenna profil rendah. Dengan meningkatkan pekali pantulan PRS, penerusan akan bertambah. Saiz dan bentuk bahan tercetak yang digunakan dan jarak PRS daripada sumber juga mempunyai kesan terhadap gain dan jalur lebar. Antenna direka untuk beroperasi pada frekuensi sekitar 10 GHz. Antenna ini direka untuk meningkatkan gain daripada 9.2 dB hingga 14.65 dB dan peningkatan jalur lebar sehingga 1%. Untuk mengesahkan analisa teori, antenna telah di reka dan di simulasi dengan menggunakan perisian CST studio....
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<tr>
<td>LHM</td>
<td>Left-handed Material</td>
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<tr>
<td>CST</td>
<td>Computer Simulated Technology</td>
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<tr>
<td>FP</td>
<td>Fabry Perot</td>
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<tr>
<td>PRS</td>
<td>Partially Reflective Surface</td>
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<td>VSWR</td>
<td>Voltage Standing Wave Ratio</td>
</tr>
<tr>
<td>FL</td>
<td>Lowest Frequency</td>
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<tr>
<td>FH</td>
<td>Highest Frequency</td>
</tr>
<tr>
<td>HPBW</td>
<td>Half-power Beamwidth</td>
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<tr>
<td>FNBW</td>
<td>First-null Beamwidth</td>
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<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<tr>
<td>EBG</td>
<td>Electromagnetic Band Gap</td>
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<td>SWA</td>
<td>Surface Wave Antennas</td>
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<tr>
<td>FDTD</td>
<td>Finite Difference Time Domain</td>
</tr>
<tr>
<td>FSS</td>
<td>Frequency Selective Surfaces</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>RCS</td>
<td>Radar Cross Section</td>
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<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronic Engineering</td>
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<tr>
<td>PCB</td>
<td>PC Board</td>
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<tr>
<td>dB</td>
<td>Decibels</td>
</tr>
<tr>
<td>SMA</td>
<td>Sub Miniature A</td>
</tr>
<tr>
<td>FR4</td>
<td>Fire Retardant 4</td>
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<tr>
<td>UTHM</td>
<td>University Tunn Hussein Onn Malaysia</td>
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<tr>
<td>MWS</td>
<td>Microwave Studio</td>
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<td>EM</td>
<td>Electromagnetic</td>
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<td>BW</td>
<td>Bandwidth</td>
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<table>
<thead>
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<th>Symbol</th>
<th>Description</th>
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<tr>
<td>GHz</td>
<td>Gegahertz</td>
</tr>
<tr>
<td>MHz</td>
<td>Megahertz</td>
</tr>
<tr>
<td>Ω</td>
<td>Ohm</td>
</tr>
<tr>
<td>λ</td>
<td>lamda (wavelength)</td>
</tr>
<tr>
<td>W</td>
<td>width of the antenna</td>
</tr>
<tr>
<td>L</td>
<td>Length of the antenna</td>
</tr>
<tr>
<td>h</td>
<td>height of the antenna</td>
</tr>
<tr>
<td>lg</td>
<td>length of the ground plane</td>
</tr>
<tr>
<td>lp</td>
<td>length of the patch</td>
</tr>
<tr>
<td>ro</td>
<td>outer radius of the feeding pin</td>
</tr>
<tr>
<td>rad</td>
<td>inner radius of the feeding pin</td>
</tr>
<tr>
<td>xf</td>
<td>feeding position</td>
</tr>
<tr>
<td>ε_r</td>
<td>dielectric constant of the substrate</td>
</tr>
<tr>
<td>C</td>
<td>speed of light in air</td>
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CHAPTER I

INTRODUCTION

1.1. Project background

In 1897, Marconi created antenna and for the first time realized radio communication. The history of antenna is just about a century, but because of its important application in military, it has been highly valued and emphasized. Due to the development in the past half century, the hardware technology of antenna is now relatively mature. Now antenna design is developing towards wide band, multi-function and high gain and directivity. Various kinds of antenna technologies like dual-polarization, adjustable electrical down-tilt and multi-frequency band multiplexing are gradually being launched into commercial operation; great advances have been made in smart antenna technology too [1].

The antenna is the transition between a guiding device (transmission line, waveguide) and free space (or another usually unbounded medium). Its main purpose is to convert the energy of a guided wave into the energy of a freespace wave (or vice versa) as efficiently as possible, while at the same time the radiated power has a certain desired pattern of distribution in space. [2]
In recent years, a patch antenna with a metamaterial cover was proposed that enhanced directivity. According to the numerical results, the antenna showed significant improvement in directivity, compared to conventional patch antennae. This was cited in 2007 for an efficient design of directive patch antennas in mobile communications using metamaterials. This design was based on the left-handed material (LHM) transmission line model, with the circuit elements L and C of the LHM equivalent circuit model. This study developed formulae to determine the L and C values of the LHM equivalent circuit model for desirable characteristics of directive patch antennas. Design examples derived from actual frequency bands in mobile communications were performed, which illustrates the efficiency of this approach. [3]

The technologies of wireless communication developed rapidly and lead to the miniaturization of the device. Hence the attraction of a compact and small size internal antenna that can operate for more than one application has grown significantly to fulfill the requirement. This project report presents a microstrip patched antenna with partially reflective surface. This type of Fabry perot antenna is capable of producing both very high gain and better performance. Planar antennas are the newest generations of antennas boasting the attractive features required, such as broad operating bandwidth, low profile, light weight and ease of integrations into arrays of radio frequency circuits, to make them ideal components of modern communications systems.

The Fabry–Perot cavity is made of a ground plane and a single metallic grid. This structure is excited by a patch antenna placed in the cavity at the vicinity of the ground plane. Generally speaking Fabry perot has two important features, first it is very thin and second only one excitation point is needed. The Fabry–Perot cavity antennas are obviously cavity antennas that have been studied for a long time in the microwave community. Fabry perot antenna has numerous applications like satellites communication, radar, telecommunications and broadcasting and sensor systems. [3]- [4]
1.2. Problem statement

Satellite communications play a vital role in the global telecommunications system. Approximately 2,000 artificial satellites orbiting Earth relay analog and digital signals carrying voice, video, and data to and from one or many locations worldwide.

The purpose of this project is to design a microstrip antenna with partially reflective surface for X-band communication. The X band is a segment of the microwave radio region of the electromagnetic spectrum). X band has many applications like satellite communications, radar systems, Terrestrial communications and networking, Space communications and Amateur radio.

Although microstrip antenna has light weight and small in size, and low volume, low profile, but its disadvantages are narrow bandwidth, low gain and low efficiency. One of the ways to resolve these problems is designing a microstrip patch with partially reflective surfaces. In this project microstrip patch antenna with partially reflective surface had been designed. A single rectangular patch is designed at the beginning of the project and simulated. Then, a periodic partially reflective surface had been developed in the proceeding steps to obtain wider bandwidth, higher gain and better performance.

The main purpose of this study is to increase the gain of the antenna by means of utilizing just a single layer reflective surface without any other additional structures or layers while the bandwidth is enhanced. The proposed FP antenna is designed and simulated for X-band applications. The design and simulation were performed using CST studio 2011.
1.3. Objective of the project

- To design a microstrip antenna with single layer partially reflective surface (PRS) for X band communication.
- To investigate the enhancement of the gain of microstrip antenna using partially reflective surface (PRS)
1.4 Scope of the project

In order to achieve the objectives of the project, the following project scopes have been listed in realizing the microstrip antenna with PRS:

- The antenna will be operating in X band frequencies 10 GHz. With a bandwidth range of 8 GHz to 12 GHz.
- Enhancement of gain up to 7dB and Bandwidth of about 2.3% improvement of microstrip patch antenna using PRS
- CST-software had been used for simulation, FR-4 substrate for fabrication and coaxial feeding technique
CHAPTER II

LITERATURE REVIEW

2.1. Introduction

This chapter discuss about the theoretical information that is related to the project such as the basics of antenna, its characteristics and essential components of the partially reflected surfaces (PRS).

This section of the thesis also reviews a number of papers, which have formed the basis for the research component of this paper. This thesis provides an insight into the background of co-formality antennas. Many papers have been studied in order to gain required knowledge that is needed in the design process. There are also many references from source such as books, publications and articles.

2.2. Antenna parameters

Antenna parameters are used to characterize performance of an antenna when designing and measuring antennas. In this Section, terms like bandwidth, radiation pattern, gain, polarization, and input impedance are explained.
2.2.1. **Return loss**

The return loss is another way of expressing mismatch. It is a logarithmic ratio measured in dB that compares the power reflected by the antenna to the power that is fed into the antenna from the transmission line.

The relationship between SWR and return loss is the following:

\[
\text{return loss (in dB)} = 20 \log_{10} \frac{SWR}{SWR-1}
\]  (2.1)

A very good antenna might have a value of -10dB (90% absorbed and 10% reflected) [5].

2.2.2. **Radiation Pattern**

An antenna radiation pattern or antenna pattern is defined as “a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates. In most cases, the radiation pattern is determined in the far field region and is represented as a function of the directional coordinates.

Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization.” The radiation property of most concern is the two- or three-dimensional spatial distribution of radiated energy as a function of the observer’s position along a path or surface of constant radius. Often the field and power patterns are normalized with respect to their maximum value, yielding normalized field and power patterns. Also, the power pattern is usually plotted on a logarithmic scale or more commonly in decibels (dB). This scale is usually desirable because a logarithmic scale can accentuate in more details those parts of the pattern that have very low values, which later we will refer to as minor lobes [5].
2.2.3. Bandwidth

Bandwidth is another fundamental antenna parameter. Bandwidth describes the range of frequencies over which the antenna can properly radiate or receive energy. Often, the desired bandwidth is one of the determining parameters used to decide upon an antenna. For instance, many antenna types have very narrow bandwidths and cannot be used for wideband operation.

The bandwidth can also be described in terms of percentage of the center frequency of the band.

\[ BW = 100 \times \frac{F_H - F_L}{F_C} \]  \hspace{1cm} (2.2)

where \( F_H \) is the highest frequency in the band, \( F_L \) is the lowest frequency in the band, and \( F_C \) is the center frequency in the band. In this way, bandwidth is constant relative to frequency [5].

If bandwidth was expressed in absolute units of frequency, it would be different depending upon the center frequency. Different types of antennas have different bandwidth limitations.

GSM900 for example works from 890MHz to 960MHz and therefore has an allocated bandwidth of 70MHz. This means the antenna must perform well over that range of frequencies.

![Graph return loss versus frequency](image)

**Figure 2.1.** Graph return loss versus frequency
Return loss is a measure of reflection from an antenna. 0 dB means that all the power is reflected; hence the matching is not good. -10dB means that 10% of incident power is reflected; meaning 90% of the power is accepted by the antenna. So, having -10dB as a bandwidth reference is an assumption that 10% of the energy loss.

Referring to figure 2.1, the value of bandwidth can be calculated in the form of percentage as formula 2.3 indicates. [5] – [6]

\[
\text{Bandwidth} = \left| \frac{f_2 - f_1}{f_2 + f_1} \right| \times 100\%
\]  

(2.3)

2.2.4. **Voltage standing wave ratio (VSWR)**

For radio (transmitter or receiver) to deliver power to an antenna, the impedance of the radio and transmission line must be well matched to the antenna’s impedance. The parameter VSWR is a measure that numerically describes how well the antenna is impedance matched to the radio or transmission line it is connected to.

VSWR stands for Voltage Standing Wave Ratio and is also referred to as Standing Wave Ratio (SWR). VSWR is a function of the reflection coefficient (s11 or return loss), which describes the power reflected from the antenna. [5]- [7]

2.2.5. **Beamwidth**

Associated with the pattern of an antenna is a parameter designated as beamwidth. The beamwidth of a pattern is defined as the angular separation between two identical points on opposite side of the pattern maximum. In an antenna pattern, there are a number of beamwidths. One of the most widely used beamwidths is the Half-Power Beamwidth (HPBW), which is defined by IEEE as: “In a plane containing the direction of the maximum of a beam, the angle between the two directions in which the radiation intensity is one-half value of the beam.”

Another important beamwidth is the angular separation between the first nulls of the pattern, and it is referred to as the First-Null Beamwidth (FNBW). Other beamwidths are those where the pattern is −10 dB from the maximum, or any other value. However, in practice, the
term beamwidth, with no other identification, usually refers to HPBW. The beamwidth of an antenna is a very important figure of merit and often is used as a trade-off between it and the side lobe level; that is, as the beamwidth decreases, the side lobe increases and vice versa. [5]- [6]- [7].

2.2.6. Directivity and Gain

Directivity is the ability of an antenna to focus energy in a particular direction when transmitting, or to receive energy better from a particular direction when receiving. In a static situation, it is possible to use the antenna directivity to concentrate the radiation beam in the wanted direction. However in a dynamic system where the transceiver is not fixed, the antenna should radiate equally in all directions, and this is known as an Omni-directional antenna. [5].

Gain is not a quantity which can be defined in terms of a physical quantity such as the Watt or the Ohm, but it is a dimensionless ratio. Gain is given in reference to a standard antenna. The two most common reference antennas are the isotropic antenna and the resonant half-wave dipole antenna. The isotropic antenna radiates equally well in all directions. Real isotropic antennas do not exist, but they provide useful and simple theoretical antenna patterns with which to compare real antennas. Any real antenna will radiate more energy in some directions than in others. Since it cannot create energy, the total power radiated is the same as an isotropic antenna, so in other directions it must radiate less energy.

The gain of an antenna in a given direction is the amount of energy radiated in that direction compared to the energy an isotropic antenna would radiate in the same direction when driven with the same input power. Usually we are only interested in the maximum gain, which is the gain in the direction in which the antenna is radiating most of the power. An antenna gain of 3 dB compared to an isotropic antenna would be written as 3 dBi. The resonant half-wave dipole can be a useful standard for comparing to other antennas at one frequency or over a very narrow band of frequencies. To compare the dipole to an antenna over a range of frequencies requires a number of dipoles of different lengths. An antenna gain of 3 dB compared to a dipole antenna would be written as 3 dBd. [4]
The gain of a rectangular microstrip patch antenna with air dielectric can be very roughly estimated as follows. Since the length of the patch, half a wavelength, is about the same as the length of a resonant dipole, we get about 2 dB of gain from the directivity relative to the vertical axis of the patch. If the patch is square, the pattern in the horizontal plane will be directional, somewhat as if the patch were a pair of dipoles separated by a half-wave; this accounts for about another 2-3 dB. Finally, the addition of the ground plane cuts off most or all radiation behind the antenna, reducing the power averaged over all directions by a factor of 2 (and thus increasing the gain by 3 dB). Adding this all up, we get about 7-9 dB for a square patch, in good agreement with more sophisticated approaches [6] - [7].

2.2.7. Antenna Gain

The term Antenna Gain describes how much power is transmitted in the direction of peak radiation to that of an isotropic source. Antenna gain is more commonly quoted in a real antenna's specification sheet because it takes into account the actual losses that occur.

An antenna with a gain of 3 dB means that the power received far from the antenna will be 3 dB higher (twice as much) than what would be received from a lossless isotropic antenna with the same input power.

Antenna Gain is sometimes discussed as a function of angle, but when a single number is quoted the gain is the 'peak gain' over all directions. Antenna Gain ($G$) can be related to directivity ($D$) by:

$$G = \varepsilon_R D$$  \hspace{1cm} (2.4)

The gain of a real antenna can be as high as 40-50 dB for very large dish antennas (although this is rare). Directivity can be as low as 1.76 dB for a real antenna (example: short dipole antenna), but can never theoretically be less than 0 dB. However, the peak gain of an antenna can be arbitrarily low because of losses or low efficiency. Electrically small antennas (small relative to the wavelength of the frequency that the antenna operates at) can be very inefficient, with antenna gains lower than -10 dB (even without accounting for impedance mismatch loss). [5]
2.2.8. **Antenna Efficiency**

The efficiency of an antenna relates the power delivered to the antenna and the power radiated or dissipated within the antenna. A high efficiency antenna has most of the power present at the antenna's input radiated away. A low efficiency antenna has most of the power absorbed as losses within the antenna, or reflected away due to impedance mismatch.

The losses associated with an antenna are typically the conduction losses (due to finite conductivity of the antenna) and dielectric losses (due to conduction within a dielectric which may be present within an antenna).

The antenna efficiency (or radiation efficiency) can be written as the ratio of the radiated power to the input power of the antenna.

\[
\varepsilon_R = \frac{P_{\text{radiated}}}{P_{\text{input}}} \tag{2.5}
\]

Efficiency is ultimately a ratio, giving a number between 0 and 1. Efficiency is very often quoted in terms of a percentage; for example, an efficiency of 0.5 is the same as 50%. Antenna efficiency is also frequently quoted in decibels (dB); an efficiency of 0.1 is 10% or (-10 dB), and an efficiency of 0.5 or 50% is -3 dB.

Equation 2.5 is sometimes referred to as the antenna's radiation efficiency. This distinguishes it from another sometimes-used term, called an antenna's "total efficiency". The total efficiency of an antenna is the radiation efficiency multiplied by the impedance mismatch loss of the antenna, when connected to a transmission line or receiver (radio or transmitter). This can be summarized in Equation 2.6, where \( \varepsilon_T \) is the antenna's total efficiency, \( M_L \) is the antenna's loss due to impedance mismatch and \( \varepsilon_R \) is the antenna's radiation efficiency.

\[
\varepsilon_T = M_L \cdot \varepsilon_R \tag{2.6}
\]
Since $M_L$ is always a number between 0 and 1, the total antenna efficiency is always less than the antenna's radiation efficiency. Said another way, the radiation efficiency is the same as the total antenna efficiency if there was no loss due to impedance mismatch.

Efficiency is one of the most important antenna parameters. It can be very close to 100% (or 0 dB) for dish, horn antennas, or half-wavelength dipoles with no lossy materials around them. Mobile phone antennas, or wifi antennas in consumer electronics products, typically have efficiencies from 20%-70% (-7 to -1.5 dB). The losses are often due to the electronics and materials that surround the antennas; these tend to absorb some of the radiated power (converting the energy to heat), which lowers the efficiency of the antenna. Car radio antennas can have a total antenna efficiency of -20 dB (1% efficiency) at the AM radio frequencies; this is because the antennas are much smaller than a half-wavelength at the operational frequency, which greatly lowers antenna efficiency. The radio link is maintained because the AM Broadcast tower uses a very high transmit power. [5] – [7]

Improving impedance mismatch loss is discussed in the Smith Charts and impedance matching section. Impedance matching can greatly improve the efficiency of an antenna.

### 2.2.9. Impedance matching

Antenna impedance relates the voltage to the current at the input to the antenna. This is extremely important as we will see. Let's say an antenna has an impedance of 50 ohms. This means that if a sinusoidal voltage is applied at the antenna terminals with an amplitude of 1 Volt, then the current will have an amplitude of $1/50 = 0.02$ Amps. Since the impedance is a real number, the voltage is in-phase with the current. Alternatively, suppose the impedance is given by a complex number, say $Z=50 + j*50$ ohms.

Note that "j" is the square root of -1. Imaginary numbers are there to give phase information. If the impedance is entirely real [$Z=50 + j*0$], then the voltage and current are exactly in time-
phase. If the impedance is entirely imaginary \([Z=0 + j*50]\), then the voltage leads the current by 90 degrees in phase. If \(Z=50 + j*50\), then the impedance has a magnitude equal to:

\[
\sqrt{50^2 + 50^2} = 70.71
\]

(2.7)

For an efficient transfer of energy, the impedance of the radio, of the antenna and of the transmission cable connecting them must be the same. Transceivers and their transmission lines are typically designed for 50Ω impedance. If the antenna has impedance different from 50Ω, then there is a mismatch and an impedance matching circuit is required.

### 2.3. Feeding methods

A planar antenna can be fed by a variety of methods. These methods can be classified into two categories such as contacting and non-contacting method. In the non-contacting method, electromagnetic field coupling is done to transfer power between the Microstrip line and the radiating patch. Meanwhile for contacting method, the RF power is fed directly to radiating patch using a connecting element such as Microstrip line. There are four most popular ways to feed a planar antenna like coaxial probe, Microstrip line, aperture coupling and proximity coupling.

#### 2.3.1. Coaxial feeding

It is one of the basic techniques used in feeding microwave power. The coaxial cable is connected to the antenna such that its outer conductor is attached to the ground plane while the inner conductor is soldered to the metal patch. It is easy to fabricate and can be placed at any location to match with its input impedance. However, it provides narrow bandwidth and it is difficult to model. An improved impedance match will ideally increase others parameter like bandwidth, return loss and improve performance by reducing the excitation of unwanted modes of radiation. For this project we used coaxial probe as feeding technique. [5] [7] – [9]
2.3.2. Microstrip line

In Microstrip feed, the patch is fed by a Microstrip line that is located on the same plane as the patch. In this case both the feeding and the patch form one structure. Microstrip feeding is simple to model, easy to match and easy to fabricate. It is also a good choice for use in antenna-array feeding networks. However Microstrip feed has the disadvantage of narrow bandwidth and the introduction of coupling between the feeding line and the patch which leads to spurious radiation and the required matching between the Microstrip patch and the 50 Ω feeding line. [7]-[9]

2.3.3. Aperture Coupled Feed

For aperture coupling method, the ground plane as shown in Figure 2.4 separates the radiating patch and the Microstrip feed line. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane. The coupling aperture is usually centered
under the patch, leading to lower cross polarization due to symmetry of the configuration. The amount of coupling from the feed line to the patch is determined by the shape, size and location of the aperture. Since the ground plane separates the patch and the feed line, spurious radiation is minimized. Generally, a high dielectric material is used for the bottom substrate and a thick, low dielectric constant material is used for the top substrate to optimize radiation from the patch [10]. The major disadvantage of this feed technique is that it is difficult to fabricate due to multiple layers, which also increases the antenna thickness. This feeding scheme also provides narrow bandwidth. [5]- [9]

![Figure 2.4: Aperture-coupled feed](image)

### 2.3.4. Proximity Coupled Feed

This type of feeding technique uses two dielectric substrates. The feed line is between the two substrates and the radiating patch is on top of the upper substrate. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (as high as 13%), due to overall increase in the thickness of the Microstrip patch antenna. This scheme also provides choices between two different dielectric media, one for the patch and one for the feed line to optimize the individual performances. The major disadvantage of this feeding technique is that it is difficult to fabricate because of the two dielectric layers which need proper alignment. Also, there is an increase in the overall thickness of the antenna. [5]- [9]
The recent explosion in antenna developments has been fueled by the increasing popularity of wireless communication systems and devices. From the traditional radio and TV broadcast systems to the advanced satellite system and wireless local area networks, wireless communications have evolved into an indispensable part of people's daily lives. Antennas play a paramount role in the development of modern wireless communication devices, ranging from cell phones to portable GPS navigators, and from the network cards of laptops to the receivers of satellite TVs. A series of design requirements, such as low profile, compact size, broad bandwidth, and multiple functionalities, keep on challenging antenna researchers and propelling the development of new antennas.

Progress in computational electromagnetics, as another important driving force, has substantially contributed to the rapid development of novel antenna designs. It has greatly expanded the antenna researchers' capabilities in improving and optimizing their designs efficiently. Various numerical techniques, such as the method of moments, finite element method, and the finite difference time domain method, have been well developed over the years.

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

2.4.1. Electromagnetic Band Gap Characteristics and classifications

Over the last decade, diversified and novel electromagnetic band gap (EBG) structures have appeared in the literature. They exhibit interesting electromagnetic properties, which are not readily available in natural materials. In this chapter, we illustrate these interesting properties of EBG structures. A classification of various EBG structures is also provided. [10] [4]

![Figure 2.6 Electromagnetic Bandgap Structure](image)

2.4.2. Resonant circuit models for EBG structures

To more readily understand the operation mechanism of EBG structures, some circuit models have been proposed. Let's start with a simple two-dimensional planar electromagnetic band gap (EBG) structure, as shown in Fig. 2.6. This structure was originally proposed in [10]. The EBG structure consists of four parts: a metal ground plane, a dielectric substrate, periodic metal patches on top of the substrate, and vertical vias connecting the patches to the ground plane. The geometry is similar to the shape of a mushroom.
2.4.3. Patch antenna with EBG structures

Electromagnetic band gap structures have been characterized and designed in previous sections. We now shift our focus to EBG applications in antenna engineering. In this chapter, the EBG structures are integrated into microstrip patch antenna designs and their surface wave band gap property helps to increase the antenna gain, minimize the back lobe, and reduce mutual coupling in array elements. Some applications of EBG patch antenna designs in high precision GPS receivers, wearable electronics, and phased array systems are highlighted. [10]

2.4.4. Patch antennas on high permittivity substrate

Microstrip patch antennas are widely used in wireless communications due to the advantages of low profile, light weight, and low cost [11-14]. In principle, the microstrip patch antenna is a resonant type antenna, where the antenna size is determined by the operating wavelength and the bandwidth is determined by the Q factor of the resonance. An important research topic in microstrip antenna designs is to broaden the inherent narrow bandwidth of microstrip antennas. Parasitic patches are used to form a multi-resonant circuit so that the operating bandwidth is improved. The parasitic patches are located on the same layer with the main patch. In [14], a multi-layer microstrip antenna is investigated with parasitic patches stacked on the top of the main patch. The multi-resonant behavior can also be realized by incorporating slots into the metal patch. Several single-layer single-patch microstrip antennas have been reported, such as the U-slot microstrip antenna and the E-shaped patch antenna. [12-14] [4] [17]

![Figure 2.7](image.png)

Figure 2.7. (a) SRR unit cell dimensions and (b) the 8x8 SRR array that is implemented as PRS.
2.4.5. Surface wave antennas

The concept of surface wave antennas (SWA) was initiated in the 1950s [10] and numerous theoretical and experimental investigations have been reported in the literature. To support the propagation of surface waves, a commonly used structure in SWA designs is a corrugated metal surface. However, the corrugated structure is thick, heavy, and costly, which may limit the applications of surface wave antennas in wireless communication systems.

In this section, novel surface wave antennas are presented. Compared to traditional SWA designs, surface waves are now guided along a thin grounded slab loaded with periodic patches, resulting in a low profile conformal geometry. In contrast to the previous wire-EBG antennas or patch antennas that radiate to the broadside direction, the proposed SWA achieve a monopole-like radiation pattern with a null in the broadside direction. The low profile SWA is more attractive than a traditional monopole antenna that is a quarter-wavelength high. [10]

2.4.6. A grounded slab loaded with periodic patches

We start with analyzing a complex artificial ground plane, which will be subsequently used in surface wave antenna designs. As we see there are two artificial surfaces: a mushroom-like EBG surface and a grounded dielectric slab loaded with periodic patches. In the latter structure vertical vias are removed, which results in different surface wave properties in the two ground planes.

To compare the electromagnetic properties of these two structures, the finite difference time domain (FDTD) method is used to simulate their performance [10–12].
2.5. Frequency selective surfaces

A frequency-selective surface (FSS) is any thin, repetitive surface designed to reflect, transmit or absorb electromagnetic fields based on frequency. In this sense, an FSS is a type of optical filter or metal-mesh optical filters in which the filtering is accomplished by virtue of the regular, periodic (usually metallic, but sometimes dielectric) pattern on the surface of the FSS. Frequency-selective surfaces have been most commonly used in the radio frequency region of the electromagnetic spectrum and find use in applications as diverse as the aforementioned microwave oven, antenna radomes and modern metamaterials. [15-16] Sometimes frequency selective surfaces are referred to simply as periodic surfaces and are a 2-dimensional analog of the new periodic volumes known as photonic crystals.

Many factors are involved in understanding the operation and application of frequency selective surfaces. These include analysis techniques, operating principles, design principles, manufacturing techniques and methods for integrating these structures into space, ground and airborne platforms. [15-18]

Figure 2.8: Geometry of fabry perot antenna
2.5.1. Types of FSS

FSS Based on shapes on shape it can be categorized as four classes.

- The center connected or N-poles
- The loop types
- Solid interiors or plate types
- Combinations of 1,2,3

FSS Characteristics

- Typically narrow band
- Periodic, typically in two dimensions
- Element type: dielectric or metallic/circuit
- Depends on Element shape, size.
- Depends on Element spacing and orientation
2.6. Fabry Perot Cavity Antenna Based on Capacitive Loaded Strips Superstrate for X-Band Satellite Communication

Over the last few years, high gain, low profile and low-cost planar antennas composed of a single feed have attracted much attention. Consequently, in recent years different planar and non-planar methods have been investigated to overcome these drawbacks. [19] The array technique is a common method which is often used to achieve high directivity and broadband antennas, while introduction of power dividers inevitably brings in some losses in the design of feeding network [20-21]. So achieving a high gain with a low-profile antenna that utilizes a single antenna element opposed to an array is always a desired design goal. The Fabry Perot (FP) optical concept is a well-known solution to this demand [21-25]. This structure in comparison with antenna array techniques has some advantages such as having a simple structure.

The model of FP antenna consists of a radiating element placed between two metallic arrays which act as partially reflective surfaces (PRS) or between one periodic metallic array and a ground plane. The PRS is placed by the distance of half a wavelength in air (λ/0/2) from the plate on which the radiating element is placed. According to antenna structure in Fig. 2.10:

![Figure 2.10: The geometry of the proposed FP antenna structure](image-url)

Figure 2.10: The geometry of the proposed FP antenna structure
Table 2.1 Comparison of resonance frequency, bandwidth and gain of three structures of antenna

<table>
<thead>
<tr>
<th>Antenna</th>
<th>$F ,(GHz)$</th>
<th>$BW%$</th>
<th>$Gain, (dB)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microstrip antenna</td>
<td>10.2</td>
<td>7.78</td>
<td>6.11</td>
</tr>
<tr>
<td>Microstrip antenna with PRS</td>
<td>10.2</td>
<td>4.28</td>
<td>10.3</td>
</tr>
<tr>
<td>Microstrip antenna with PRS and EBG</td>
<td>10.3</td>
<td>8.6</td>
<td>12</td>
</tr>
</tbody>
</table>

The table 2.1 indicates the effect of partially reflective surface and also the effect of combining Partially Reflective Surface with Electromagnetic Bandgap structure. So the performance of the antenna is getting better each time. The Gain of the antenna is increased when Microstrip antenna with only PRS is used from 6.11 to 10.3 decibels. When PRS and EBG are used together the gain is 12 decibels.
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