RECONFIGURABLE MICROSTRIP ARRAY ANTENNA

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by

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LIST OF ABBREVIATIONS

etc.	et cetera
i.e.	that is
RF	Radio Frequency
PCB	Printed Circuit Board
CST	Computer Simulation Technology
VSWR	Voltage Standing Wave Ratio
SMA	Sub-Miniature version A
LHS	Left hand side
TM	Transverse magnetic
3D	Three dimensional

ABSTRAK

Projek ini membentangkan satu antena susunan mikrostrip yang frekuensi boleh tala apabila bilangan element berubah. Jalur operasi dan pendapatan antena juga dikonfigurasikan dengan perubahan dalam nombor elemen susunan.Semua reka bentuk di peringkat simulasi dijalankan dengan menggunakan CST 2008. Pada mulanya, reka bentuk antena bermula dengan antena tunggal, diikuti oleh konfigurasi antena susunan 1x2, akhirnya pergi ke konfigurasi antena susunan 1x4. Teknik penyuapan yang berbeza digunakan dalam reka bentuk antena tunggal untuk mengetahui kaedah penyuapan yang sesuai untuk reka bentuk ini. Selepas itu, rangkaian penyuapan korporat digunakan dalam reka bentuk antena susunan kerana rangkaian ini boleh memastikan semua isyarat boleh mencapai setiap patch antena pada magnitud dan fasa yang sama kerana kepanjangan baris penyuapan mereka adalah sama. Transformer suku gelombang yang digunakan untuk membuat impedans pasti dipadankan pada semua persimpangan baris penyuapan. Salah satu daripada kebimbangan utama apabila mereka bentuk rangkaian susunan adalah ketakselanjaran yang berlaku di setiap selekoh sudut kanan, simpang T dan langkah perubahan dalam lebar talian, ketakselanjaran akan memperkenalkan reaktan parasit yang boleh membawa kepada fasa amplitud dan kesilapan. Dalam usaha untuk mengurangkan masalah ini, beberapa teknik pampasan seperti selekoh mitered dan selekoh melengkung telah dijalankan. Dalam projek ini, semua reka bentuk antena telah dioptimumkan sepenuhnya dengan mencari titik penyuapan yang sesuai di peringkat simulasi. Semua reka bentuk direka dan dikerahkan pada FR-4 dengan ketebalan 1.6mm, pemalar dielektrik 4.5 dan tangen kehilangan bagi 0.021. Hasil pengukuran menunjukkan bahawa apabila nombor peningkatan resonator dari satu elemen kepada empat elemen, prototaip antena yang dicadangkan boleh meliputi julat frekuensi dari frekuensi 2.515 GHz kepada 2.53 GHz. Pada masa yang sama,

pendapatan antena akan meningkat daripada 1.799 dB kepada 5.8 dB dan lebar jalur frekuensi akan meningkat daripada 91.1 MHz hingga 120 MHz. Peratus perbezaan frekuensi salunan simulasi dan ukuran adalah kecil, iaitu kira-kira 5-7% untuk semua reka bentuk antena.

ABSTRACT

This project presents a frequency tunable microstrip array antenna as the number of radiating element changes. Operating bandwidth and gain are also reconfigured with the change in number of array elements. All designs in simulation stage are carried out using CST 2008. At first, the design start with single element antenna, followed by 1x2 array antenna configuration, finally proceed to 1x4 array antenna configuration. Different feeding techniques are used in single element antenna design to find out suitable feeding method for this design. After that, corporate feeding network is used in array antenna design as this feeding network can ensure all signal can reach every antenna patch at same magnitude and phase since their feed line length are same. Quarter-wave transformers are used to make sure impedance is matched at all feed line junction. One of the major concerns when designing array network is the discontinuities that happened at every right angle bends, T junctions and step changes in line width, discontinuities will introduce parasitic reactances that may lead to phase and amplitude error. In order to reduce this problem, some compensation techniques such as mitered bend and curved bend have been carried out. In this project, all antenna designs have been fully optimized by finding suitable feed point in simulation stage. All design are fabricated and deployed on FR-4 with thickness of 1.6mm, dielectric constant of 4.5 and loss tangent of 0.021. Measurement results show that as number of resonator increases from one element to four elements, the prototype of proposed antenna can cover frequency range from frequency 2.515 GHz to 2.53 GHz. At the same time, antenna gain will increase from 1.799 dB to 5.8 dB and bandwidth will increase from 91.1 MHz to 120 MHz. The percentage of difference of simulated and measured resonant frequency is small, which is around 5-7% for all antenna designs.

CHAPTER 1

INTRODUCTION

1.0 Background

In the last few decades, development of communication system, especially in wireless and mobile communication system made a huge advancement. This development cannot be achieved without the rapid development of microstrip antenna as microstrip antenna was used in many applications. In 1953, the concept of microstrip radiators was first proposed by Deschamps. After 20 years, the first practical antenna was developed by Howell and Munson (Garg et al., 2001). Since then, numerous advantages and designs of microstrip antenna are exploited. Today, microstrip antenna is widely used especially in mobile communication and commercial applications.

This project presents a reconfigurable microstrip array antenna with multiple radiating elements, or resonator. The concept of reconfigurable stated here is reconfigurable in term of operating frequency and bandwidth as the number of resonator varying. The antenna operates at frequency around 2.4 GHz, it can be used for amateur radio, satellite, wireless network equipment compatible with IEEE 802.11b and 802.11g standards etc.

Circular disk geometry is used in this project because it can save more space(Garg et al., 2001) compared to other antenna patch shapes. Through this project, design procedures such as parameter calculation and layout drawing are included. Some powerful computer aided design software is used to design, modify and optimize the antenna design. Simulation result from simulator helped a lot in predicting the properties and characteristic of actual microstrip antenna. At the end of this project, a few microstrip antennas with different configuration are fabricated and tested.

1.1 Motivation of Research

With the development of technology, the performance requirement imposed on antenna is getting higher in order to meet the requirement of entire system. Single element antenna that working on single frequency may be able to satisfies the desirable radiation characteristic. Hence, array antenna will be one of the solutions because it can provide high gain, while different number of element will offer different operating frequency and bandwidth. On top of that, this project also provides better understanding and exposure on design of microstrip array antenna.

1.2 Problem Statement

One of the major disadvantages of microstrip antenna is lower gain compared to other conventional antenna such as helical and horn antenna. Usually the gain of single element microstrip antenna is around 5 to 6 dB(Garg et al., 2001). By using an array of fed antenna, a larger antenna gain is achievable. Array antenna provides greater effective aperture and therefore higher gain compared to single element antenna. Table 1.1 shows typical gain of conventional antenna.

Table 1.1 Typical Gain of Conventional Antenna Elements(Lee and Luk, 2010)

Element	Typical Gain(dB)
Yagi (Dipole + parasitic)	12
Dipole+ corner reflector	12
Helical antenna	16
Horn antenna	20

As number of radiating element increases, antenna will operate at different frequency with different bandwidth. Nowadays, multiple resonant frequency antenna is much more preferable in various applications compared to single frequency antenna.

For instance, dual frequency antenna can reuse frequency to increase system transmission and reception capability or produce polarization diversity (Shynu et al., 2006).

1.3 Objective

Objectives of this project are:

- To design a microstrip array antenna that is reconfigurable
- To study the effect of varying substrate material, patch width, patch length and substrate height on a microstrip antenna
- To study the relationship between number of radiating element with antenna gain, resonant frequency and bandwidth
- To find the differences between theoretical result and experimental result and explain why is it happen
- To analyst the radiation pattern of antenna with different array configuration

1.4 Scope of Research

The aim of this project is to design and fabricate a microstrip array antenna that is frequency tunable by modifying the number of radiating elements. The antenna is set to resonate around frequency 2.4 GHz. As the change in number of array elements, operating bandwidth and gain also reconfigured.

In this project, a single element antenna is developed first, following by 2-element antenna, 1x2 array antennas and finally 1x4 array antennas. The resonant frequency and other important parameters such as gain, directivity, bandwidth and return loss will be studied and analyzed in every design stages.

Essentially, this project can be divided into two part, software and hardware part. In software part, antenna design and simulation are being conducted using computer software CST 2008. By using this powerful design tool, analysis and synthesis of microstrip array antenna can be carried out efficiently and precisely.

After design and optimization of microstrip array antenna, the prototype of the array antenna will be fabricated in PCB lab with the help of lab technicians. Once the antenna is fabricated, antenna's important parameters are collected using Digital Communication Lab's measuring device.

1.5 Outline of Thesis

Chapter 1: Introduction

This chapter gives an overview of this project, following by problem statement that arises from the design of array antenna. Besides that, it also includes project scope and objectives of doing this project.

Chapter 2: Literature Review

This chapter discusses some background studies about the concept of microstrip antenna. Important antenna parameters will be stated and explained. Furthermore, some reviews will be conducted on several journals that are related to this project.

Chapter 3: Methodology

This chapter describes the entire project process start from the beginning until the end. It contains the details about every project steps and states the specification for proposed antenna. Software design and simulation results also included. At the end of this chapter, hardware fabrication of designed antenna will be illustrated.

Chapter 4: Result and Discussion

This chapter covers simulation and measurement results that are collected using network analyzer (see Appendix F). All results will be analyst and discussed in detail. After that, simulation result and practical result will be compared and explanation will be made.

Chapter 5: Conclusion and Suggestion

This chapter contains the summary of this project and conclusion will be made. Limitations encountered in this project will be stated. Besides that, some helpful suggestions will be included for future improvement.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter is divided into six sections. Section 2.1 introduces the overview of the chapter. Section 2.2 describes the theoretical background of various antennas along with antenna properties. Section 2.3 covers some knowledge about microstrip antenna. Section 2.4 contains some designs about microstrip patch antenna that are going to be used in this project. Section 2.5 covers the related works that have been done by previous researcher. Finally, Section 2.6 summarize chapter 2 in a short paragraph.

2.2 Theoretical Background

The theoretical background comprises of some theories that are needed to aid the design of microstrip array antenna. These theories include basic operation of antenna, parameters that affecting antenna performance, pros and cons of microstrip antenna, basic formulae for predesign calculation.

2.2.1 Basic Operation of Antenna

Antenna is one of the vital parts of communication system. Basically, antenna is an electrical device that transmits or receives electromagnetic waves as depicted in Figure 2.1(Minoli, 2009). It works as a transducer that converts propagating electromagnetic waves to and from conducted electrical signals. Antenna is a reciprocal device, all the electrical properties of antenna such as resonant frequency, radiation pattern and bandwidth remain the same irrespective of the signal travelling direction, either transmitting or receiving.

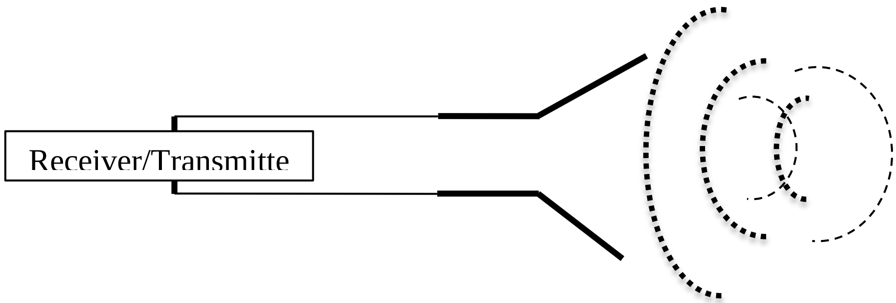

Figure 2.1: Simple Antenna Model(Minoli, 2009)

For transmitting antenna, RF signal that has been generated in a radio transmitter travels through a transmission line to the antenna and then being transmitted into free space.

As the electromagnetic field strikes the receiving antenna, a voltage is induced into the antenna, which serves as a conductor. The induced RF voltages are then used to recover the transmitted RF information. Antenna doesn't generate power itself.

2.2.2 Types of Antenna

Generally, antenna can be divided into several types based on their radiation direction(Milligan, 2005).

a) Highly-directional

Highly directional antennas, or beam antennas are designed for point-to-point signal transmission; For example, parabolic antennas that being used at repeaters are highly directional. They radiate a very narrow beam over a long distance with little interference from undesired source.

b) Semi directional

Semi directional antennas are typically used to provide coverage over designated large areas. One of the examples of a semi directional antenna is a Yagi antenna.

c) Omnidirectional

Omnidirectional antennas are designed to provide coverage in all directions. Theoretically it can radiate signal uniformly in all direction within one plane, and produce a donut-shaped radiation pattern. However, practically it is impossible to achieve due to science limitation. Hence, omnidirectional antenna attempts to provide general coverage in all directions. This is the most common antenna type that found in base station, radio broadcast station and mobile phone, as in these device and station; good coverage in a general spherical area around the antenna is desirable.

2.2.3 Models of Antenna

Antennas are classified into different types of model based on their antenna structure and functions. Some of the typical antenna models are discussed below.

a) Isotropic Antenna

The isotropic radiator is a purely theoretical antenna that radiates equally in all directions (1993). It is considered to be a point in space with no dimensions and no mass. This antenna cannot physically exist, but is useful as a theoretical model for comparison with all other antennas. Most antennas' gains are measured with reference to an isotropic radiator, and are rated in dBi (decibels with respect to an isotropic radiator).

b) Dipole Antenna

Dipole antenna is one of the basic antenna that most commonly being used in human history. Basically, dipole antenna consists of two different poles. Current and voltage at these poles cause the radiation of electromagnetic wave. The length of dipole is key parameter in determining the resonant frequency of the antenna. Dipole antenna can be divided into several types, including short pole, half-wave-pole, quarter-wave pole, etc(Milligan, 2005). Dipole antenna is the simplest practical antenna; hence it is as reference model for other antennas. Usually dipole antenna is used as TV antenna or shortwave antenna. Gain of dipole antenna is labeled as dBd.

c) Aperture Antenna

Aperture antenna is an antenna that comprise of open-ended waveguide, horn antennas and reflectors. Usually aperture antenna is excited by transmission wave instead of transmission line at which that transmission wave was produced by another antenna. Horn antenna is an antenna that has small waveguide with large aperture. This antenna has directive radiation pattern, wide frequency range and high gain, usually lies between 10 to 20 dB(Stutzman and Thiele, 2012). Typically horn antenna consists of rectangular waveguide and a large rectangular aperture. The horn aperture is always measured in wavelength.

d) Reflector Antenna

Reflector antenna is antenna that use reflector to reflect electromagnetic wave. Typically examples of reflector used are corner reflector, parabolic reflector and flat reflector. Parabolic reflector, also known as satellite dish antenna is well-known with low cross polarization and very high antenna gain. Typically the gain can go up to 30 to

40 dB(Milligan, 2005). Focal length and diameter of reflector are important parameter for reflector antenna.

e) Travelling Wave Antenna

Travelling wave antenna is antenna that uses one or more travelling waves to produce radiation mechanism on guided structure. Travelling-wave antenna can be classified into two general group, slow-wave antenna and leaky-wave antenna. One of their differences is the phased velocity of propagating wave. For slow-wave antenna, phased velocity of the wave is slower than speed of light in free space while phased velocity of wave for leaky-wave antenna is faster than speed of light in free space. Examples of travelling wave antenna are helical antenna and Yagi-Uda antenna. Yagi-Uda antenna, or commonly known as Yagi antenna, is antenna that consists of a single feed element along with several number of parasitic element that responsible for electromagnetic transmission in one particular direction(Milligan, 2005).

f) Frequency independent Antenna

Frequency independent antenna is a class of antenna that its radiation and impedance characteristic is unaffected by the variation of frequency over a wide range of frequencies(Rudge, 1983). Examples of frequency independent antenna are spiral antenna and log-periodic antenna. Spiral antenna is formed by etching a thin metal foil spiral pattern on substrate, typically the feeding is originated from the center.

g) Microstrip Antenna

Microstrip antenna, or known as printed antenna, is one of the popular antenna that being used in various fields. Microstrip antenna consists of a thin layer of radiating element pattern etched on top of a thicker dielectric substrate, which has a ground plane on the other side of the substrate. Further discussion on microstrip antenna can be found in Section 2.3.

2.2.4 Basic Antenna Parameter

Every antenna has different properties, and these properties are characterized by some of the important parameter discussed below, such as impedance, VSWR, antenna gain, bandwidth etc.

a) Impedance

The input impedance of antenna must match with the characteristic impedance of transmission line so that maximum energy transfer between transmission line and antenna can be achieved. If the input impedance and characteristic impedance are mismatch, energy reflection well occur and cause the reduction of whole system efficiency(Pozar, 2012).

b) VSWR

VSWR stands for Voltage Standing Wave Ratio, also known as Standing Wave Ratio (SWR). VSWR is a function of the reflection coefficient, which describes the power reflected from the antenna. The VSWR is always a real and positive number for antennas. The smaller the VSWR is, the better the antenna is matched to the transmission line and the more power is delivered to the antenna. In ideal case, the minimum VSWR is 1.0, which means that no power is reflected from the antenna. VSWR can be calculated using Eq. (2.1) and (2.2) (Pozar, 2012).

$$VSWR = \frac{1+\tau_L}{1-\tau_L} \tag{2.1}$$

Where $\tau_L = \frac{Z_{in} - Z_{out}}{Z_{in} + Z_{out}}$ (2.2)

c) Bandwidth

The bandwidth of an antenna is defined as the range of frequencies at which the performance of the antenna is maintained with respect to some antenna characteristics meets a set of specification criteria.

d) Antenna Gain

Antenna gain is an important measure which combines the antenna's directivity and electrical efficiency. In the definition of the antenna gain level, an isotropic antenna is typically used as a reference standard. An isotropic antenna is a theoretical antenna radiating energy equally in all direction of space. This antenna has a directivity of 0 dB since energy is distributed equally in all direction.

When the direction is given, then antenna gain is defined as the ratio of the intensity in that direction to the radiation intensity that obtained if the power received by antenna was radiated isotropically. Usually the ratio is expressed in decibels, unit is in decibels-isotropic (dBi) . If the direction is stated, the power gain is usually considered in the direction of maximum radiation. Gain is given in Eq.(2.3) and (2.4) (Balanis, 2008):

$$G = \frac{|S_{12}|(\frac{4\pi d}{\lambda_o})}{\sqrt{(1-|S_{11}|^2)(1-|S_{22}|^2)}} \quad (2.3)$$

$$G = \eta D \quad (2.4)$$

For Eq. (2.3), d is the distance between transmitting and receiving antenna. For Eq. (2.4), η is the antenna efficiency while D is the antenna directivity.

e) Directivity

Directivity measures the intensity of antenna radiation in the maximum radiation direction relative to the average radiation intensity(Milligan, 2005).

f) Radiation Direction

Basically, the radiation of array antenna can be either broadside or end fire according to different design. Broadside radiation means that antenna radiates perpendicularly to array surface (z-axis) while end fire radiation means that the antenna radiate along the array orientation (y-axis) (Moernaut and Orban, 1998).

g) Radiation Patten

Radiation pattern refer to a plot of the gain as a function of direction. In other words, radiation pattern is a graph which shows the variation of actual field strength of electromagnetic field of all the points equidistant from antenna. It describes how an antenna focuses or directs the energy it radiates or receives through free space. The two basic radiation patterns are field strength radiation pattern which is expressed in terms of field strength E (in V/m) and power radiation pattern expressed in terms of power per unit solid angle. A typical 3-dimensional radiation pattern of microstrip patch antenna is shown in Figure 2.2.

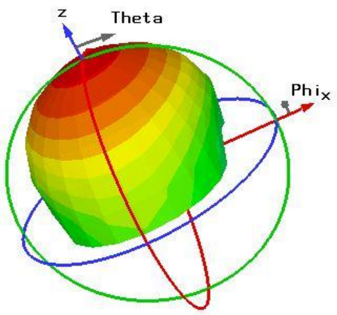

Figure 2.2: 3D Radiation Pattern

h) Polarization

Polarization refers to the direction of E-Field (electric vector) portion of the electromagnetic wave that being transmitted in space with respect to ground. Polarization is determined by the physical structure of the antenna and by its orientation. There are several types of polarization that apply to antennas. They are Linear (which comprises vertical and horizontal), oblique, Elliptical (left hand and right hand polarizations), circular (left hand and right hand) polarizations. Low frequency antenna is generally vertically polarized while high frequency antenna is horizontally polarized(Milligan, 2005).

i) Impedance Bandwidth

Impedance bandwidth is referred to limitation of frequency range over which element can be matched to it feed line during variation of impedance with antenna frequency. In other words, impedance bandwidth is the frequency range that antenna is well matched with transmission feed(Milligan, 2005). The impedance bandwidth of a patch antenna is strongly influenced by the spacing between the patch and the ground plane. Usually impedance bandwidth is defined in return loss or maximum standing wave ratio over a frequency range.

j) Scattering Parameter

Scattering parameter, or better known as S parameter, is used to describe the input-output relationship between ports (or terminals) in an electrical system. Figure 2.3 shows a typical two port network.

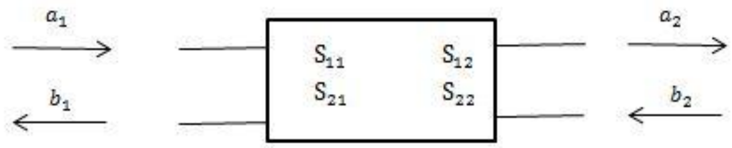

Figure 2.3: Two Port Network(Pozar, 2012)

Table 2.1: S-parameter (two-port network)(Pozar, 2012)

S parameter	Role in 2 ports network
S_{11}	input port voltage reflection coefficient
S_{21}	reverse voltage gain
S_{12}	forward voltage gain
S_{22}	output port voltage reflection coefficient

In antenna design, typically $S_{11}$is the most important S parameter as it represents the return loss of the antenna as shown in Table 2.1. If S_{11}equal to 0 dB, this means all the radiated power is reflected from the antenna and nothing is radiated.

2.3 Microstrip Antenna

Microstrip is an open wave guiding structure that is used as electronics components such as filter, couplers, resonators and also transmission line (James et al., 1981). On 1953, the concept of microstrip radiators was first proposed by Deschamps. In 1970s, by the findings of good substrates with low loss tangent and better thermal and mechanical properties, the development of microstrip antenna accelerate and then first practical antenna was developed by Howell and Munson (Garg et al., 2001). Since then, numerous advantages of Microstrip Antenna are exploited and various types of substrate with large range of dielectric constant and loss tangent values have been developed.

2.3.1 Radiation Mechanism of Microstrip Antenna

As microstrip antenna is connected to microwave source, a charge distribution will be formed on the upper and lower surface of the patch and on the surface of the ground as depicted in Figure 2.4.

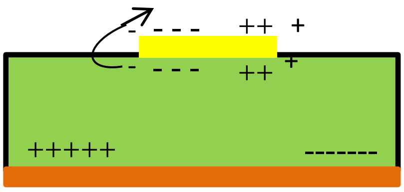

Figure 2.4: Charge Distribution on Microstrip Antenna(Garg et al., 2001)

At the patch, repulsive force exists among like charges and this force tend to pushes some charges at bottom surface to top surface around its edges. For microstrip antenna with small h/w ratio, attractive force between charges still dominate and majority of charges remain underneath the patch, only minority of current flow to upper surface. Hence, one can assume the tangential magnetic field is zero. A wall with zero tangential magnetic field is known as magnetic wall. Hence a magnetic wall exists at edges of the patch. In addition, the electric field is almost normal to patch surface and field variation at direction normal to patch surface is negligible since height of substrate, h, is much smaller than free space wavelength, λ_o. Consequently, the patch can be modeled as a cavity with magnetic wall at the periphery of the patch and electric wall at the top and bottom of the patch surface. This model also known as cavity model. It has higher validity for thin substrate with high dielectric constant(Garg et al., 2001). Using cavity mode, radiation will occur at side wall of patch antenna because the side wall is not conducting in natural and field inside the cavity can leak out to space. Note that only transverse magnetic (TM) modes are possible in this cavity, meaning that no magnetic field exists in the direction of propagation.

2.3.2 Types of Microstrip Antenna

Generally, microstrip antenna can be classified into four groups(Garg et al., 2001).

a) Microstrip Patch Antennas

Microstrip patch antennas is fabricated by etching a patch of conductive material on upper side of a dielectric slab that backed by a ground plane. The shape of the patch can be any shapes by the radiation pattern will be differing. Further explanation can be found in Section 2.4.1.

b) Microstrip Travelling-wave Antennas

Microstrip travelling-wave antennas use travelling wave for signal radiation in a guided structure such as periodic chain-shape pattern shown in Figure 2.5. One of the terminals of the antenna is terminated with matching circuit to reduce effect of reflected wave.

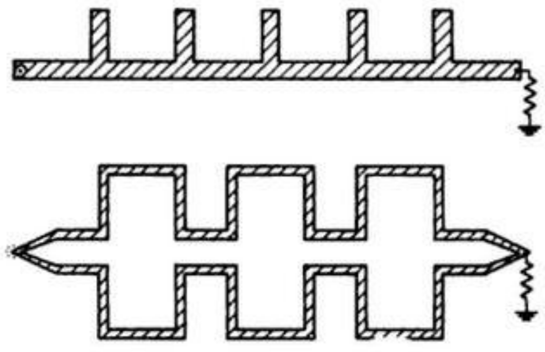

Figure 2.5: Example of Microstrip Travelling-wave Antenna Configuration(Garg et al., 2001)

c) Microstrip Dipoles Antennas

Microstrip dipoles antenna has similar longitudinal current distributions with microstrip patch antenna. However, they are different in bandwidth, radiation resistance and length-to-width ratio. Thicker substrate in dipoles antenna resulting in higher bandwidth and make it a better choice for high frequency application. For dipole antenna, wider width will cause a lower resonant frequency (Jamaluddin et al., 2005).

d) Printed Slot Antennas

Printed slot antennas consists of a conducting slot in the ground plane that underneath a substrate. Like microstrip patch antenna, the slot can be in any shape. Characteristics of different antenna is summarized in Table 2.2(Singh and Tripathi, 2011).

Table 2.2: Comparison of Different Types Of Microstrip Antenna(Singh and Tripathi, 2011)

Characteristic	Microstrip Patch Antenna	Microstrip Slot Antenna	Printed Dipole Antenna
Profile	Thin	Thin	Thin
Fabrication	Very Easy	Easy	Easy
`Polarization	Both linear and circular	Both linear and circular	Linear
Dual frequency operation	Possible	Possible	Possible
Spurious Radiation	Exists	Exists	Exists
Bandwidth	2-50%	5-30%	-30%
Shape flexibility	Any shape	Mostly rectangular and circular shapes	Rectangular and triangular shapes

2.3.3 Advantages and Disadvantages of Microstrip Antenna

Microstrip antennas have several advantages over conventional antennas(Bancroft, 2009).

- Low fabrication cost, can be produced by printed circuit technology
- Light weight, small in size and thin

- Mechanically rugged
- Can use linear or circular polarization with simple feed
- Dual polarization and dual-frequency can be easily made
- Can be easily integrated with microwave integrated circuits(MICs)

Advantages listed above make microstrip antenna become the favorite of antenna designers. Microstrip antenna is low profile; a thin substrate allows microstrip antenna can be made conformal to a shaped shape. Smaller antenna size also makes it become a better choice for portable electronic device. Cheaper fabrication cost means that microstrip antenna can be manufactured in large quantity. However, there are several limitations associate with microstrip antennas(Bancroft, 2009).

- Narrow bandwidth (5% to 10% without any special techniques)
- Low power handling capability (~100watt)
- Lower gain
- Large ohmic loss in the feeding network
- Poor polarization purity
- Surface wave-associated limitation such as radiation pattern degradation, increase mutual coupling

After years of research did by other researchers, many limitations of microstrip antenna have been overcome. For example, array orientation can be used to increase the antenna gain. Surface wave-associated limitation can be solved by using photonic bandgap structure (Qian et al., 1999). Many bandwidth-widening have been developed to increase impedance bandwidth of microstrip antenna. Bandwidth increment up to 50% can be achieved at the sacrifice of antenna physical volume (Lee and Luk, 2010).

2.3.4 Feeding Techniques and Modeling

Radiating elements are located at upper side of substrate; suitable feeding technique has to be used to transmit the power to radiating element, either directly or indirectly. Suitable feeding method has to be chosen for every antenna design so that impedance is matched between radiating structure and feed structure .At present, most commonly used feeding techniques are microstrip-line feed, coaxial probe feed, aperture-coupled feed and proximity-coupled microstrip feed(Garg et al., 2001).

a) Microstrip-line feed

A microstrip line is directly connected to radiating subject on the same substrate. However, since impedance at the edge of patch antenna is usually higher than 50Ω., alternative method such as inset feed or quarter-wave transformer will be used to avoid impedance mismatch. This technique provides ease of fabrication and low fabrication cost per element(Garg et al., 2001).

b) Coaxial probe feed

The inner conductor of coaxial connector passes through ground plane and substrate, soldered to radiating structure directly while the outer conductor of coaxial connector is connected to ground plane. This feeding method is most commonly being used because the impedance can be easily matched as the coaxial probe can be placed at any preferred location.

c) Aperture-coupled feed

Radiating structure and an open-ended microstrip feed line are separated by ground plane. There is an aperture or a slot on the ground plane that allows excitation to happen. This feeding method is able to produce wider bandwidth compared to coaxial feed technique (Lee and Luk, 2010). However, the fabrication process becomes harder as the thickness of antenna increases.

d) Proximity-coupled microstrip feed

An open-ended microstrip line is placed underneath the radiating structure and used to feed the radiating structure by proximity coupling. The primary advantage of this method is that it provides a very high bandwidth and eliminates spurious feed radiation (Garg et al., 2001).

2.3.5 Type of Substrate

Substrate is one of the vital parts of microstrip antenna, it provides mechanical support for radiating element and also space between the patch and ground plane. The substrate geometry is in the range of 0.01 to 0.05 of free-space wavelength. Typically, material used for substrate is Teflon-based with a relative permittivity between 2 and 3(Lee and Luk, 2010). For lowest cost, FR-4 (see Appendix D) may be used as substrate although the dielectric losses in FR-4 are too high at microwave frequencies, and the dielectric constant is not sufficiently tightly controlled.

2.4 Microstrip Patch Antenna

Nowadays, microstrip patch antenna is one of the popular antennas that usually being used in frequency range of 100 MHz to 100 GHz because the dimension of the microstrip patch antenna is inversely proportional to antenna operating frequency. As the operating frequency is higher, the antenna size is smaller(Garg et al., 2001).

2.4.1 Geometry and Shapes

Microstrip patch antenna consists of highly conductivity metal and dielectric substrate. The conductivity metal, which is usually thin copper, will form patch antenna, microstrip transmission line and ground plate. Antenna patch is etched on the upper surface of substrate, and a ground plate will be at the bottom side of the substrate. Microstrip patch antenna is usually fabricated using photolithographic etching or mechanical milling process. Figure 2.6 (Garg et al., 2001)shows the geometry of a basic rectangular microstrip antenna.

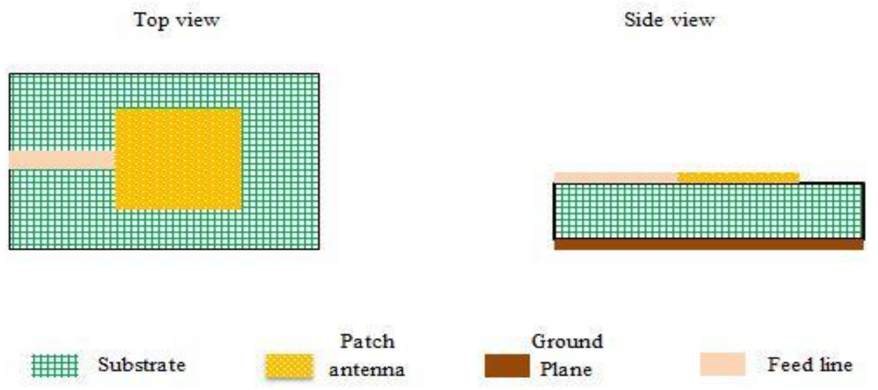

Figure 2.6: Geometry of Rectangular Microstrip Antenna

The patch antenna can be varying in shapes, but the most common shapes are rectangular and circular patch antenna. Figure 2.7 (Garg et al., 2001) illustrates some of the basic microstrip patch antenna usually used in practice.

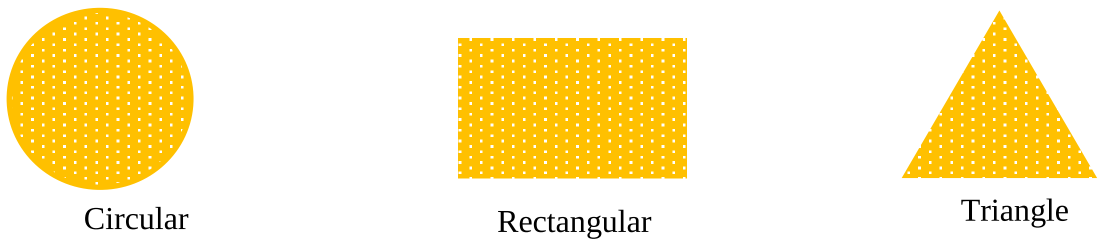

Figure 2.7: Basic Shapes of Microstrip Antenna Patch

The dimensions of patch antenna greatly affect the operating frequency and performance of that antenna. Due to the fringing effect, the effective antenna dimension will be usually larger than actual dimension(Elrashidi et al., 2011). Fringing field is a field that exist when electron clump on the surface of patch antenna especially at the edge. Hence, during designing stage, dimension of antenna is usually trimmed by 2 to 4% to achieve desired resonant frequency.

2.4.2 Microstrip Array

A primary drawback of microstrip patch antenna is lower antenna gain compared to some conventional antenna such as parabolic antenna and horn antenna. One of the solutions to increase the gain of microstrip patch antenna is to use an array of radiating elements. An array of element able to produce greater aperture and hence greater gain compared to single microstrip antenna (Bancroft, 2009).

In an array of radiating element, mutual coupling between radiating element is the key factor that will affect electrical performance of array antenna. A thicker substrate and larger number of radiating array will result in higher mutual coupling. A larger element spacing and substrate with lower dielectric constant will decrease mutual coupling of that array antenna (Lee and Luk, 2010).

As spacing between elements increase, directivity and gain of antenna will make a small increment along with higher level of grating lobes. Nevertheless, mutual coupling will be too strong if element spacing is lower than 0.5λ. Hence, typically the element spacing is range within $0.5\,\lambda$ and λ.

Gain of array antenna and number of side lobe will increase with the number of radiating element. However, when the number of elements increase indefinitely, eventually the gain will stop due to the increasing surface wave that is no longer negligible in large array (Lee and Luk, 2010).

2.4.3 Feeding Network

Every radiating element on a set of array is fed by a feed network. The complexity of a feeding network is affected by the amplitude of the distribution, the number of elements etc. Basically there are two types of fed network, corporate feed and series fed.

a) Corporate-fed

The corporate feed has an input port and several output ports that being arrange in parallel by power division method. Usually the transmission line will be divided at each branching network, until the microstrip line reach radiating element as illustrated in Figure 2.8(Lee and Luk, 2010). This configuration is simpler, having broader bandwidth, and flexible choice of element spacing. It has identical path length from input port to radiating element since power is equally divided at each branching network. Nevertheless, the drawbacks are more space is needed and the length of transmission line is longer, resulting in increase of insertion loss, mutual coupling and cross-polarization of the array (Lee and Luk, 2010).

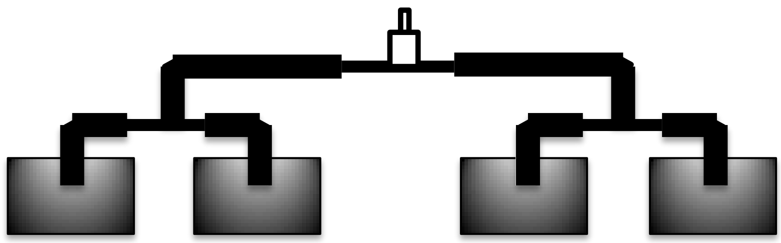

Figure 2.8: Corporate-fed Array