



ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
FACULTY OF TECHNOLOGY

**BANDWIDTH IMPROVEMENT OF MICROSTRIP ANTENNA USING LOG
PERIODIC TECHNIQUE**

A thesis submitted to school of Graduate Studies of Addis
Ababa University in partial fulfillment of Masters of Science
in Electrical Engineering (Communication Engineering)

By

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March 2008



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ACKNOWLEDGEMENTS

I wish to express sincere thanks to my advisor, Dr.Ing Mohammad Abdo, for giving me this opportunity to work on this thesis and for his invaluable time and effort. I would like to acknowledge that without his advice and critical reading this thesis would not have been completed at all.

I would like to extend my gratitude to Dr. Roy for not only advice, but also for his effort to schedule and allow me to present my thesis. It is also my pleasure to thank Ato Tegay Araga for being such a great help in making simulation work inside the laboratory. I would like also to extend a word of thanks to all my friends who have made my work fruitful. I like to thank my family, whose unlimited love and support has made this effort possible. Finally, I thank Almighty God for always being there to guide me through thick and thin.

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ABBREVIATIONS

WLAN: wireless local area networks
LPA: Log Periodic Antenna
MMIC: millimeter-wave integrated circuits
FR4: Flame Retardant 4
RF: Radio Frequency
SWR: Standing wave ratio
VSWR: Voltage standing wave ratio
3D: Three dimension
FDTD: Finite Difference Time Domain Method
GUI: GANYMEDE of the Empire simulator

SYMBOLS

t - Patch thickness
 λ_0 - Free space wave length
 h - Height of dielectric material
 ϵ_r - Relative dielectric constant
 L - Length of the patch
 B - Substance of the patch
 G - Conductance of the patch
 ϵ_{reff} - Effective dielectric constant
 f - Resonant frequency (not consider the fringing effect)
 f_r - Resonant frequency (consider the fringing effect)
 P_{rad} - Radiated power
 Y - Admittance
 λ - Wavelength in the dielectric substrate
 Y_{in} - Total resonant input admittance
 Z_{in} - Resonant input impedance
 E_1 - Electric field radiated by slot one

H_2 - Magnetic field radiated by slot two
 V_0 - Voltage across the slot
 q - Fringe factor
 K_0 - Wave number
 G_{12} - Mutual conductance
 z_0 - Characteristic impedance
 J_b and J_t - Corresponding current densities of the bottom and top surfaces of the patch
 E_a and H_a - Represent the electric and magnetic fields of the slots
 M_s - Magnetic current density
 A_x - Vector potential of Cavity model
 Q_t - Total quality of factor
 Q_{rad} - Quality factor due to radiation losses
 Q_c - Quality factor due to conduction losses
 Q_{dm} - Quality factor due to dielectric losses
 Q_{sc} - Quality factor due to surface wave
 $\tan \delta$ - Loss tangent
 σ - Conductivity
 G_t / l is the total conductance per unit length
 A_{mnp} - Amplitude coefficients of each mnp mode

XML: eXtensible Markup Language

ABSTRACT

The thesis covers two aspects of microstrip antenna designs. The first is the analysis and design of single element narrowband rectangular microstrip antenna which operates at the central frequency of 2.4 GHz and the second aspect is the design of five element broadband Log Periodic microstrip antenna. Both antennas have been modeled, designed and simulated. Basically, transmission line and cavity modeling are going to use to model both antennas. First, the design parameters for single element of rectangular patch antenna have been calculated from the transmission line model equation and extend the antenna design to five element log periodic microstrip antenna using log periodic analytical technique. The simulation process has been done through momentum simulation using Empire software. Each data from the Finite Difference Time Domain Method (FDTD) simulation extract and combine with the microstrip transmission line. The rectangular microstrip antenna design uses Flame Retardant 4, FR4, microstrip board with dielectric constant 4.7, scaling factor 0.95 and loss tangent is 0.019. The properties of antenna such as bandwidth, S parameter has been investigated and compared between a single element rectangular and a five element log periodic rectangular microstrip antenna.

CHAPTER ONE

OVERVIEW

1.1 Introduction

Wireless communication has been developed rapidly in the past decades and it has already a dramatic impact on human life. In the last few years, the development of wireless local area networks (WLAN) represented one of the principal interests in the information and communication field. Thus, the current trend in commercial and government communication systems has been to develop low cost, minimal weight, low profile antennas that are capable of maintaining high performance over a large spectrum of frequencies. This technological trend has focused much effort into the design of microstrip (patch) antennas. With a simple geometry, patch antennas offer many advantages not commonly exhibited in other antenna configurations. For example, they are extremely low profile, lightweight, simple and inexpensive to fabricate using modern day printed circuit board technology, compatible with microwave and millimeter-wave integrated circuits (MMIC), and have the ability to conform to planar and non planar surfaces. In addition, once the shape and operating mode of the patch are selected, designs become very versatile in terms of operating frequency, polarization, pattern, and impedance. The variety in design that is possible with microstrip antenna probably exceeds that of any other type of antenna element.

Using the Log Periodic Antenna (LPA) concept, in this thesis, a log-periodic microstrip antenna is designed,

simulated and tested. There are quite a few software programs available, which allow us to analyze antennas numerically. The Empire simulator is one of the software tools for solving Maxwell's equations, especially for radio and microwave frequency applications. It works based on the Finite Difference Time Domain Method (FDTD), which means that structure of the microstrip antenna is discretized into a number of cells based on space and time. The simulator tool computes most of the useful quantities of interest such as radiation pattern, input impedance and gain.

The thesis attempts to confirm the bandwidth enhancement of log periodic microstrip antenna by designing and simulation of a single element rectangular microstrip and a five element log periodic microstrip antenna.

1.2 General Motivation

Despite the many advantages of patch antennas, they do have some considerable drawbacks. One of the main limitations with patch antennas is their inherently narrowband performance due to its resonant nature. With bandwidths as low as a few percent; broadband applications using conventional patch designs are limited. Other characteristics of patch antennas include low efficiencies, limited power capacity, spurious feed radiation, poor polarization purity, and manufacturing tolerance problems.

Recently, much progress has been made to broaden the bandwidths of microstrip antennas. Many of these techniques involve adjusting the placement and/or type of element used

to feed (or excite) the antenna. The simplest and most direct approach is to increase the thickness of the substrate, while using a low dielectric substrate. This can extend bandwidth of microstrip antenna significantly. However, power loss is maximized due to the fact of surface wave loss of side lobe. The limitation of high surface wave loss, in general losses, forces to search alternative techniques that can achieve larger bandwidth with minimum loss.

Since most WLANs are operated at 2.4 GHz (i.e license free frequency band) and also since design and implementation of broadband log periodic microstrip antenna is simpler, easy to implement and cost effective compared to other designing methods; the thesis concentrates on the designing of broadband log periodic microstrip antenna that operate at 2.4 GHz and study its performance.

1.3 Outline of the Thesis

The thesis is organized as follows: Chapter one gives an introduction and general motivation of the thesis which describes the flow of the thesis. Chapter two provides a brief technical description of single element rectangular microstrip antennas focusing on basic characteristics, typical excitation (feeding) methods, and concludes with an analytical model of a patch. Chapter three introduces the concept of log periodic rectangular microstrip antenna to determine the dimension of log periodic elements. The simulation of single element rectangular microstrip antenna and five element log periodic microstrip antenna using Empire software and discussion of the radiation characteristics of those antennas are described in Chapter

four. Chapter five concludes this research and offers suggestions for future directions. The background of the simulator software and overview of scattering parameters in conjunction to bandwidth is addressed in Appendix.

CHAPTER TWO

ANTENNA THEORY

2.1 Microstrip Antenna

One of the most exciting developments in antenna and electromagnetic history is the advent of microstrip antenna (known also as patch antenna). It is probably the most versatile solution to many systems requiring planar radiating element. Microstrip antenna falls into the category of printed antennas: radiating elements that utilize printed circuit manufacturing processes to develop the feed and radiating structure. Of all the printed antennas, including dipole, slots, and tapered slots; microstrip antenna is by far the most popular and adaptable. This is because of all its salient features: including ease of integration, good radiation control, and low cost of production.

The microstrip antenna is constructed from dielectric substrate and patch metal and that a portion of the metallization layer is responsible for radiation. Microstrip antenna was conceived in the 1950s, and then extensive investigations of the patch antennas followed in the 1970s and resulted in many useful design configurations. Through decades of research, it was identified that the performance and operation of a microstrip antenna is driven mainly by the geometry of the printed patch and the material characteristics of the substrate onto which the antenna is printed.

2.2 Basic Characteristics

As shown in Figure 2.1, conventional microstrip antennas consist of a pair of parallel conducting layers separating a dielectric medium, referred to as substrate. In this configuration, the upper conducting layer or “patch” is the source of radiation where electromagnetic energy fringes off the edges of the patch and into the substrate. The lower conducting layer acts as a perfectly reflecting ground plane, bouncing energy back through the substrate and into free space. Physically, the patch is a thin conductor that is an appreciable fraction of a wavelength in extent. The patch which has resonant behavior is responsible to achieve adequate bandwidth. Conventional patch designs yield few percent bandwidths. In most practical applications, patch antenna is rectangular or circular in shape; however, in general, any geometry is possible.

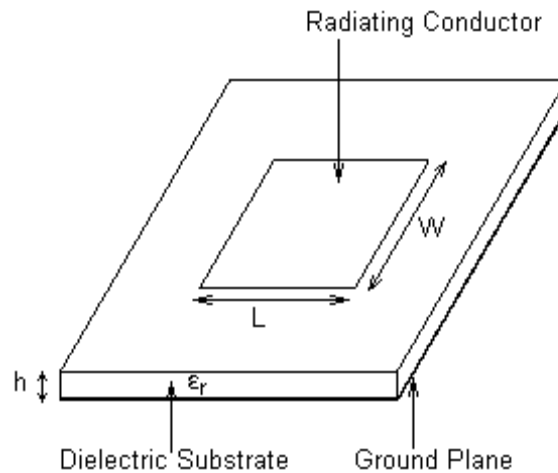


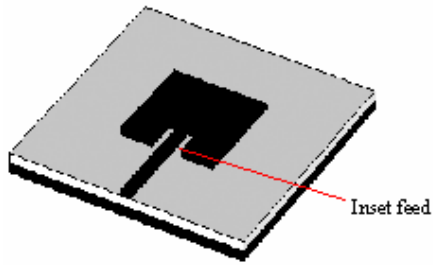
Figure 2.1 Conventional rectangular microstrip antenna

Microstrip antenna should be designed so that its maximum wave pattern is normal to the patch. This is accomplished by proper choice of mode of excitation beneath the patch. Generally, patch of microstrip antenna thickness is very thin in the range of $t \ll \lambda_0$ (λ_0 is free space wave length) and the height h of dielectric material is between $0.003\lambda_0 < h < 0.05\lambda_0$. For a rectangular path, the length L of the element is usually $\lambda_0/3 < L < \lambda_0/2$.

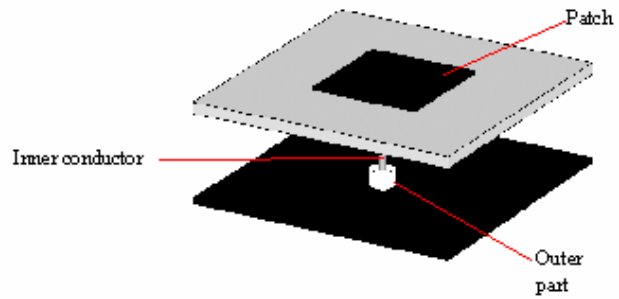
There are numerous substrate that can be used for the design of microstrip antenna, and their dielectric constants are usually in the range of $2.2 < \epsilon_r < 12$, where ϵ_r is relative dielectric constant. The substrate whose size is thick and dielectric constant is in the range of lower end provides better efficiency and bandwidth; but it expenses large element size.

2.3 Feeding Methods

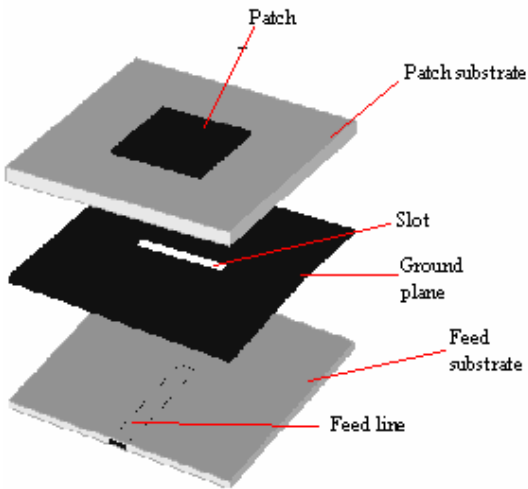
There are several techniques available to feed or transmit electromagnetic energy to a microstrip antenna. The four most popular feeding methods are the microstrip line, coaxial probe, aperture coupling and proximity coupling. These are displayed in Figure 2.2.



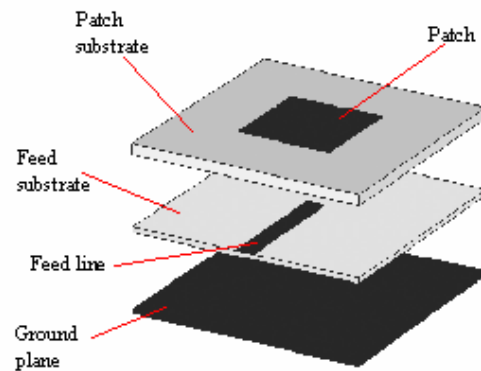
a) Microstrip line feed



b) Coaxial line feed



c) Aperture coupling feed



d) Proximity coupling feed

Figure 2.2 Techniques for feeding microstrip patch antenna

The microstrip line feed, Figure 2.2.a, has usually small size width compared to the patch. The microstrip line feed is easy to fabricate, simple to match by controlling the inset position and easy to model. However, as the substrate thickness increases, surface waves and spurious

feed radiation increase which limits the bandwidth in the practical design.

Coaxial line feed, Figure 2.2.b, where the inner conductor of the coax is attached to the radiation patch while the outer conductor is connected to the ground plane, are also widely used. The coaxial probe feed is also easy to fabricate and match, and it has low spurious radiation. However, it also has narrow bandwidth and more difficult to model.

Aperture coupling, Figure 2.2.c, is non-contacting feed method which consists of two substrates separated by a ground plane. On the bottom side of the lower substrate there is a microstrip feed line whose energy is coupled to the patch through a slot on the ground plane separating the two substrates. This arrangement allows independent optimization of the feed mechanism and the radiating element. Typically a high dielectric material is used for the bottom substrate, and thick low dielectric constant material for the top substrate. Matching of aperture coupling is preformed by controlling the width of the feed line and length of the slot.

Proximity coupling, Figure 2.2.d, is also non-contacting feed method that provides largest bandwidth and low spurious radiation. However, its fabrication is more difficult relative to other kinds of feeding method.

The equivalent circuits of each type of feed method are illustrated in the following Figure 2.3.

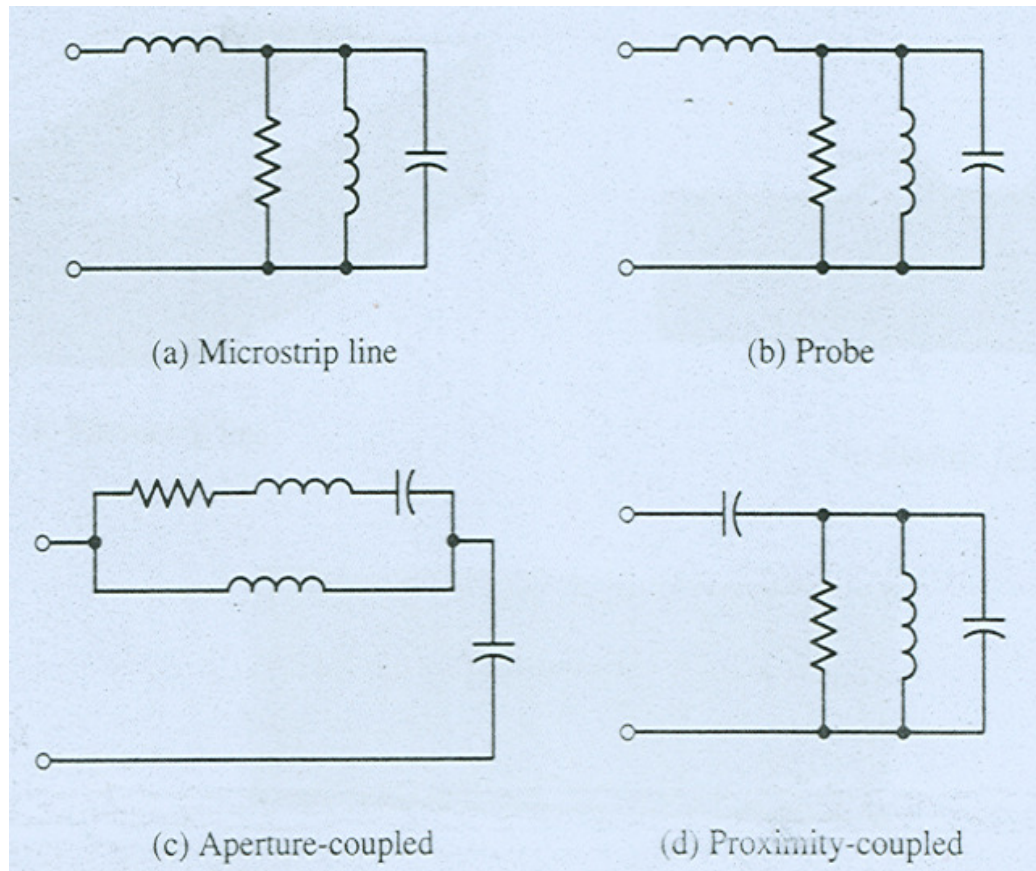


Figure 2.3 Equivalent circuits of typical feeding methods [1]

2.4 Analytical Evaluation of a rectangular Patch Antenna

The Objectives of antenna analysis are to predict the radiation characteristics such as radiation patterns, gain, and polarization as well as input impedance, bandwidth, mutual coupling, and antenna efficiency. The analysis of microstrip antennas is complicated by the presence of inhomogeneity of dielectric and boundary conditions, narrow frequency band characteristics, and a wide variety of feed,

patch shape, and substrate configurations. The good model has the following basic characteristics:

- It can be used to calculate all impedance and radiation characteristics of the antenna.
- It's result are accurate enough for the intended purpose.
- It is simple as possible, while providing the proposed accuracy for the impedance and radiation properties.
- It lends itself to interpretation in terms of known physical phenomena.

In common practice, microstrip antennas are evaluated using one of three analysis methods: the transmission line model, the cavity model, and the full-wave model. The transmission line model is the easiest of all, it gives good physical insight. But it is less accurate and more difficult to model coupling effect of antenna. Compared to the transmission line model, the cavity model is more accurate but at the same time more complex and difficult to model coupling effect. In general, when applied properly, the full wave model is very accurate, and very versatile. It can analyze single element, finite array, layered elements and arbitrary shaped element of microstrip antenna and also coupling effect of the antenna.

2.4.1 Transmission line modeling

The transmission line model, as shown in the Figure 2.4, represents the microstrip antenna by two slots,

separated by susceptance B and conductance G of length L patch. Due to the dimensions of the patch are finite (or shorter than the base plate) along in length and width, the fields at the edges of the patch undergo fringing. The fringing fields act to extend the effective length of the patch. Thus, the length of a half-wave patch is slightly less than a half wavelength in the dielectric material.

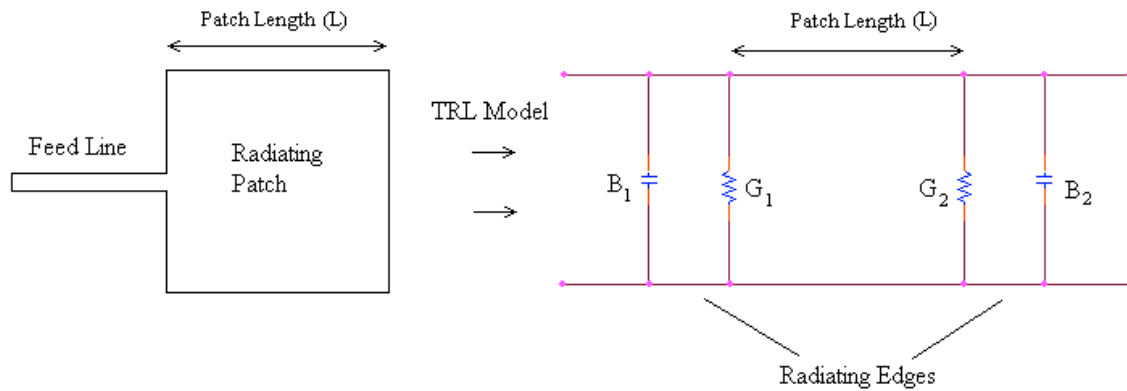


Figure 2.4 Transmission line model

2.4.1.1 Fringing effect

The amount of fringing of the antenna is a function of the dimensions of the patch and the height of the substrate. Due to fringing electric field lines travels in non-homogeneous material, typically substrate and air, an effective dielectric constant ϵ_{reff} is introduced. For electric line with air above the substrate, the effective dielectric constant has values in the range of $1 < \epsilon_{\text{reff}} < \epsilon_r$. The dielectric constant for most applications is much greater than unity. The effective dielectric constant is expressed by the function of frequency. As the frequency of operation increases, most of the electric field

concentrates in the substrate, and therefore, the microstrip behaves more like a homogeneous electric line of one dielectric, and the effective dielectric constant approaches the value of one dielectric constant of the substrate. Experimental results of the effective dielectric constant for microstrip with three different substrates are shown in Figure 2.5.

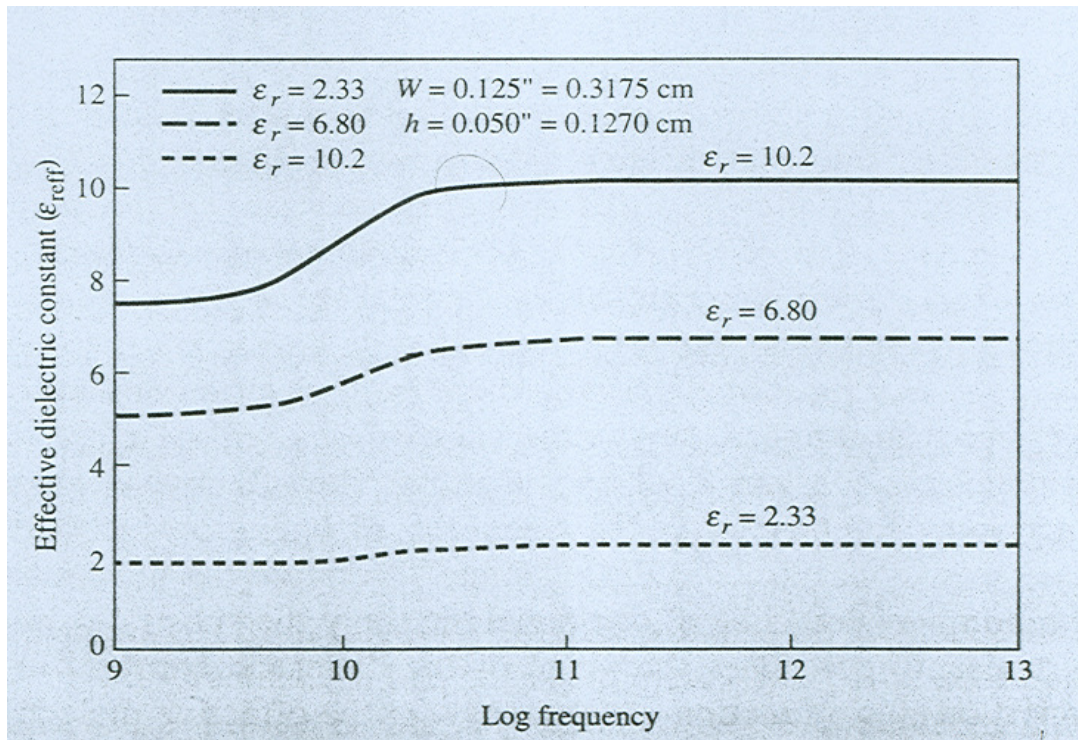


Figure 2.5 Effective dielectric constant versus frequency for typical substrates [2]

Generally, the relationship of width, W height, h effective dielectric constant, ϵ_{eff} and relative dielectric constant of the substrate ϵ_r are related as follow [4][15].

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \frac{1}{\left(1 + 12 \frac{h}{W}\right)^{\frac{1}{2}}} \quad 2.1$$

A very popular and practical approximation relation for normalized extension of the length is obtained from below equation. [5][15].

$$\Delta L = 0.412h \frac{(\epsilon_{eff} + 0.3) \left(\frac{W}{h} + 0.264\right)}{(\epsilon_{eff} - 0.258) \left(\frac{W}{h} + 0.8\right)} \quad 2.2$$

Substrate thickness should be chosen as large as possible to maximize bandwidth, but not so large to minimize the risk of surface wave excitation. The substrate should also has low dielectric constant in order to achieve high efficiency.

Since the effective length of the patch has been extended by ΔL on each side, the effective length of the patch is expressed as

$$L_{eff} = L + 2\Delta L \quad 2.3$$

After analyzing and determining the physical nature of the microstrip antenna with reference of resonant frequency, f_r , relative dielectric constant, ϵ_r , height of the substrate h ; it is possible to design rectangular

microstrip antenna dimension, width W and Length L , of patch as follow. [6]

$$W = \frac{\lambda_0}{2} \left(\frac{\epsilon_r + 1}{2} \right)^{-\frac{1}{2}} \quad 2.6$$

$$L = \frac{1}{2f_r \sqrt{\epsilon_{eff}} \sqrt{\mu_0 \epsilon_0}} - 2\Delta L \quad 2.7$$

2.4.1.2 Resonant input resistance

As shown in figure 2.4, a mirostrip antenna is represented by an equivalent circuit with two slots having conductance, G , and susceptance, B . The total admittance at slot one (input admittance) is obtained by transferring the admittance of slot two from the output terminal to input terminals using the admittance transformation equation of transmission lines. Ideally two slots are separated by $\lambda/2$ where λ is the wavelength in the dielectric (substrate). However, because of the fringing the length of the patch is electrically longer than the actual length. Therefore the actual separation of the two slots is slightly less than $\lambda/2$. If the reduction of the length is properly chosen using equation 2.2, the transformed admittance of the slot two becomes

$$Y_1 = Y_2 \quad G_1 = G_2 \quad B_1 = -B_2 \quad 2.8$$

Therefore the total resonant input admittance is real and is given by

$$Y_{in} = Y_1 + Y_2 = 2G_1 \quad 2.9$$

Since the total input admittance is real, the resonant input impedance is also real.

$$Z_{in} = \frac{1}{Y_{in}} = R_{in} = \frac{1}{2G_1} \quad 2.10$$

Considering the mutual effects between the slots, the above equation will be modified as [13]

$$R_{in} = \frac{1}{2(G_1 \pm G_{12})} \quad 2.11$$

where the plus (+) sign is used for modes with odd (anti-symmetric) resonant voltage distribution beneath the patch and the slots while minus (-) sign is used for modes with even (symmetric) resonant voltage distribution.

However, the mutual conductance of microstrip antenna is defined as [1]

$$G_{12} = \frac{1}{|V_0|^2} \operatorname{Re} \iint_s E_1 \cdot x H_2^* \cdot ds \quad 2.12$$

where E_1 is the electric field radiated by slot one, H_2 is the magnetic field radiated by slot two, V_0 is the voltage across the slot.

The equation 2.12 considers the effect of magnetic field radiated by slot two over slot one of the equivalent circuit of microstrip antenna. The integration is performed over the sphere of large radius.

Hence, G_{12} can also be calculated using [14]

$$G_{12} = \frac{1}{120\pi^2} \int_0^\pi \left[\frac{\sin\left(\frac{k_0 W}{2} \cos \theta\right)}{\cos \theta} \right]^2 J_0(k_0 L \sin \theta) \sin^3 \theta d\theta \quad 2.13$$

Where J_0 is the Bessel function of the first kind of order zero and K_0 is a wave number

However, the conductance, G_1 , is obtained from radiated power expression: [1]

$$G_1 = \frac{2P_{rad}}{|V_0|^2} \quad 2.14$$

where P_{rad} is the radiated power of microstrip antenna [1] given as:

$$P_{rad} = \frac{|V_0|^2}{2\pi\eta_0} \int_0^\pi \left[\frac{\sin\left(\frac{k_0 W}{2} \cos \theta\right)}{\cos \theta} \right]^2 \sin^3 \theta d\theta \quad 2.15$$

Therefore the conductance can be expressed as

$$G_1 = \frac{I_1}{120\pi^2} \quad 2.15$$

where

$$I_1 = \int_0^\pi \left[\frac{\sin\left(\frac{k_0 W}{2} \cos \theta\right)}{\cos \theta} \right]^2 \sin^3 \theta d\theta \quad 2.15.a$$

The approximated result of equation 2.15.a is [1]

$$I_1 = -2 + \cos(X) + XS_i(X) + \frac{\sin(X)}{X} \quad 2.15.b$$

$$X = k_0 W \quad 2.15.c$$

Where K_0 is a wave number

And hence, asymptotic value of the equation is described by [1]

$$G_1 = \frac{1}{90} \left(\frac{W}{\lambda_0} \right)^2 \quad W \ll \lambda_0 \quad 2.16$$

$$G_1 = \frac{1}{120} \left(\frac{W}{\lambda_0} \right)^2 \quad W \gg \lambda_0$$

Graphical representation of equation 2.16 to determine G_1 is presented in the Figure 2.6 (A plot of G_1 as a function of W/λ_0). It shows that magnitude of conductance of the microstrip antenna increases linearly as W/λ_0 increases.

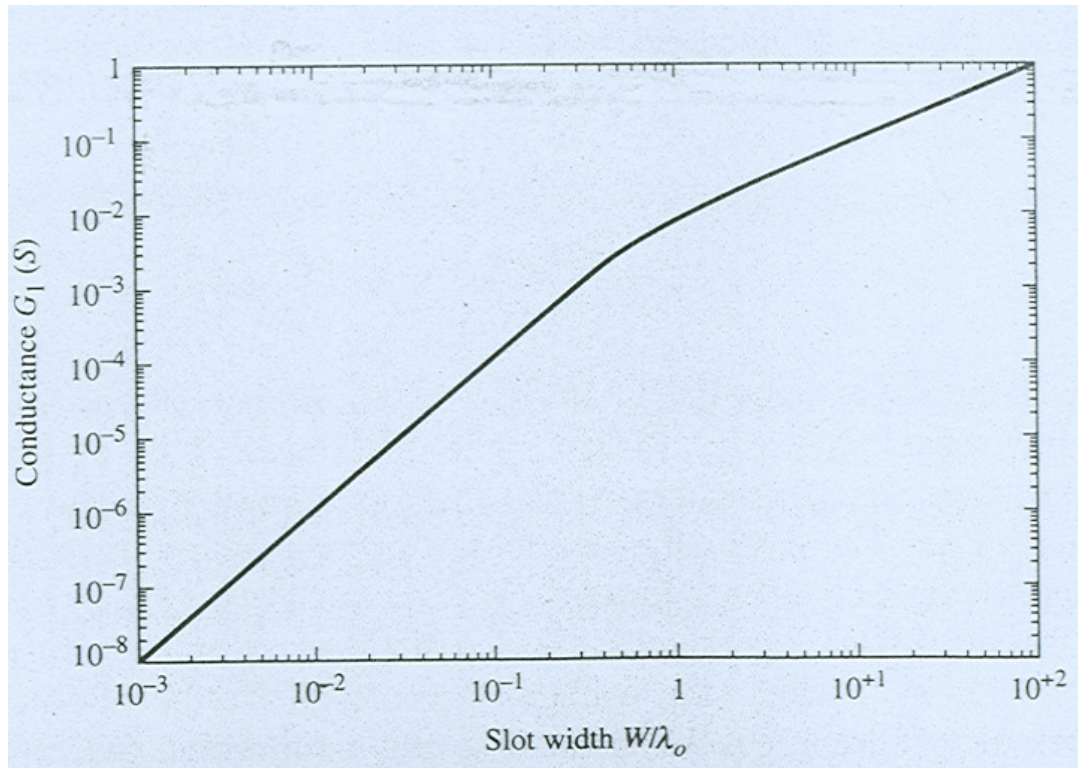


Figure 2.6 Slot conductance as a function of slot width [1]

2.4.1.3 Inset Feed

The resonant input resistance of the microstrip antenna obtained by equation 2.11 can be changed to appropriate value using inset feed or other alternative technique in order to achieve maximum power transfer.

The inset technique changes the resonant input resistance by introducing a physical notch, as shown in Figure 2.7, which in turn introduces a junction

capacitance. The physical notch and its corresponding junction capacitance influence slightly the resonant frequency. The maximum resonant input resistance value occurs at the edge of the slot ($y_0 = 0$) where the voltage is maximum and current is minimum. However, the minimum resonant input resistance value occurs at the center of the patch ($y_0 = L/2$). As the inset feed point moves from edge toward the center of the patch the resonant input impedance decreases monotonically and reaches zero at the center. When the value of the inset feed-point reaches the center

of the patch ($y_0 = L/2$), the $\cos^2\left(\frac{\pi}{L}y_0\right)$ function varies very rapidly; therefore the input resistance also changes rapidly with the position of the feed point.

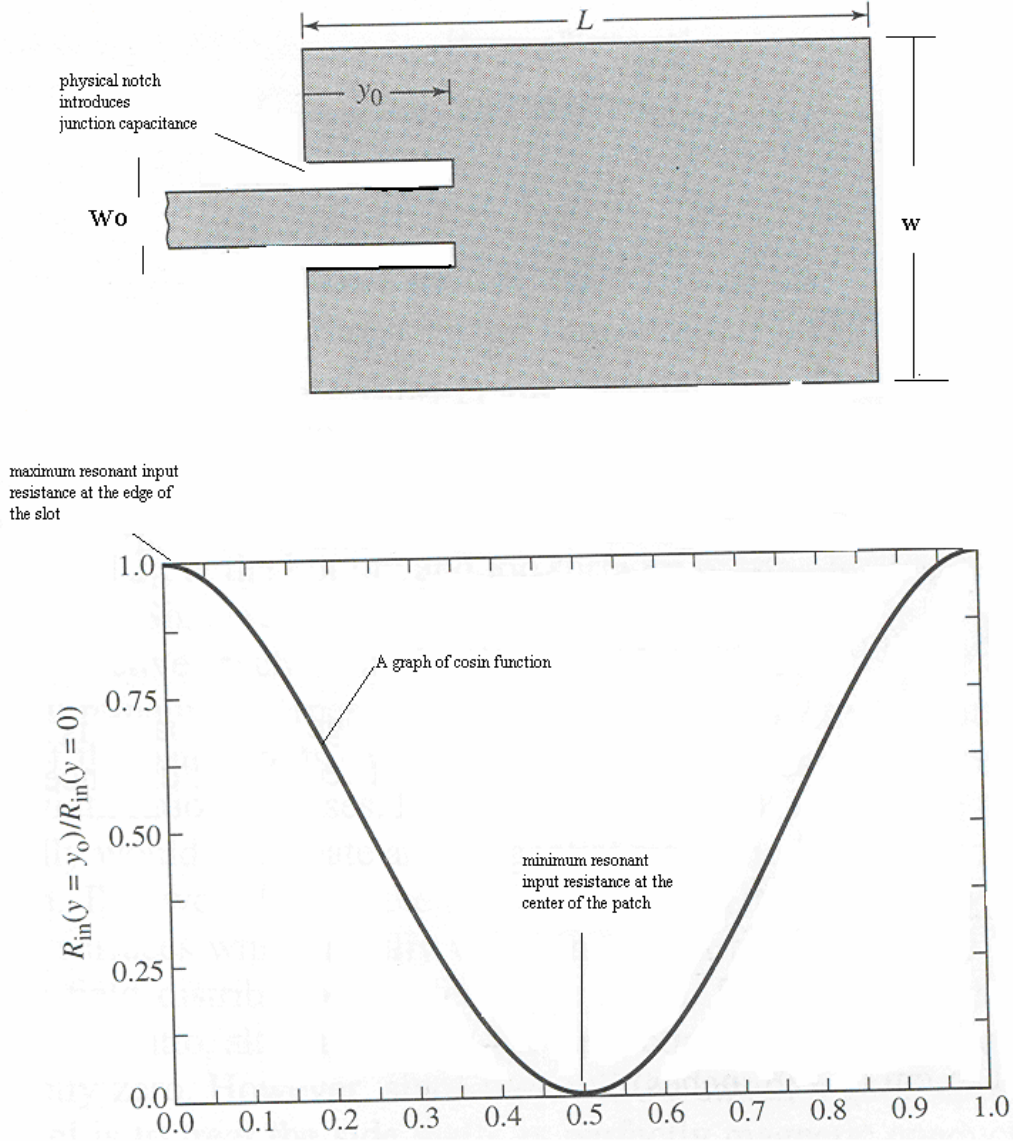


Figure 2.7 Microstrip line inset feeding and variation of normalized input resistance [1]

Analytically, the input resistance for inset feed is given approximately by [1][16]

$$R_m(y = y_0) = \frac{1}{2(G_1 \pm G_{12})} \cos^2\left(\frac{\pi}{L} y_0\right) \quad 2.17$$

Similarly, the characteristic impedance z_0 of microstrip line feed is given by [4]

$$Z_c = \frac{60}{\sqrt{\epsilon_{reff}}} \ln\left[\frac{8h}{W_0} + \frac{W_0}{4h}\right] \quad \frac{W_0}{h} \leq 1 \quad 2.18$$

$$Z_c = \frac{120\pi}{\sqrt{\epsilon_{reff}} \left[\frac{W_0}{h} + 1.393 + 0.667 \ln\left(\frac{W_0}{h} + 1.44\right) \right]} \quad \frac{W_0}{h} > 1$$

Characteristic impedance of microstrip line as function w/h is given in Figure 2.8 for common substrates such as RT (2.33), beryllium oxide (6.8) and alumina (10.2). As it is indicated in the Figure 2.8 the characteristic impedance Z_0 is decreased as w/h values increased. For instance, the characteristic impedance 50 ohm is obtained for RT (2.33) dielectric material at the ratio value of w/h of $10^{0.5}$.

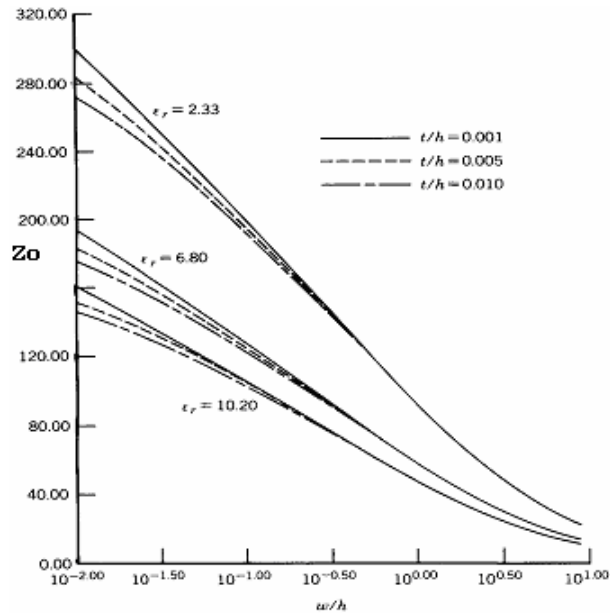


Figure 2.8 Characteristic impedance of microstrip line as a function of w/h [4]

2.4.2 The Cavity model

Microstrip antenna resembles dielectric loaded cavities, and exhibit higher order resonances. The normalized fields within the dielectric substrate can be found more accurately by treating that region as a cavity bounded by electric conductors (above and below) and by magnetic wall along the perimeter of the patch. The bases for this assumption are the following points (for height of substrate $h \ll$ wave length of the field λ).

- The fields in the interior region do not vary with z -axis because the substrate is very thin, $h \ll \lambda$

- The electric field is z-axis directed only, and the magnetic field has only the transverse components in the region bounded by the patch metallization and the ground plane. This observation provides for the electric walls at the top and bottom.
- The electric current in the patch has no component normal to the edge of the patch metallization, which implies that the tangential component of magnetic field along the edge is negligible, and a magnetic wall can be placed along the periphery.

This approximation model leads to reactive input impedance, and it does not radiate any power. However, the actual fields can be approximated to the generated field of the model and is possible to analyze radiation pattern, input admittance, and resonant frequency.

2.4.2.1 Current Densities

When the microstrip antenna (cavity modeled) is energized, charge distribution is established on upper and lower surfaces of the patch, as well as on the surface of the ground plane. The charge distribution is controlled by two mechanisms; attractive and a repulsive mechanism. The attraction is between the corresponding opposite charges on the bottom side of the patch and ground plane, which tends to maintain the charge concentration on the bottom of the patch. The repulsive is between like charges from the bottom of the patch, around its edges, to its top surface. (See Figure 2.9) The movement of these charges creates

corresponding current densities J_b and J_t , at the bottom and top surfaces of the patch.

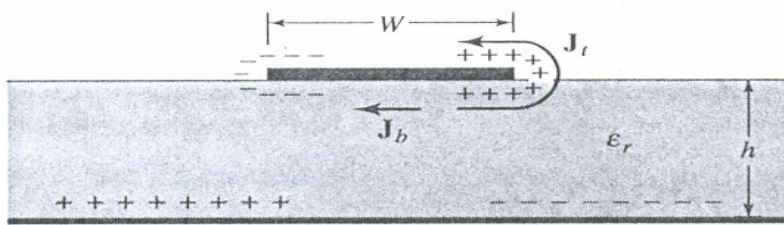


Figure 2.9 Charge distribution and current density

Since for the most practical microstrip the height to width ratio is very small, and due to attractive and a repulsive mechanism of charges, only small amount of current flows at the top surface of the patch and large amount of charges are concentrated underneath the patch. The concentration of charges produces current density J_b and J_t at the patch. However, this flow of current decrease as the height to width ratio increases. It implies that there is no tangential magnetic field component at the edges of the patch. This condition allows a microstrip antenna to be modeled by a four sided magnetic wall (Figure 2.10) model.

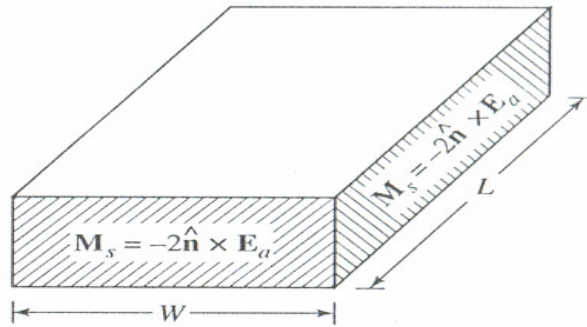


Figure 2.10 Cavity model of rectangular microstrip antenna

As shown in the Figure 2.10, the four sides slot is represented by the equivalent electric current density and equivalent magnetic current densities, respectively as follows

$$J_s = nxH_a \quad \text{and} \quad M_s = -nxE_a \quad 2.19$$

where E_a and H_a represent the electric and magnetic fields at the slots

Considering the presence of the ground plane, the only nonzero current density is the equivalent magnetic current density M_s .

Applying image theory of the magnetic current in the electric ground plane, equivalent magnetic current density M_s is given as

$$M_s = -2nxE_a \quad 2.20$$

Typical E and H plane of microstrip antenna of two slots with the source of the same magnitude and phase is presented in Figure 2.11.

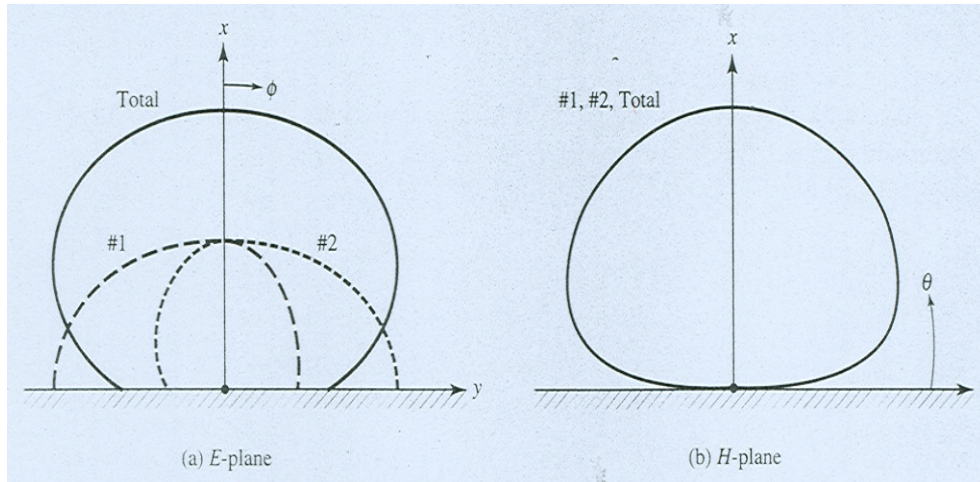


Figure 2.11 Typical E and H plane pattern of microstrip patch slots [1]

Treating the cavity model as microstrip antenna is not sufficient to find the absolute amplitude of the electric and magnetic fields. Naturally, the cavity is lossless and requires introducing losses by considering effective loss tangent to behave as an antenna. Because the thickness of the microstrip antenna is usually very small, the waves generated within the dielectric substrate undergo considerable reflections when the fields arrive at the edge of the patch. The electric field is nearly normal to the surface of the patch. Therefore, only TM field configuration is considered within the cavity.

2.4.2.2 Field configuration

It is common practice in the analysis of electromagnetic boundary-value problems to use auxiliary vector potentials as aids in obtaining solution for electric (**E**) and magnetic (**H**) fields. The most common vector potential functions are the **A**, Magnetic vector potential,

and \mathbf{F} , electric vector potential. These field configurations must satisfy Maxwell's equations or the wave equation and the appropriate boundary conditions.

Transverse magnetic modes, TM, (often also known as transverse magnetic field) are field configurations whose magnetic field components lie in a plane that is transverse to the direction of wave propagation. Consider that the wave propagation of the microstrip antenna is to x-axis and hence, magnetic vector potential of cavity model is generally obtained from the homogeneous wave equation [4][8].

$$\nabla^2 A_x + k^2 A_x = 0 \quad 2.21$$

where $k^2 = \omega^2 \mu \epsilon$

Since the field expression of TM to a given direction is independent of the other coordinate system, it is sufficient to let the vector potential \mathbf{A} have only a component in the direction in which the fields are propagated. The remaining components of \mathbf{A} as well as all of \mathbf{F} are set equal to zero.

The solution for equation 2.21 is expressed as follow [4]:

$$A_x = [A_1 \cos(k_x x) + B_1 \sin(k_x x)][A_2 \cos(k_y y) + B_2 \sin(k_y y) + B_2 \sin(k_y y)][A_x \cos(k_z z) + B_3 \sin(k_z z)]$$

$$2.22$$

where k_x , k_y and k_z are the wave numbers along x , y , z directions, respectively. Its value is determined subject to the boundary conditions.

Considering the boundary condition of the cavity model, $H_z(0 < x < h, y=0, 0 < z < W) = 0$ and $H_z(0 < x < h, y=L, 0 < z < W) = 0$, the vector potential is described as

$$A_x = A_{mnp} \cos(k_x x') \cos(k_y y') \cos(k_z z') \quad 2.23$$

where A_{mnp} represents the amplitude coefficients of each mnp mode

Resonant frequency determines the dominant mode of cavity operation and it is obtained using the following equations [4][1].

1. If $L > W > h$, the mode with lowest frequency (dominant mode) is TM_{010} and its resonant frequency is:

$$(f_r)_{010} = \frac{1}{2L\sqrt{\mu\epsilon}} \quad 2.24$$

2. If $L > W > L/2$, the mode is TM_{001} and its resonant frequency is:

$$(f_r)_{001} = \frac{1}{2W\sqrt{\mu\epsilon}} \quad 2.25$$

3. If $L > L/2 > W > h$, the order of the mode is TM_{020} and its resonant frequency is:

$$(f_r)_{020} = \frac{1}{L\sqrt{\mu\epsilon}} \quad 2.26$$

CHAPTER THREE

ANTENNA PARAMETERS

3.1 Gain and directivity

The gain of an antenna is the radiation intensity in a given direction divided by the radiation intensity that would be obtained if the antenna radiated all of the power delivered equally to all directions. The definition of gain requires the concept of an isotropic radiator; that is, one that radiates the same power in all directions. An isotropic antenna, however, is just a concept, because all practical antennas must have some directional properties. Nevertheless, the isotropic antenna is very important as a reference. It has a gain of unity ($g = 1$ or $G = 0$ dB) in all directions, since all of the power delivered to it is radiated equally well in all directions.

Although the isotrope is a fundamental reference for antenna gain, another commonly used reference is the dipole. In this case the gain of an ideal (lossless) half wavelength dipole is used. Its gain is 1.64 ($G = 2.15$ dB) relative to an isotropic radiator.

The gain of an antenna is usually expressed in decibels (dB). When the gain is referenced to the isotropic radiator, the units are expressed as dBi; but when

referenced to the half-wave dipole, the units are expressed as dBd. The relationship between these units is

$$G_{dBd} = G_{dBi} - 2.15 \text{ dB} \quad 3.1$$

Directivity is the same as gain, but with one difference. It does not include the effects of power lost (inefficiency) in the antenna. If an antenna were lossless (100 % efficient), then the gain and directivity (in a given direction) would be the same.

3.2 Antenna Polarization

The term polarization has several meanings. In a strict sense, it is the orientation of the electric field vector E at some point in space. If the E -field vector retains its orientation at each point in space, then the polarization is linear; if it rotates as the wave travels in space, then the polarization is circular or elliptical. In most cases, the radiated-wave polarization is linear and either vertical or horizontal. At sufficiently large distances from an antenna, beyond 10 wavelengths, the radiated, far-field wave is a plane wave.

3.3 Input impedance

There are three different kinds of impedance relevant to antennas. One is the terminal impedance of the antenna, another is the characteristic impedance of a transmission line, and the third is wave impedance. Terminal impedance is defined as the ratio of voltage to current at the

connections of the antenna (the point where the transmission line is connected). The complex form of Ohm's law defines impedance as the ratio of voltage across a device to the current flowing through it.

The most efficient coupling of energy between an antenna and its transmission line occurs when the characteristic impedance of the transmission line and the terminal impedance of the antenna are the same and have no reactive component. When this is the case, the antenna is considered to be matched to the line. Matching usually requires that the antenna be designed so that it has a terminal impedance of about 50 ohms or 75 ohms to match the common values of available coaxial cable.

The input impedance of patch antenna is in general complex and it includes resonant and non-resonant part. Both real and imaginary parts of the impedance vary as a function of frequency. Ideally, both the resistance and reactance exhibit symmetry about the resonant frequency as shown in Figure 3.1. Typically, the feed reactance is very small, compared to the resonant resistance for thin substrates.

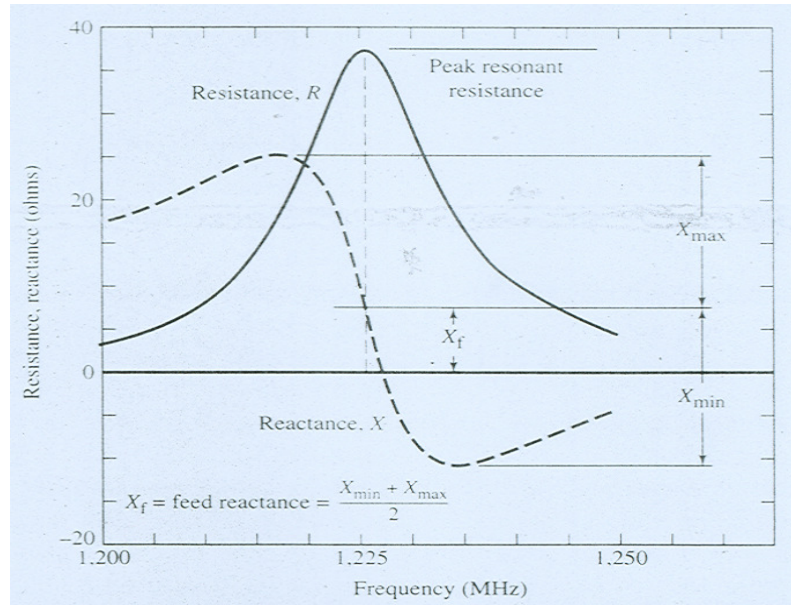


Figure 3.1 Typical variation of resistance and reactance of rectangular microstrip antenna versus frequency [18]

3.4 Voltage Standing Wave Ratio

The standing wave ratio (SWR), also known as the voltage standing wave ratio (VSWR), is not strictly an antenna characteristic, but is used to describe the performance of an antenna when attached to a transmission line. It is a measure of how well the antenna terminal impedance is matched to the characteristic impedance of the transmission line. Specifically, the VSWR is the ratio of the maximum to the minimum RF voltage along the transmission line. The maxima and minima along the lines are caused by partial reinforcement and cancellation of a forward moving RF signal on the transmission line and its reflection from the antenna terminals.

If the antenna terminal impedance exhibits no reactive (imaginary) part and the resistive (real) part is equal to the characteristic impedance of the transmission line, then the antenna and transmission line are said to be matched. It indicates that none of the RF signal sent to the antenna will be reflected at its terminals. There is no standing wave on the transmission line and the VSWR has a value of one. However, if the antenna and transmission line are not matched, then some fraction of the RF signal sent to the antenna is reflected back along the transmission line. This causes a standing wave, characterized by maxima and minima, to exist on the line. In this case, the VSWR has a value greater than one. The VSWR is easily measured with a device and VSWR of 1.5 is considered excellent, while values of 1.5 to 2.0 is considered good, and values higher than 2.0 may be unacceptable.

As stated above and elsewhere, an ideal match between the antenna and transmission line is desired; but this can often be achieved only for a single frequency. In practice, an antenna may be used for an entire frequency band, and its terminal impedance will vary across the band. In an antenna specification, either the impedance versus frequency across a band is given or the VSWR versus frequency is given.

3.5 Bandwidth

The bandwidth of an antenna is defined as the range of frequency within the performance of the antenna. In other words, characteristics of antenna (gain, radiation pattern, terminal impedance) have acceptable values within the

bandwidth limits. For most antennas, gain and radiation pattern do not change as rapidly with frequency as the terminal impedance does. Since the transmission line characteristic impedance hardly changes with frequency, VSWR is a useful, practical way to describe the effects of terminal impedance and to specify an antenna's bandwidth.

For broadband antennas, the bandwidth is usually expressed as the ratio of the upper to lower frequencies of acceptable operation. However, for narrowband antennas, the bandwidth is expressed as a percentage of the bandwidth.

[1]

3.6 Quality factor

The quality factor is a figure-of-merit that representative of the antenna losses. Typically there are radiation, conduction, dielectric and surface wave losses.

$$\frac{1}{Q_t} = \frac{1}{Q_{rad}} + \frac{1}{Q_c} + \frac{1}{Q_d} + \frac{1}{Q_{sc}} \quad 3.2$$

Q_t : total quality of factor

Q_{rad} : quality factor due to radiation losses

Q_c : quality factor due to conduction losses

Q_{dm} : quality factor due to dielectric losses

Q_{sc} : quality factor due to surface wave

The quality factor, bandwidth and efficiency are antenna figures-of-merit, which are interrelated, and there is no complete freedom to independently optimize each one.

For very thin substrates $h \ll \lambda_0$ of arbitrary shapes including rectangular, there approximate formulas to represent the quality factors of the various losses.

These can be expressed as

$$Q_c = h \sqrt{\pi f \mu \sigma} \quad 3.3$$

$$Q_d = \frac{1}{\tan \delta} \quad 3.4$$

$$Q_{rad} = \frac{2 \omega \epsilon_r k}{h G_t / l} \quad 3.5$$

Where $\tan \delta$ is the loss tangent of the substrate material, σ is the conductivity of the conductors associated with the patch and ground plane, G_t / l is the total conductance per unit length of the radiating aperture and k for rectangular microstrip antenna is $L/4$.

The Q_{rad} as represented by 3.5 is inversely proportional to the height of the substrates. A typical variation of the bandwidth for a microstrip antenna as a function of the normalized height of the substrate, for two different substrates, is shown in Figure 3.1. It is evident that the bandwidth increases as the substrate height increases. However, the radiation efficiency of the patch antenna described by the ratio of power radiated over the input power (3.6) decreases as normalized height of the substrate increased.

$$\eta = \frac{Q_i}{Q_{rad}} \quad 3.6$$

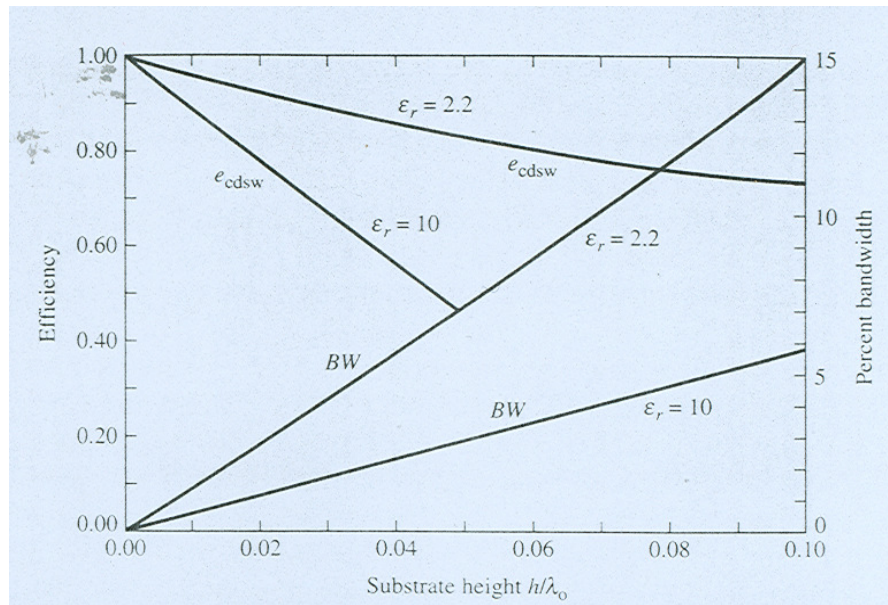


Figure 3.2 Efficiency and bandwidth versus substrate height at constant resonant frequency for rectangular microstrip patch for two different substrates [19]

CHAPTER FOUR

LOG PERIODIC MICROSTRIP ANTENNA

4.1 Log periodic microstrip antenna Theory

The advents of broadband systems have demanded the design of broadband radiators. The use of simple, small, lightweight, and economical antennas, designed to operate over the entire frequency band of the system, would be most desirable. However, in practice all the desired features and benefits cannot usually be derived from a single radiator. On the other hand, antenna characteristics such as impedance, radiation pattern, polarization, and so forth are invariant to a change of physical size if similar change is also made in the operating frequency or wavelength; such antenna is called frequency independent antenna. However, frequency dependent antennas usually exhibit different radiation properties at different frequencies due to their physical dimensions. Variations of radiation characteristics with frequency limit the bandwidth of the antenna and thus the information carrying capacity of the communication link to which the antenna belongs.

The log periodic microstrip antenna is a more conventional approach for the implementation of a broadband antenna. The basis of this design is the linear array of coplanar patch antennas, with the size and spacing of the patches increasing in a log periodic manner. At any given

frequency throughout the designed bandwidth, there will always be a number of the patch antennas resonating and radiating within the log periodic array, thus producing the broadband characteristic.

4.1.1 Description

A log periodic antenna (LPA) is a frequency independent antenna having a structural geometry introduced by DuHamel and Isbell such that its impedance and radiation characteristics repeat periodically as the logarithm of frequency. [1][9]

As shown in Figure 4.1, the log-periodic microstrip antenna consists of several rectangular microstrip elements which have different lengths and different relative spacing elements. A microstrip transmission line type of feeder system is used to excite the individual elements. The element lengths and relative spacing, beginning from the feed point for the array, are seen to increase smoothly in dimension. This is the feature upon which the design of the LPA is based, and which permits changes in frequency to be made without greatly affecting the electrical operation. With changes in operating frequency, there is a smooth transition along the array of the elements which comprise the active region.

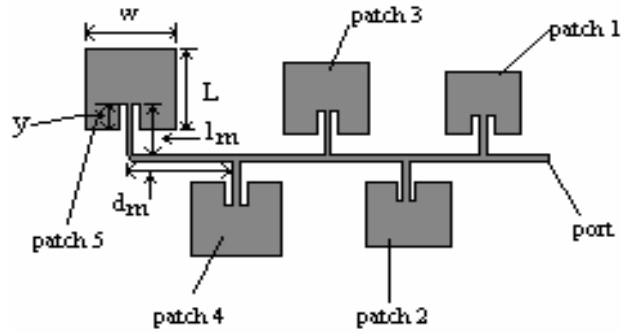


Figure 4.1 Layout for log periodic microstrip antenna of five elements

A log periodic microstrip antenna may be designed to meet the requirements at nominal cost: high gain, low VSWR. The LPA exhibits a relatively low SWR (usually not greater than 2) over a wide band of frequencies.

4.2 Analytical Evaluation of Log-Periodic microstrip Antenna

Consider an antenna whose geometry is described by spherical coordinate (r, θ, Φ) , and has feeding point set at the origin of the coordinate. Consider that the surrounding media of the antenna is homogeneous and isotropic. Thus, it is possible that to determine the antenna dimension (length along the surface and edge), r , by function of surface, $F(\theta, \Phi)$. [1]

$$r = F(\theta, \phi) \tag{4.1}$$

where r represents the length of the patch along the surface or edge

If the antenna is required to radiate to frequency that K times lower/greater than original frequency, the antenna's physical surface must be made K times greater/lower to maintain the same electrical characteristic. Thus, the new dimension of the patch can be described by:

$$r' = KF(\theta, \phi) \quad 4.2$$

Since the antenna is placed at $\theta=0$ to π -axis (stationary along θ), the new and old surfaces of antenna are identical except to ϕ . Thus, the above equation modifies as

$$KF(\theta, \phi) = F(\theta, \phi + C) \quad 4.3$$

where C is angle of rotation

The angle of rotation C depends on K but neither depends on θ or ϕ . Physical congruence implies that the original antenna electrically would behave the same at both frequencies. However, the radiation pattern will be rotated azimuthally through an angle C. For unrestricted values of K ($0 < K < \text{infinity}$), the pattern will rotate by C in ϕ with frequency without alerting the shape of antenna. Thus, the impedance and pattern will be frequency independent.

To obtain the functional representation of $F(\theta, \phi)$, it required to differentiated both sides of equation 4.3 with respect to C and ϕ

Differentiate equation 4.3 with respect to C

$$\frac{d}{dC} [KF(\theta, \phi)] = \frac{dK}{dC} F(\theta, \phi) = \frac{\partial}{\partial C} [F(\theta, \phi + C)]$$

$$= \frac{\partial}{\partial(\phi+C)} [F(\theta, \phi+C)] \quad 4.4$$

and differentiate equation 4.3 with respect to Φ

$$\frac{\partial}{\partial\phi} [KF(\theta, \phi)] = K \frac{\partial F(\theta, \phi)}{\partial\phi} = \frac{\partial}{\partial\phi} [F(\theta, \phi+C)] = \frac{\partial}{\partial(\phi+C)} [F(\theta, \phi+C)] \quad 4.5$$

Equating equation 4.5 to 4.4 and yields

$$\frac{dK}{dC} F(\theta, \phi) = K \frac{\partial F(\theta, \phi)}{\partial\phi} \quad 4.6$$

Using equation 4.1, it is possible to write equation 4.6 as follow

$$\frac{1}{K} \frac{dK}{dC} = \frac{\partial F(\theta, \phi)}{\partial\phi} \quad 4.7$$

Since the left side of equation 4.7 is independent of θ and Φ , a general solution for surface $r=F(\theta, \Phi)$ of the antenna is

$$r = F(\theta, \phi) = e^{a\phi} f(\theta) \quad 4.8$$

Where $a = \frac{1}{K} \frac{dK}{dC}$ and $f(\theta)$ is arbitrary function.

Thus for any antenna to have frequency independent characteristics, its surface must be described by equation 4.8. This can be accomplished by specifying the function $f(\theta)$ or its derivatives. [1] The equiangular spiral such as planer spiral and conical spiral is one of the geometric

configurations whose surface can be described by angles (see Figure 4.2). It fulfills all requirements for shapes that can be used to design frequency independent.

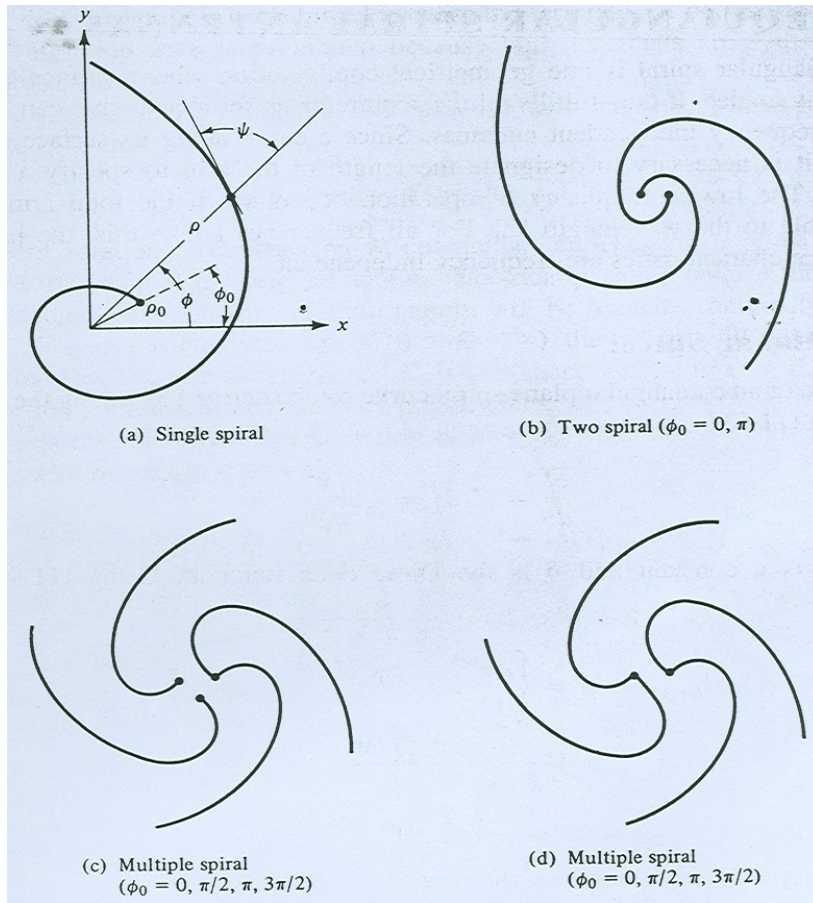


Figure 4.2 Typical Spiral Wire Antennas [1]

Since the entire shape of log-periodic antenna is not possible to describe by an angle; it is mandatory to consider the distance characteristic of the antenna while log-periodic antenna is designed. For log-periodic microstrip antenna, the distance characteristic or geometric structure ratio, τ , is defined by the ratio of frequencies which are apart to each other by a period, i.e

$$\tau = \frac{f_1}{f_2}, f_2 > f_1 \quad 4.10$$

As operating frequency f_1 is shifted to another frequency f_2 within the pass band of the antenna, where $f_2 > f_1$, the relationship can be expressed by the factor of geometric structure ratio, τ , as follow

$$f_2 = f_1/\tau \quad \text{where, } \tau < 1.0$$

Similarly, it is possible to express for all pass band frequency of the antenna using geometry structure ratio, τ

$$f_3 = f_2/\tau$$

$$f_4 = f_3/\tau$$

:

:

:

$$f_n = f_{n-1}/\tau$$

where $n = 1, 2, 3 \dots n$

f_1 = lowest frequency

f_n = highest frequency

In other words, the frequencies becomes,

$$f_n = f_{n-1}/\tau \quad f_{n-1} > f_n$$

Taking the logarithm of both sides,

$$\log f_n = \log (f_{n-1}) + \log (1/\tau) \quad 4.11$$

The above equation (4.11) shows that the performance of the log periodic antenna is periodic in a logarithmic scale which the behavior of the antenna repeats periodically with period of τ .

The geometry of a frequency independent log periodic antenna is a multiplicity of adjoin antenna element. Each antenna element is scaled in dimensions relative to the adjacent element by factor that remains constant within the structure. The elements may be two or three dimensional. If L_n represents some dimension of the n^{th} element and L_{n+1} is the corresponding dimension of the $(n+1)^{\text{th}}$ element, then the relationship between adjacent elements can be stated as [1][9]

$$\tau = \frac{L_{n+1}}{L_n} \quad 4.12$$

Thus, log periodic microstrip antenna (see Figure 4.1) whose dimension of patch length (L), width (W), inset length (y), and spacing distance (d) is related to the factor τ as follow

$$\tau = \frac{y_{n+1}}{y_n} = \frac{L_{n+1}}{L_n} = \frac{d_{n+1}}{d_n} = \frac{W_{n+1}}{W_n} \quad 4.13$$

The elements of log periodic microstrip antenna characterize as resistive (active), capacitive (directive) and inductive (reflective) region depending to the flow of current in the element (see Figure 4.3). A distributive

type of feeder system is used to excite the individual elements which has the current both real and imaginary part. The real current flowing in the resistive component of the impedance of a particular, active region, of microstrip element, but the imaginary flowing in the reactive components. (Note that each element of microstrip antenna behaves to radiate at specific frequency with in the radiating frequency range and the active element shift to a different element of the antenna depending to the operating frequency.).

The capacitive current components in smaller size elements exceed the conductive components hence; these elements receive little power from the feeder and act as parasitic directors. However, the inductive current components in larger size elements are dominant and they act like parasitic reflectors.

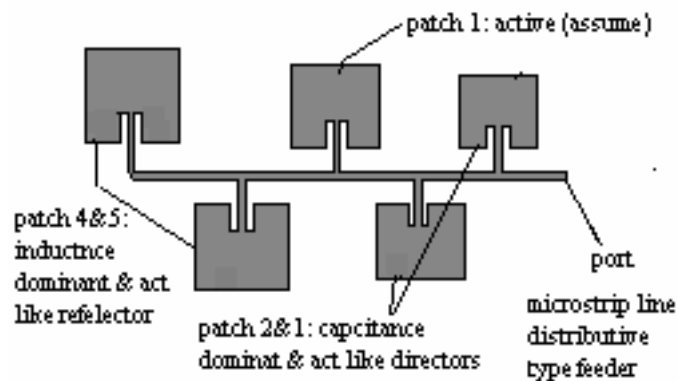


Figure 4.3 Active, director, and reflector elements of log periodic microstrip antenna

Since the log periodic antenna is frequency independent, the input impedance of the antenna behaves

periodic. A typical variation of the impedance as a function of frequency is shown in Figure 4.4. Other parameters that undergo similar variations are the radiation pattern, directivity, beam-width, and side lobe level.

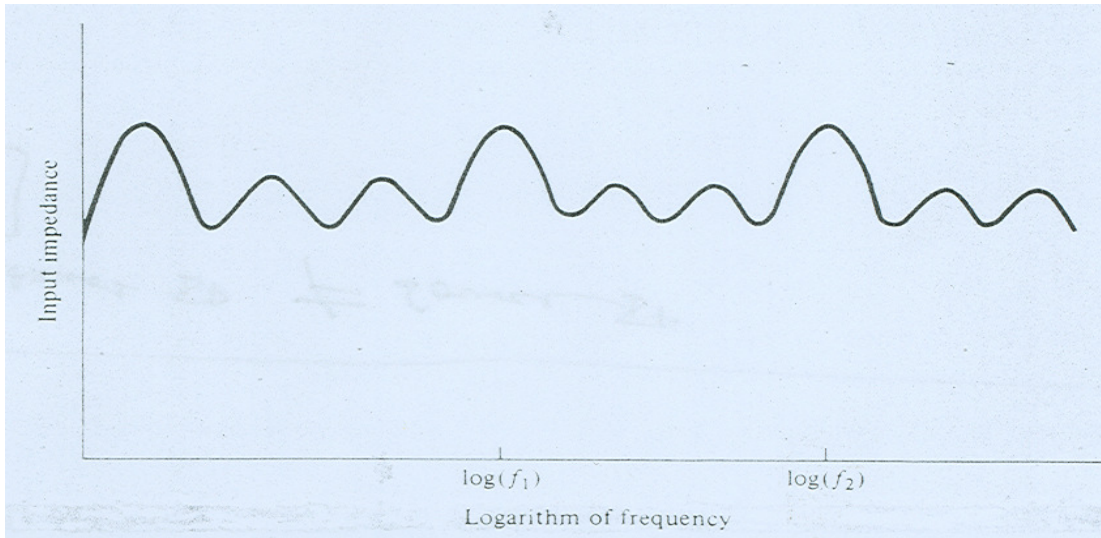


Figure 4.4 Typical input impedance variation of log periodic antenna as a function of the logarithm of the frequency [1]

4.3 Rectangular microstrip antenna design

A single element of rectangular patch antenna, as shown in Figure 4.5, can be designed for the 2.4 GHz resonant frequency using transmission line model (equations 2.6, 2.7, 2.13 and 2.20).

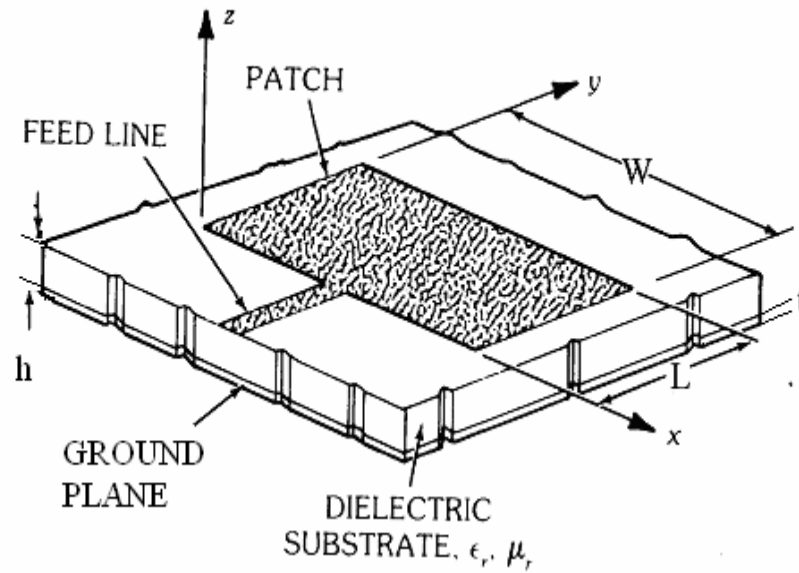


Figure 4.5 Typical rectangular patch antenna

In the typical design procedure of the microstrip antenna, the desired resonant frequency, thickness and dielectric constant of the substrate are known or selected initially. In this design of rectangular microstrip antenna, a FR4 dielectric material is selected as the substrate with 1.6 m.m height[7]. Then, a patch antenna that operates at the specified resonant frequency (2.4 GHz) can be designed by the following the flow chart shown in Figure 4.6 using transmission line model equations.

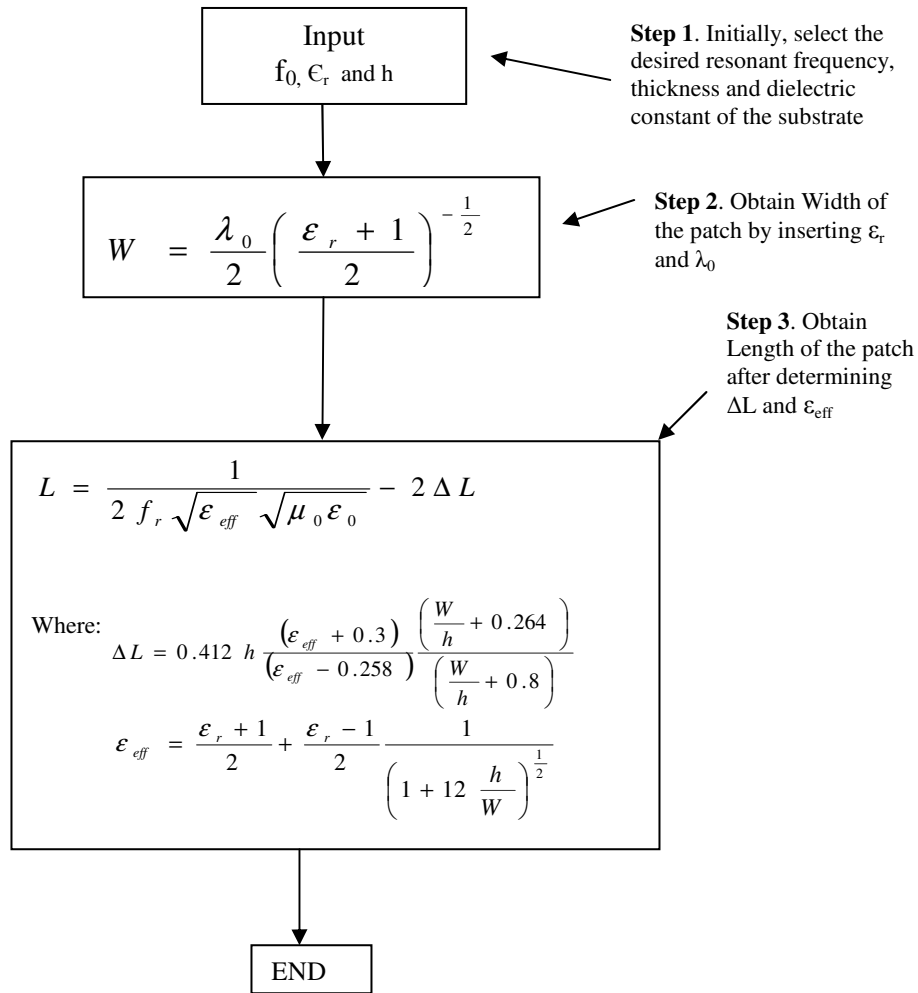


Figure 4.6 Flow chart based on usual design procedure for rectangular patch antenna

It is also possible to determine the inset length of the patch to ensure matching from the flow chart (Figure 4.7) taking the resonant wave length λ_0 , width W and length L of the patch as input.

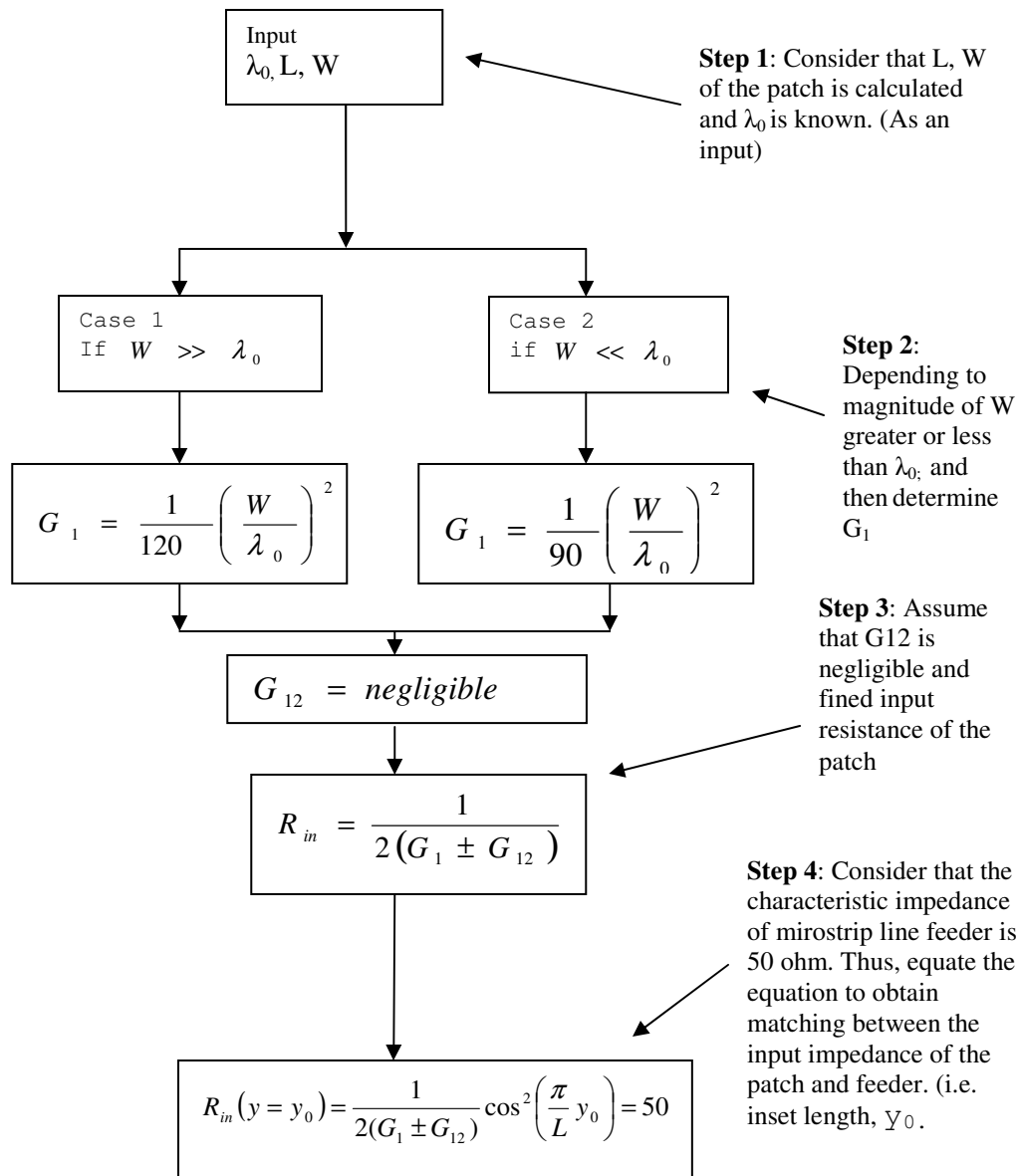


Figure 4.7 Flow chart to determine the inset length of the patch

Calculation result of rectangular patch microstrip antenna is given in Table 4.1.

Result:

Design result of single element rectangular microstrip antenna	
Width of patch, W	<i>37021μm</i>
Effective dielectric constant, ϵ_{eff}	<i>4.351</i>
Length of patch, L	<i>28498.4μm</i>
Input resistance patch, R_{in}	<i>256.5Ω</i>
Inset distance of the patch, Y_0	<i>10400μm</i>
Width size of port, W_0	<i>3000μm</i>

Table 4.1 Calculated result of monopole rectangular microstrip antenna

4.4 Log periodic microstrip antenna design

A log periodic rectangular microstrip antenna of five elements, as shown in Figure 4.8, can be designed for the 2.4 GHz resonant frequency of equation 4.13. The design principle for log periodic microstrip antenna requires scaling of dimensions from period to period so that performance is periodic with the logarithm of the frequency.

The performance of a log periodic microstrip antenna is mainly determined by the design parameter τ . The optimum

value of τ ranges between $0.8 < \tau < 1.0$. The maximum gain is achieved by using τ near to 1.0. Thus, in this five element rectangular microstrip antenna, it is chosen that $\tau = 0.95$ and the dimensions of the patch elements of the log periodic antenna are presented in Table 4.2.

The patch elements of log periodic antenna are proportionally decreased successively its size by factor of τ from the initial design of patch antenna that resonate at 2.4 GHz in order to cover the five element log periodic antenna frequency band 2.4 GHz to 2.92 GHz.

Result:

Design result of five element rectangular microstrip antenna using $\tau = 0.95$					
Patch	Resonant Frequency f (GHz)	Width W (μm)	Length L (μm)	Spacing d (μm)	Inset length y (μm)
Patch 1	2.92	30457	23445	11722	8227
Patch 2	2.77	31980	24617	12308	8638
Patch 3	2.646	33579	25848	12924	9070
Patch 4	2.52	35258	27141	13570	9523
Patch 5	2.4	37021	28498	14249	10000

Table 4.2 Calculated result of five element rectangular log periodic microstrip antenna

CHAPTER FIVE

SIMULATION

5.1 Rectangular microstrip antenna simulation

Simulation of the antenna was performed using Empire simulator to obtain computational results for the designed rectangular microstrip antenna. The simulation method is based upon the explicit solution of Maxwell's equations in FDTD.

Considering the calculated dimensions of single element rectangular microstrip antenna of Table 4.1, the performance of the antenna is simulated. The result of the simulation is presented below.

5.1.1 Physical structure

The 2D and 3D GANYMEDE editor of Empire simulator shows layout (Figure 5.1 and 5.2) of the physical structure of the single element rectangular antenna after calculated dimensions are fed.

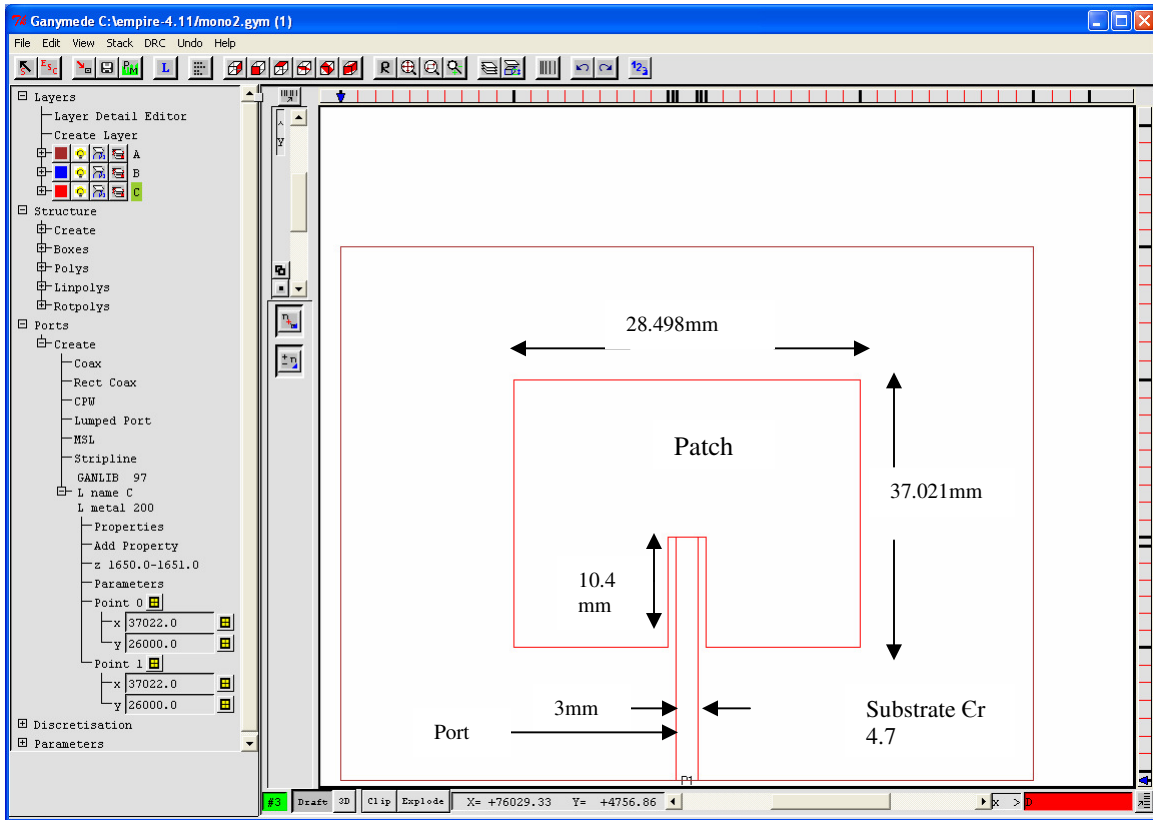


Figure 5.1 Top view of the single element patch antenna (2D)

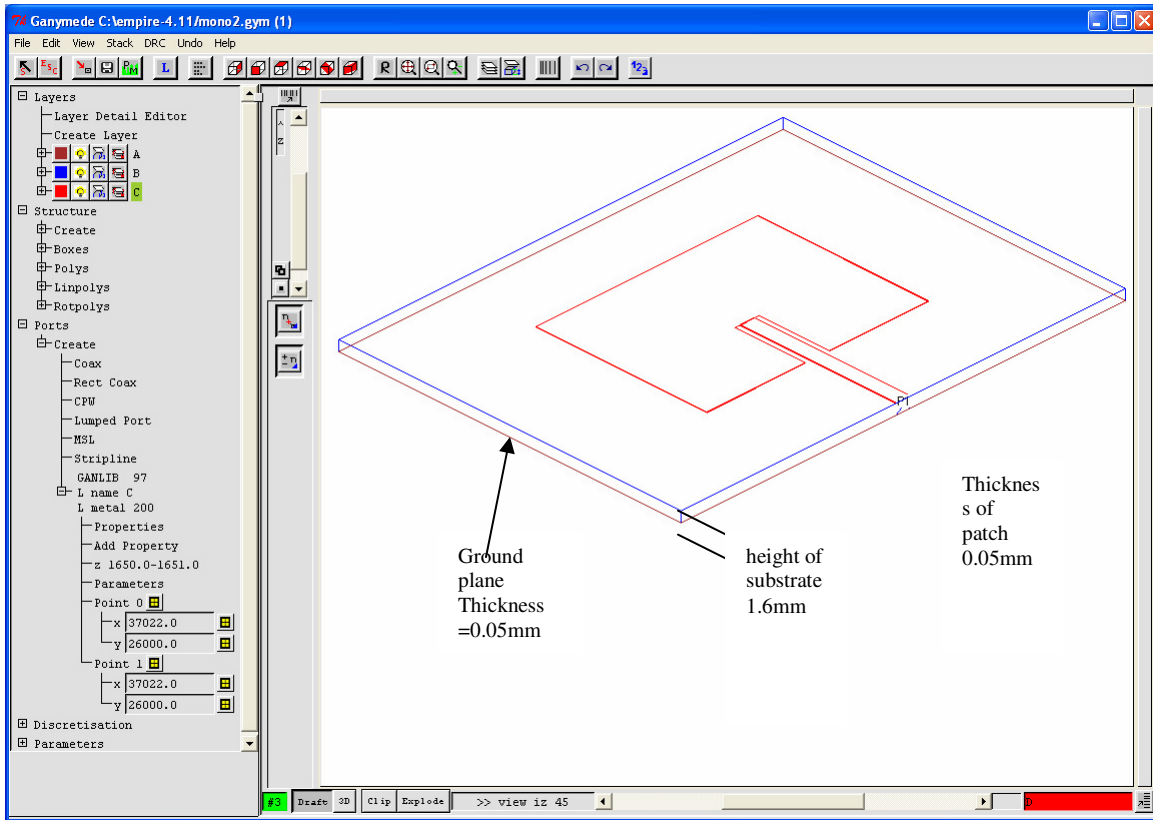


Figure 5.2 Single element patch antenna of 3D

5.1.2 Scattering parameter

The simulated result of S_{11} scattering parameter of single element microstrip antenna is presented in Figure 5.3. From the figure, the antenna has almost 2.4 GHz resonant frequency and it has 60Mz bandwidth at 10 dB (the difference of 2.43 GHz and 2.37 GHz). In percentage, the bandwidth of the antenna is 2.5%.

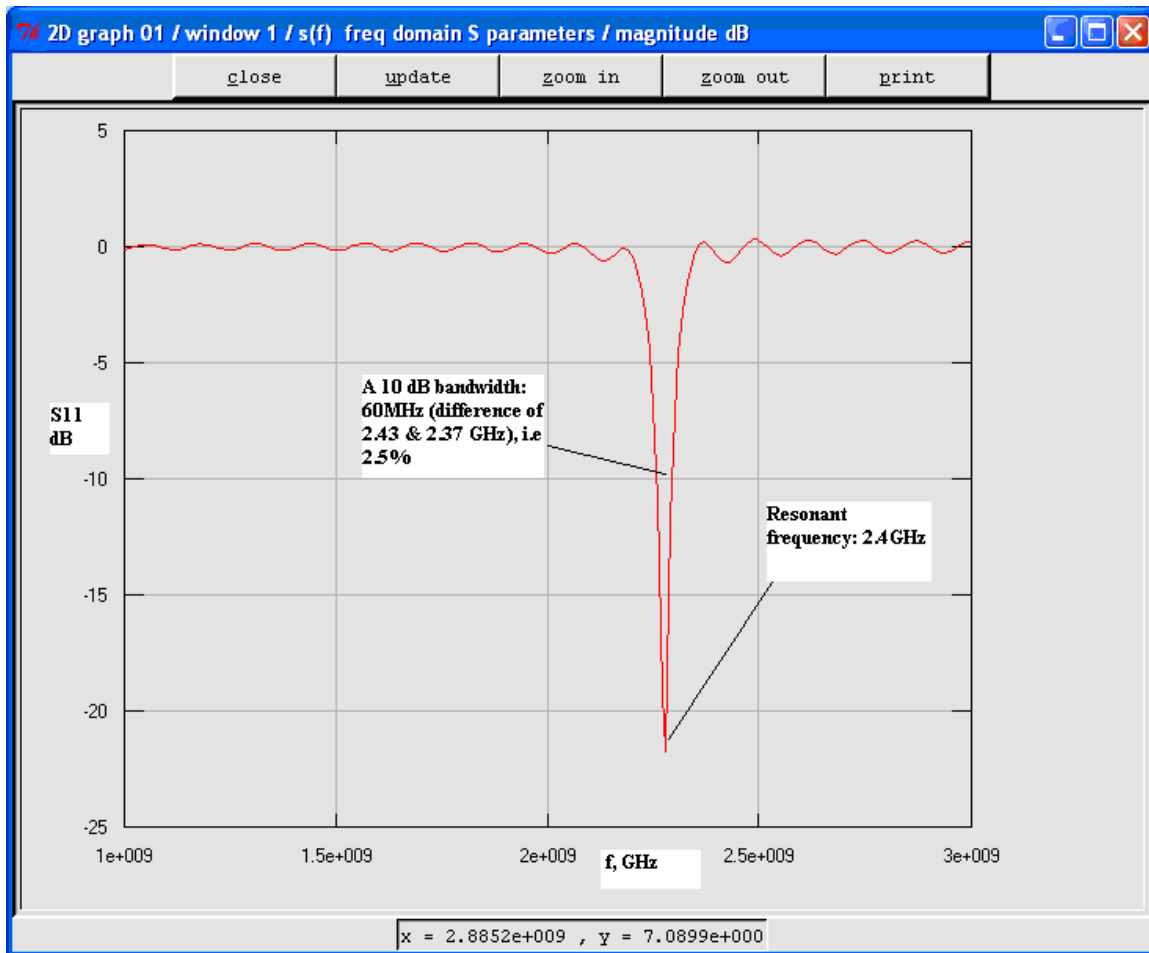


Figure 5.3 Frequency versus magnitude (dB) S_{11} of single element patch antenna

5.1.2 The Smith chart plot

The Empire simulator also provides smith chart plot of patch antenna. The result indicates that the line impedance magnitude of the patch antenna intersects the unit circle of the smith chart. A load whose lines of magnitude cross a unit circle, where reflection coefficient $|\Gamma|$ is zero, confirms no reflected power due to of mismatching. (The matching technique used in the design is Inset method.)

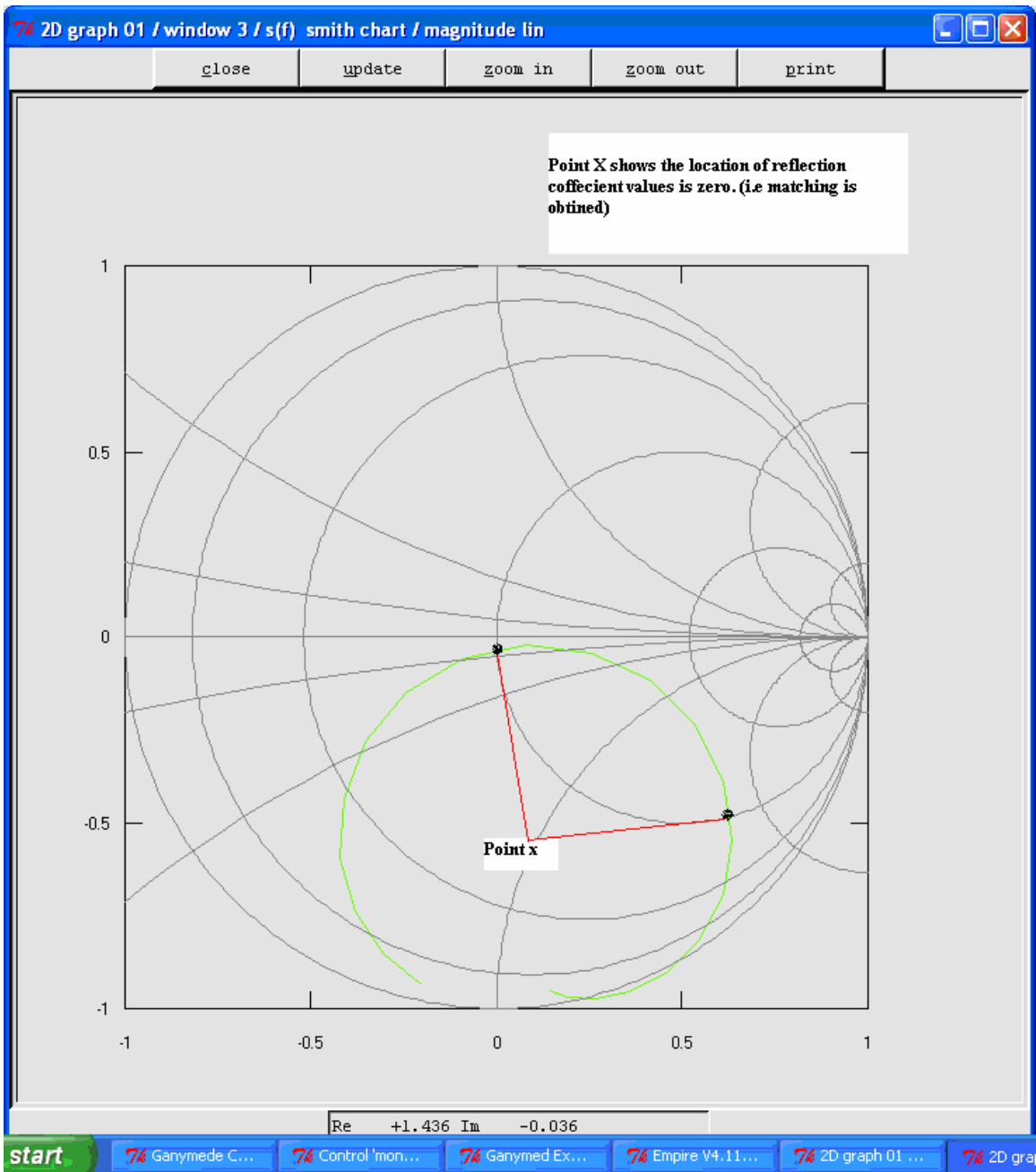


Figure 5.4 Single element patch antenna matching point

5.2 Log periodic microstrip antenna simulation

The five element rectangular log periodic microstrip antenna was simulated using Empire simulator by considering the design values of antenna (Table 4.2). The result of the simulation is presented below.

5.2.1 Physical structure

Similar to rectangular microstrip antenna, the physical structure of five element log periodic rectangular microstrip antenna is presented in Figure 5.5 and 5.6. Each element of log periodic microstrip antenna is active at specific log frequency without varying characteristic of the antenna. Of course, the dimension of elements is a multiple of design parameter, $\tau = 0.957$.

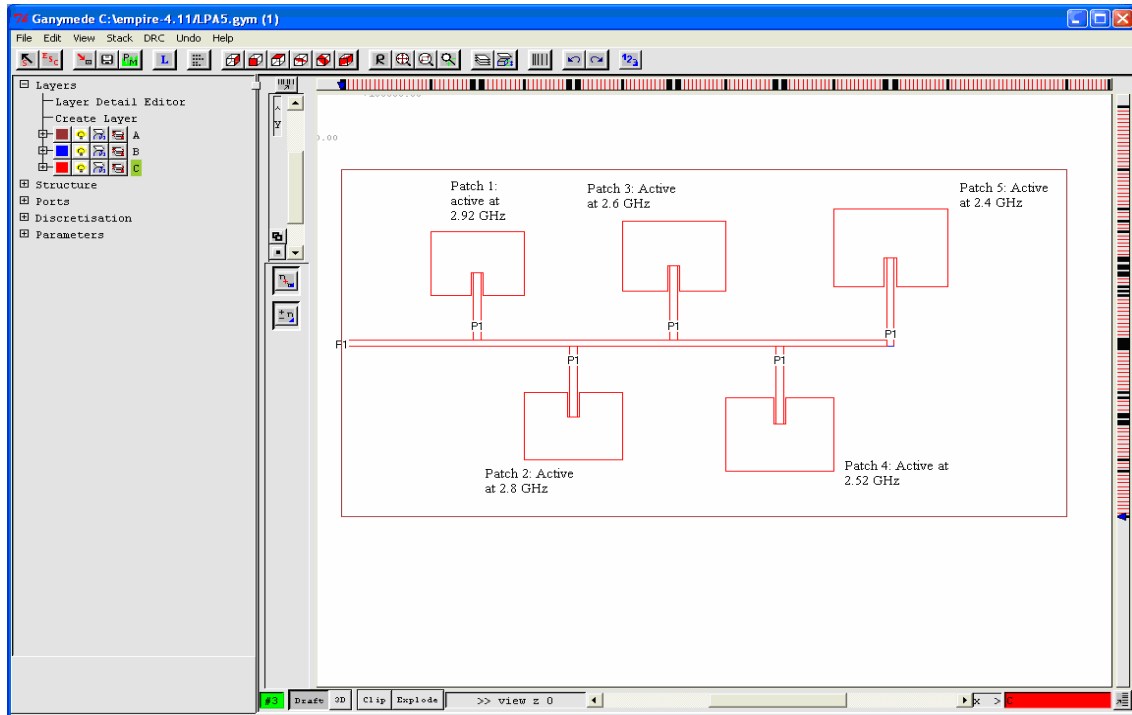


Figure 5.5 Top view of five element rectangular log periodic microstrip antenna

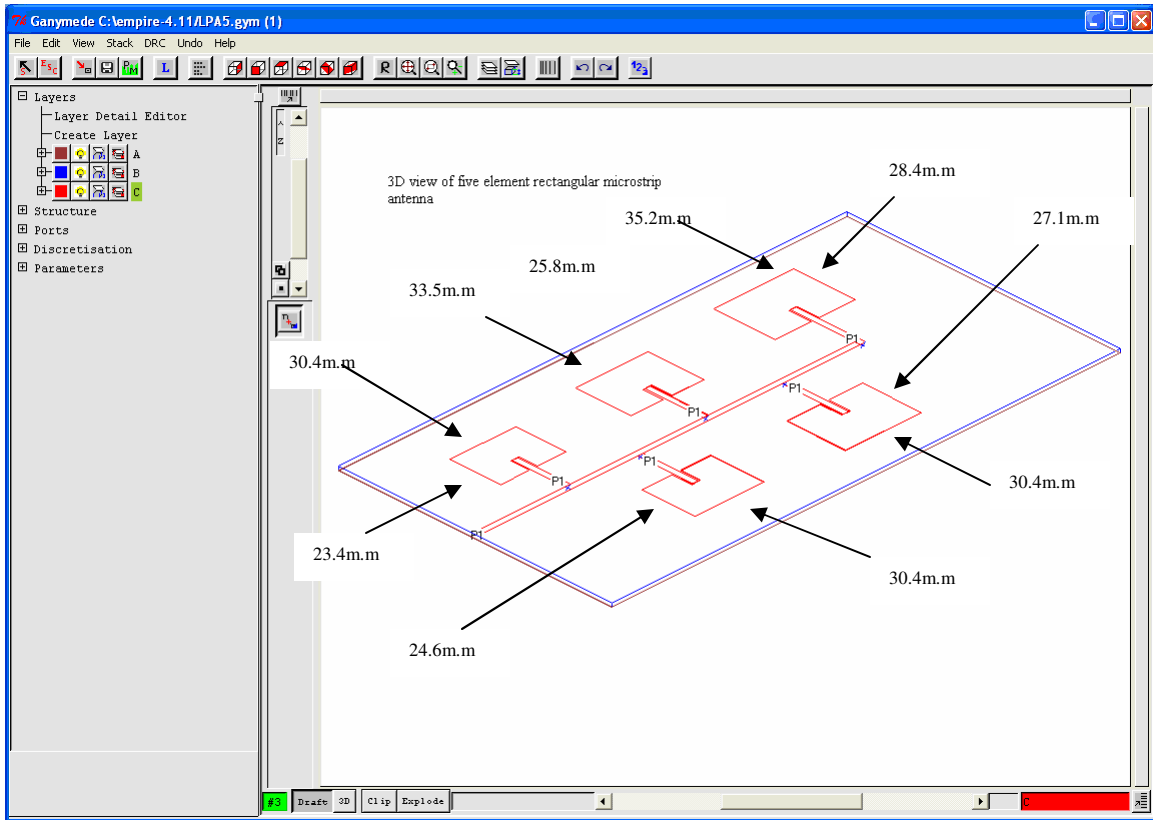


Figure 5.6 3D of five element rectangular log periodic microstrip antenna

5.2.2 Scattering parameter

The scattering parameter, S_{11} of the five element rectangular microstrip antenna is given in Figure 5.7. Since the antenna is designed for the range of frequency starting from 2.4GHz to 2.4GHz. Thus, the scattering parameter, S_{11} has desired values about 2.65 GHz to 3 GHz. i.e. bandwidth of the log periodic antenna has been extended in the frequency range of 350 MHz (difference of 3 GHz and 2.65 GHz). In percentage, it is 13.2%.

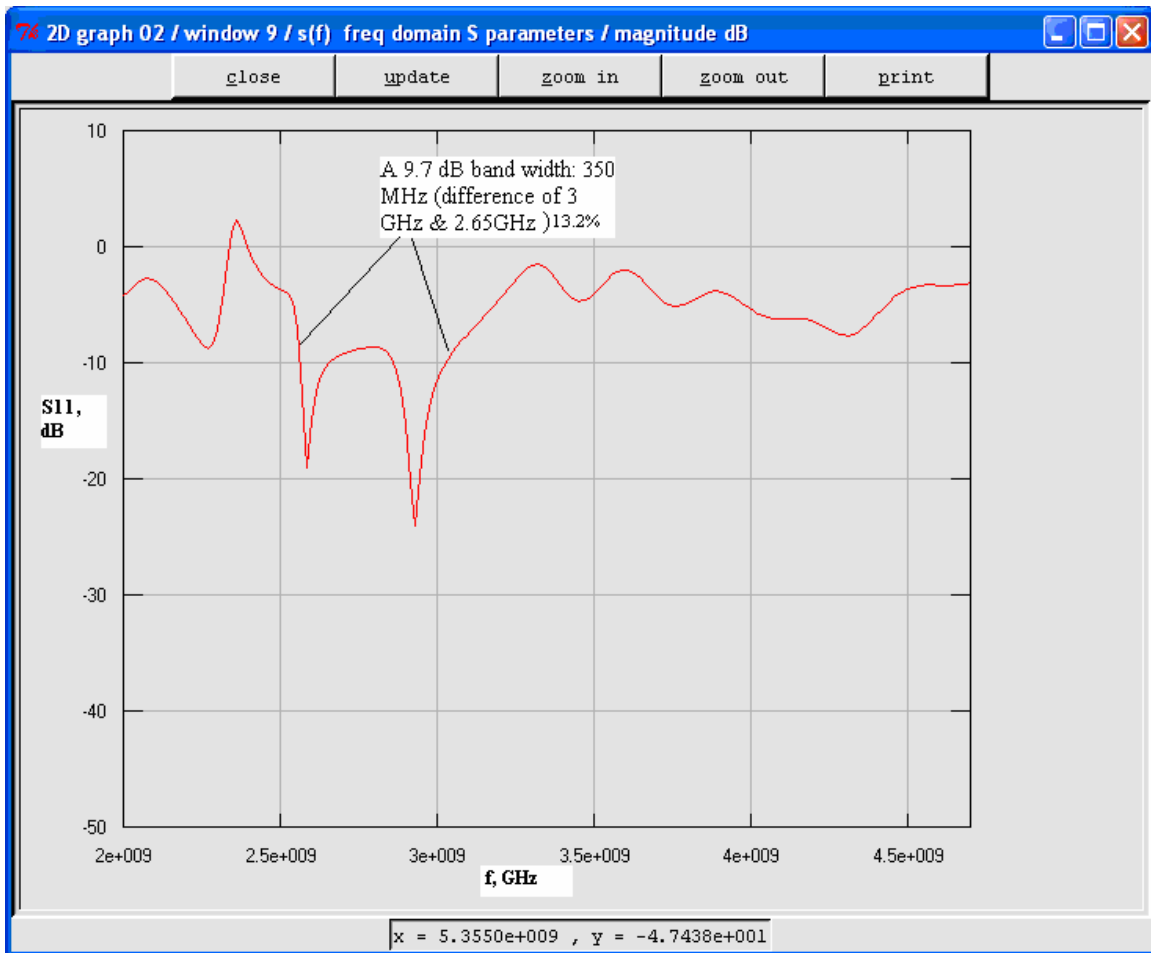


Figure 5.7 Frequency versus magnitude (dB) S_{11} of single element patch antenna

5.2.3 The Smith chart plot

The simulation shows (see Figure 5.8) that impedance lines of Log periodic microstrip antenna intersect the unit circle of the smith chart in the frequency range of 2.3 GHz - 3.5 GHz. It cross a unit circle, where the reflection coefficient $|\Gamma|$ is zero, confirms no reflected power due to mismatching. (The matching technique used in the design is Inset method.)

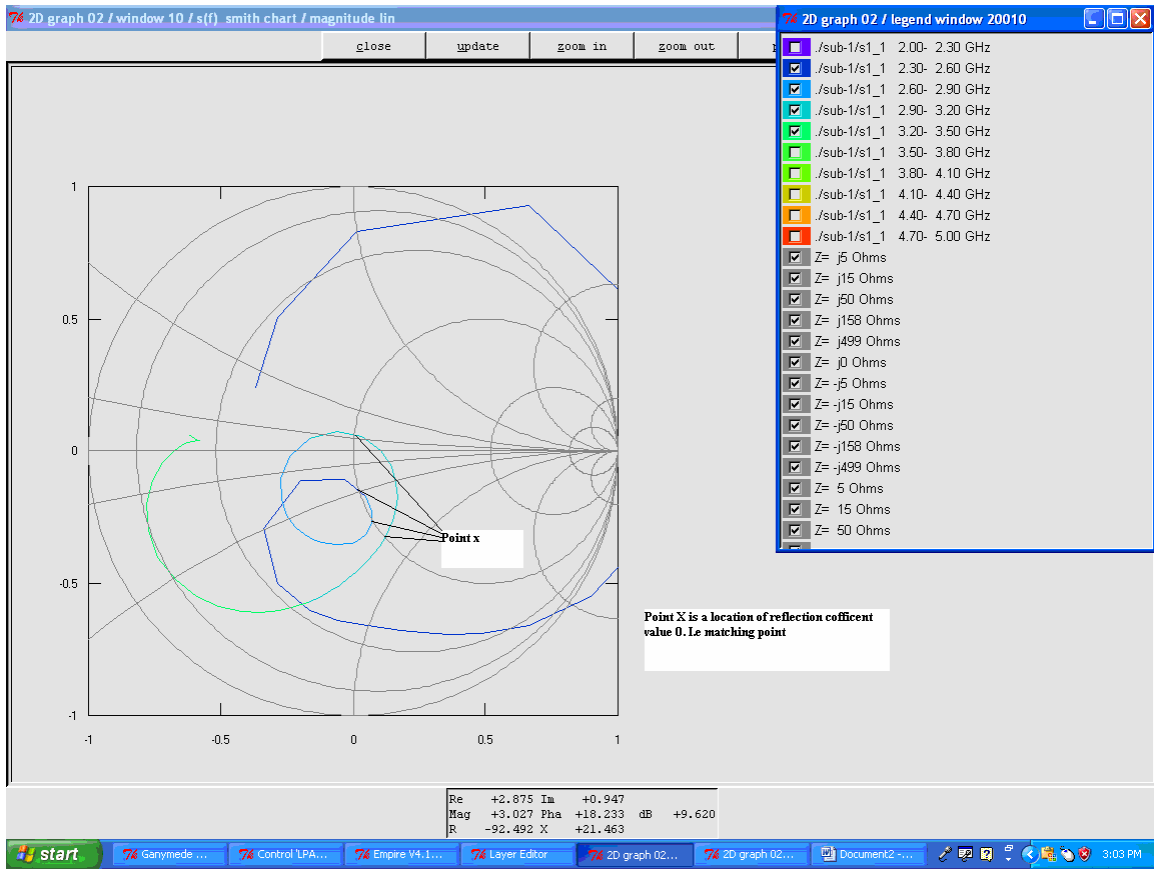


Figure 5.8 Log periodic patch antenna matching point

5.3 Comparison of typical rectangular microstrip antenna and five element log periodic rectangular microstrip antenna

Performance comparison of both the single and the five element rectangular microstrip antennas are presented in tabular form below.

Parameters	Typical Rectangular microstrip antenna	Log periodic microstrip antenna
Operating frequency range	<i>2.43GHz to 2.37GHz</i>	<i>2.64GHz to 3GHz</i>
Bandwidth	<i>60MHz (2.5%)</i>	<i>350MHz (13.5%)</i>
Input impedance	<i>50 ohm</i>	<i>50 ohm</i>
Matching	<i>Yes</i>	<i>yes</i>
Maximum Gain	<i>Maximum 20dB</i>	<i>Maximum 24dB</i>
Gain range	<i>Between 20 to 10 dB</i>	<i>Between 24 to 9.7 dB</i>

Table 5.1 Performance comparison of typical rectangular microstrip antenna and five element log periodic microstrip antenna

CHAPTER SIX

CONCLUSION AND SUGGESTIONS

6.1 Conclusion

Two aspects of microstrip antennas have been studied in this thesis. The first aspect is the design of typical rectangular microstrip antenna and the second is the design of five element log periodic microstrip antenna. A simple and efficient technique of inset method has been introduced for an impedance matching improvement of the antennas. The thesis main concern is to study the bandwidth improvement of the microstrip antenna.

The log periodic microstrip antenna is a more conventional approach for the implementation of a broadband antenna. The basis of this design is the linear array of coplanar patch antennas, with the size and spacing of the patches increasing in a log periodic manner. Initially, single element rectangular microstrip antenna is design to operate at frequency 2.4 GHz. And then, the five element log periodic microstrip antenna is design to resonate at frequency range 2.4 GHz to 2.92GHz. The smallest patch is designed to resonate at 2.92 GHz and the biggest patch to be resonating at 2.4 GHz (the factor τ is 0.95).

Using log periodic technique, a bandwidth of microstrip antenna can be increased by 13.5% (considering five element log periodic). This bandwidth is sufficient to

accommodate multimedia services that useful for portable devices.

6.2 Suggestions for Future Work

Based on gathered observations while completing this thesis; topics were identified which would benefit for further investigation.

1. Circular Log periodic Microstrip Antenna

- 1) Using the log-periodic microstrip antenna as a basis, the circular log-periodic microstrip antenna can be developed. To maintain the same relative distance, in terms of wavelength, between the corresponding radiating elements in each branch, the "spokes" of the antenna are arranged around the circumference. As shown in Figure 6.1, the antenna model that consist four spokes with the corresponding element between the branches separated by half a wavelength has larger return loss of over linear rectangular periodic antenna. [2]

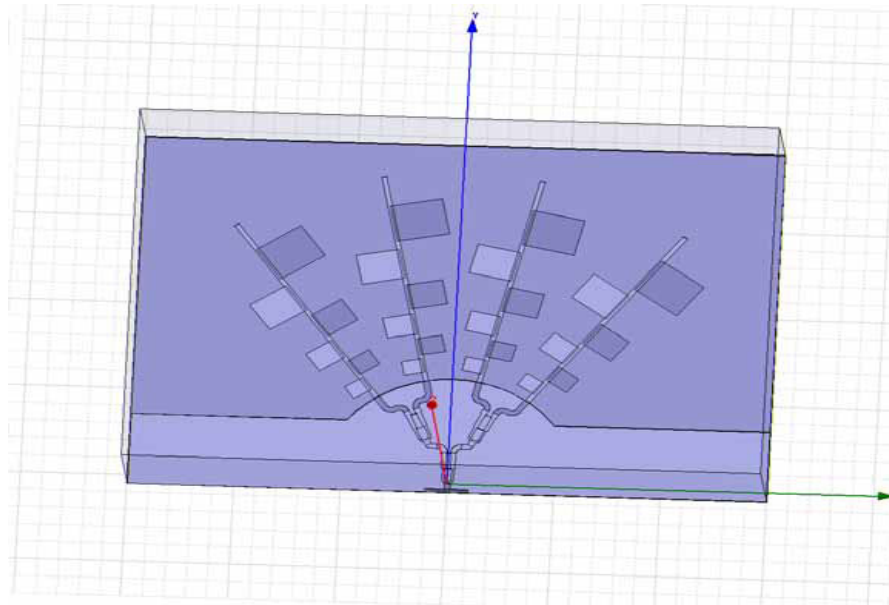


Figure 6.1 The 4-spoke circular log-periodic microstrip antenna

2. Further investigations in the current design

Further investigations into the current design are required to study the effect of mutual coupling between elements when they are configured in an array. The current design of a log periodic microstrip antenna is promising in terms of providing wideband performance. A number of possible changes to the current design need to be explored towards achieving the above objectives. Some of the suggested improvements to the current design are:

- a. **Feed Arrangement:** In the current design of the radiating element, the radiating patches use a microstrip transmission line as a feeder. It is envisaged that proximity feed or slot coupled arrangement of feeding power to the radiating

patches could improve the overall performance of the antenna over the desired wideband.

b. **Variation of Substrate Permittivity:** During the design of radiating element to improve the bandwidth; spurious radiations in the lower frequency band is expected from the smaller patches of the antenna. It is suggested that a careful examination of variation in the permittivity of the substrate and optimization of radiating patch size needs to be undertaken for suppressing the spurious radiations.

REFERENCES

- [1] C.A. Balanis, *Antenna Theory*, 2nd Ed., John Wiley & Sons, Inc., New York, 1982
- [2] Ross Kyprianou, Bobby Yau, and Balanis, "Investigation into Novel Multi-band Antenna Design", Defence Science and Technology Organization, Australia, 2006
- [3] S.J. Orfanidis, *Electromagnetic & Antenna*, Norwood, Mass. Artech House, 2004
- [4] C.A. Balanis, *Advanced Engineering Electromagnetics*, John Wiley & Sons, New York, 1989
- [5] E.O. Hammerstad, "Equations for Microstrip Circuit Design," Proc. Fifth European Microwave Conference, page 268-272, 1975
- [6] I.J. Bahl and P. Bhartia, *Microstrip Antennas*, Artech House, Dedham, MA, 1980
- [7] *Microstrip Patch Antennas, A Designer's Guide*, by Rodney B. Waterhouse, 1999
- [8] Stutzman and Thiele, *Antenna Theory and Design*, 2nd ed: John Wiley & Sons, Inc., 1998.
- [9] Pozar and Schaubert, "Microstrip Antennas," Proceedings of the IEEE, vol. 80, 1992
- [10] Stutzman and Thiele, *Antenna Theory and Design*, 2nd ed: John Wiley & Sons, Inc., 1998.
- [11] Macnamara, T. *Handbook of Antennas for EMC*. Norwood, Mass. Artech House
- [12] Zurcher, J.-F., et al. *Broadband Patch Antennas*. Norwood, Mass. Artech House

- [13] A.G Derneryd, *A Theoretical Investigation of the Rectangular Microstrip Antenna Element*, IEEE Trans. Antenna Propagation, Vol. 26, No. 4, page 532-535
- [14] W.F. Richards, *Antenna Handbook: Theory, Application, and design*, Chapter 10, microstrip antenna
- [15] Bhartia P., *Millimeter-Wave Microstrip and Printed Circuit Antennas*. Norwood, Mass. Artech House 1991
- [16] James J.R., P.S. Hall and C. Wood. *Microstrip Antenna Theory and Design*. London, United Kingdom. Peter Peregrinus 1981., pp 87-89
- [17] P.S. Hall, "Multioctave bandwidth log-periodic microstrip antenna array," *IEE Proc.*, vol.133, Part H, pp127-136, April 1986.
- [18] W.F. Richards, J.R. Zinecker, R.D. Clark, Taylor and Francis, *Electromagnetics*, Vol.3 No. 3 and 4, p.33,
- [19] D.M. pozar, *microstrip antenna*, Proc. IEEE. Vol. 80, No.1, January 1992

APPENDIX

I. Overview of Empire simulator

Empire is the leading three dimension 3D electromagnetic field simulator. It is based on the powerful Finite Difference Time Domain Method (FDTD), which to solve Maxwell's equations. Empire includes specially modified algorithms and methods for efficient utilization of multiple floating points and caches to achieve ultra fast solution times and excellent accuracy. The FDTD method employs an efficient time stepping method to simulate the RF and microwave parameters including scattering and radiation patterns without limitation shape and material distribution of the structure.

Finite Difference scheme discrete the structure into cells in which the material properties are constant. These cells are formed by intersecting planes of a Cartesian co-ordinate system. The basic idea of the algorithm is to place the unknown field components in a certain position of each cell so that every electrical field component is surrounded by four circulating magnetic field components as shown in Figure A, and approximate Maxwell's differential equations.

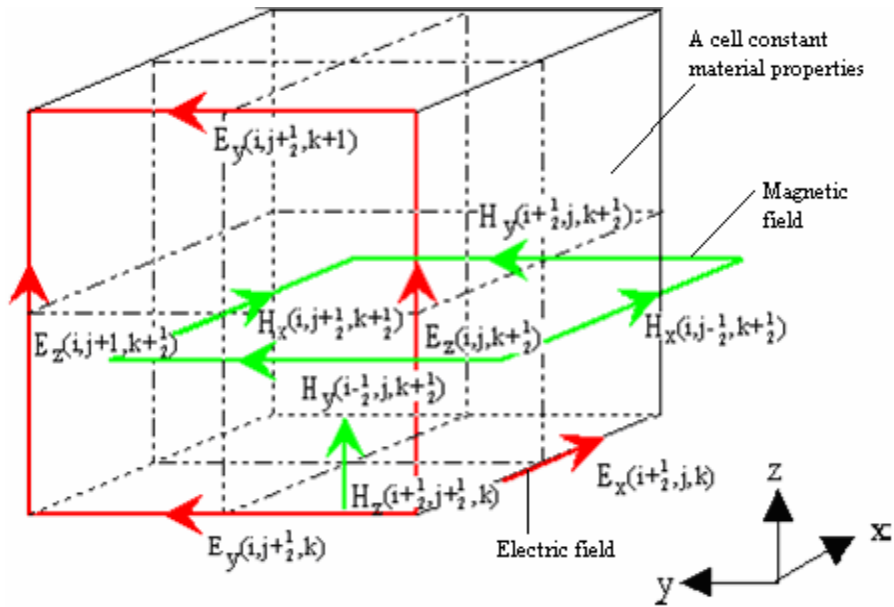


Figure A Empire simulator and Finite Difference scheme

The 3D-editor (GUI) GANYMEDE is included in the Empire basic package. AutoCAD, the well-known mechanical desktop program, can be used, too, allowing for technical drawings to be used as a base. Monitoring and animation capabilities give physical insight into electromagnetic wave phenomena while accurate results are obtained with little effort.

Some of the main applications of the Empire simulator are listed below:

- ✓ Planar and multi-layered circuits including layout synthesis
- ✓ Microwave passive components

Basic Features of the Empire simulator:

- ✓ Advanced 3D editor with layout feature
- ✓ Library elements for line and port definition

- ✓ Parameter variation capability
- ✓ Condensed ports for embedding active devices
- ✓ State of the art boundary conditions
- ✓ Arbitrarily shaped waveguide termination
- ✓ Smart signal processing
- ✓ Near and far field plots
- ✓ 3D visualization and animation
- ✓ Automatic post processing
- ✓ Diagrams, Smith charts, polar patterns
- ✓ Support delivered by experienced RF-engineers

Broadly, the most important results when analyzing RF and microwave elements with a field Empire simulator are scattering parameters, representing reflected and transmitted waves at the ports. Therefore, a single element rectangular microstrip and five element log periodic microstrip antennas are going to simulate using Empire basically scattering to analyze radiating behavior of the antennas.

II. Scattering parameter

Linear one-port (like antenna) and other multi-port networks are characterized by a number of equivalent circuit parameters, such as their transfer matrix, impedance matrix, admittance matrix, and scattering matrix.

One-port scattering matrix is described by A.1

$$b_1 = S_{11}a_1$$

A.1

In practice, microwave frequencies of input impedance $Z_0 = 50 \text{ ohm}$ is modeled by the scattering matrix. A typical network analyzer including Empire simulator can measure S-parameters over a large frequency range from 50 MHz to 40 GHz. Frequency resolution is typically 1 Hz and the results can be displayed either on a Smith chart or as a conventional gain versus frequency graph.

The actual measurements of the S-parameters of the antenna are made by achieving match of the network i.e, $Z_L = Z_0$. Then, the S-matrix equations will give:

$$s_{11} = \left. \frac{b_1}{a_1} \right|_{z_L=z_0} = \text{reflection coefficient} \quad \text{A.2}$$

The traveling wave can also be expressed in simpler form:

$$b_1 = \Gamma_{in} a_1 \quad \text{A.3}$$

where Γ_{in} is reflection coefficient at input of the antenna

In general sense, it is possible to express power flow and system stabilities of the one-port by S parameters. Power flow into and out of the one-port is expressed very simply in terms of the traveling wave amplitudes but in order to have unconditional stability, the stability regions must contain the unit-circle in its entirety.

DECLARATION

I, the undersigned, here by declare that this thesis is my original work performed under the supervision of Dr.ing. Mohammad Abdo has not been presented as a thesis for a degree program in any other university and all source of materials used for the thesis are duly acknowledged

Name: Maare Mekonen

Signature: _____

Place: Addis Ababa

Data of submission: _____

This thesis has been submitted for examination with our approval as university advisor.

Dr.ing. Mohammad Abdo

Signature: _____

Addis Ababa

Ethiopia

March, 2008

CHAPTER 1.
