UHF MICROSTRIP ANTENNA DESIGN AND SIMULATION

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JAN/BSTE/18

ABSTRACT

This paper presents a design studies in the development for a lightweight, low volume, low profile planar microstrip antenna in the application for a military band short range radio communication system (UHF), at a frequency range of 200Mhz - 400Mhz. Currently, most military aviation platforms are equipped with UHF communication system for their operational requirements. As most conventional communication antennas fitted onboard the aerial platforms are dipole-type and these antennas are located on the external structure of the platforms, this protruding antenna configuration will increase the aerial platform's radar cross section (RCS) significantly as these antenna fins will act as a radar reflector. Antenna size is dictated by its operating frequency and the lower the frequency, the larger the antenna. In addition, these antennas will also affect the aerodynamics and handling of the aerial platforms. Altering the antenna size would be more cost-effective than other measures to improve aerodynamics, which may inadvertently affect radar, visual or any other signatures of the aircraft.

As microstrip antennas have several advantages compared to conventional microwave antennas, these can be used to replace the antenna currently onboard the platforms. The microstrip antenna can also be made low profiled and conformal to fit on each individual platform, hence reducing or even eliminating antenna visual and radar signatures and increasing platform survivability significantly. However, the main disadvantage of the microstrip antennas is the narrow bandwidth.

Hence, in this paper, bandwidth enhancement techniques such as use of thick substrate with low relative dielectric constant (ε_r), size of antenna, short circuit antenna as well as U- slotted patch antenna are discussed and explained.

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INTRODUCTION

1.1 Background

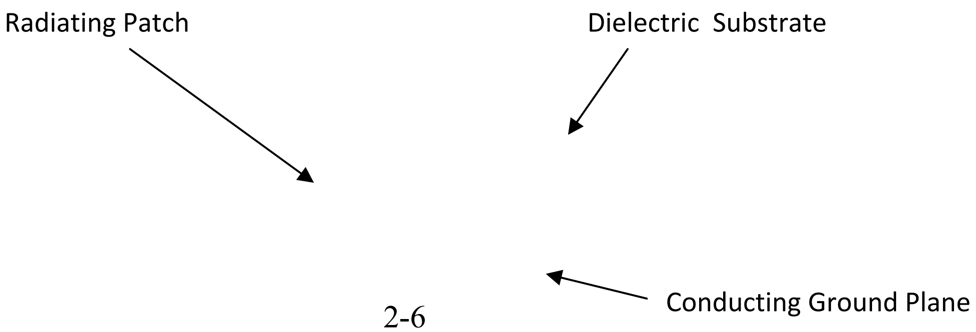
1.1.1 Radio Antenna

The antenna is usually the last element considered when designing a RF equipment. However, in a wireless link environment, the transmitting and receiving antenna are directly involved to achieve the desired overall performance.

An antenna is a conductive element which converts electrical energy into an electromagnetic field in the transmitter, or converts an electromagnetic field into electrical energy in the receiver. An important feature is the property of reversibility; the same antenna can be used with the same characteristics as a transmitter or as a receiver antenna [1]. An antenna is characterized by its center frequency, bandwidth (BW), polarization, gain, radiation pattern and impedance [1].

1.1.2 Introduction to Microstrip Antenna

The concept of microstrip antenna dates back to the 1950's, but it was not until the 1970's that greater emphasis was given to develop this technology. This is mainly due to the availability of good substrates. Since then, extensive research and development of microstrip antenna and arrays, exploiting the numerous advantages such as light weight, low volume, low cost, planar configuration, compatibility with integrated circuits, have led to diversified applications and to the establishment of the topic as a separate entity within the broad field of microwave antennas [3].



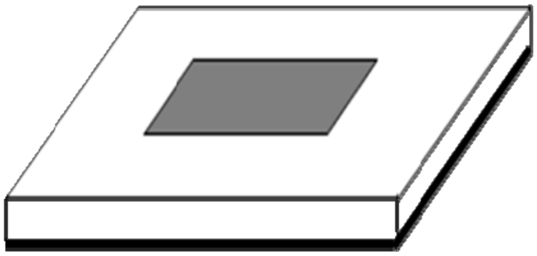


Figure 1 Basic features of Patch Antenna

1.1.3 <u>Advantages and Disadvantages of Microstrip Antennas</u>

Microstrip antennas have several advantages compared to conventional microwave antennas and therefore many applications over the broad frequency range from ~100 MHz to ~100 GHz. Some of the principle advantages of microstrip antennas compared to conventional microwave antenna are [2][3]:

- **lightweight**, **low volume**, low profile planar configurations which can be made conformal
- **low fabrication cost** using print circuit (photolithographic) techniques; readily amenable to mass production
- can be made thin; hence they do not perturb the **aerodynamics** of host aerospace vehicles
- simple array readily created
- Linear and circular polarisation easy to implement by position of feed
- Dual frequency use is possible
- Solid-state devices easily integrated
- Feed lines and matching fabricated with antenna

However, microstrip antennas also have some disadvantages compared to conventional microwave antennas including:

- **narrow** bandwidth
- **low efficiency** (lower gain) at higher frequencies
- spurious feed radiation
- poor polarization purity

- limited power handling capacity (~100W)
- associated tolerance problems
- possibility of excitation of surface waves

While it may not be possible to entirely eliminate all the limitations; there are ways to minimize their effects. For example, bandwidth can be increased by special loading techniques, lower gain and power handling limitation can be overcome through an array configuration. Poor efficiency can be overcome by the use of photonic bandgap structures.

1.2 Problem Definition

The two most serious limitation of the microstrip antennas are its narrow bandwidth and low gain. The requirement for a low volume and low profile in the antenna further deteriorates these two parameters. This is because of the fact that there is a fundamental relationship between the size, bandwidth and efficiency of an antenna. As antennas are made smaller, either the operating bandwidth or the antenna efficiency must decrease. The gain is also related to the size of the antenna, which is small antenna typically provides lower gain than larger antenna.

Till date, with the key design considerations such as the size reduction, together with the bandwidth and gain enhancement in wireless communication, many researchers have developed various techniques to enhance the bandwidth and gain of the microstrip antenna and some of the techniques are loading of high permittivity dielectric superstrate, stacked configuration and slotted patch antenna. The use of the superstrate loading technique helps to increase the radiation efficiency. Stack configuration with 2 patches, driven and parasitic, and 2 substrates are used to enhance the gain and increases the bandwidth of the antenna ranging from 10-20%. The patch loaded with slots like the U-slotted patch also can be used to enhance the bandwidth by 10-40%.

1.3 Solution Employed

As stated in [2] and [3], rectangular and circular patch antennas are widely used with a typical gain between 5 and 6 dB and exhibit a 3-dB beamwidth between 70° and 90°.

These 2 types of patches are the most basic and commonly used microstrip antennas and they can be used for the simplest and most demanding applications.

When comparing both the rectangular and circular disk microstrip antennas which are operating at the same frequency and with the same substrate parameters, the directivity and efficiency are found to be the same for both antennas. Although the circular disk antenna has a smaller beamwidth in both horizontal and vertical planes, and is 16% smaller than the rectangular antenna, the rectangular antenna has a better bandwidth characteristic (almost 2 times) as compared with the circular disk antenna.

With the application of an UHF antenna in mind, the design of the antenna will be focused mainly on the microstrip patch antenna (MPA). A MPA consists of a conducting patch of any planar or nonplanar geometry on one side of a dielectric substrate with a ground plane on the other side. The MPA has some slight advantages in its characteristics when compared with the rest in terms of the ease of fabrication, flexibility in shape as well as the higher bandwidth (2-50%) [3].

Hence, as aim of this project is to design a UHF microstrip patch antenna, that operates at 200-400MHz, and for the purpose of this project research and in relation to the time available for the project, the rectangular microstrip antenna is chosen as it is by far the most widely used configuration in microstrip antenna design. In addition, this configuration has been used as a basic standardized design by many designers before applying to other geometric shapes. In addition, part of the research is also to study ways to enhance the bandwidth of the antenna using technique like quarter wavelength (short circuit) microstrip antenna and U-slotted patch antenna.

CHAPTER 2

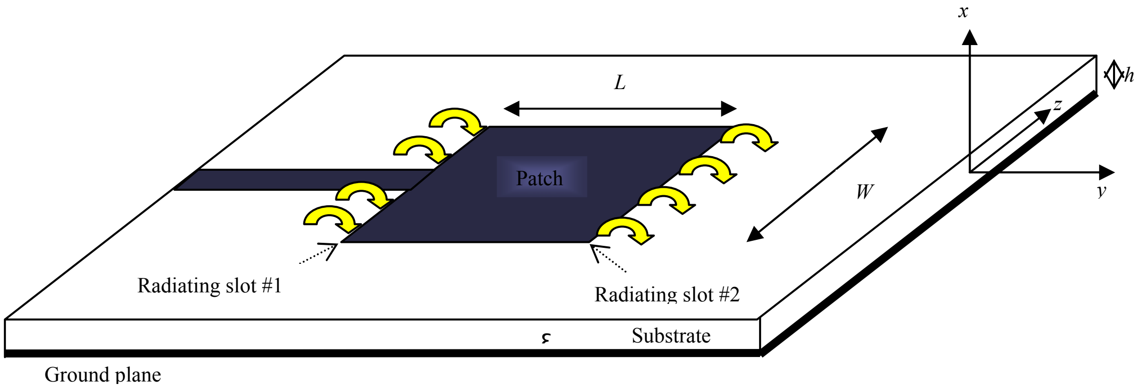
LITERATURE REVIEW

2.1 Microstrip Antenna Configuration

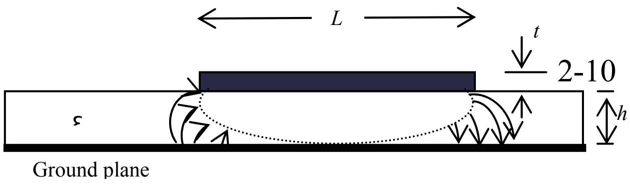
2.1.1 Rectangular Patch Microstrip Antenna

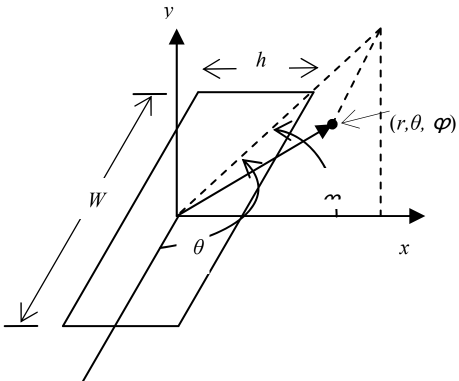
Microstrip antennas are characterized by a larger number of physical parameters than a conventional microwave antenna. All microstrip antennas can be divided into four categories: microstrip patch antennas, microstrip dipoles, printed slot antennas and microstrip traveling-wave antennas [2][3]. As shown in Figure 2.1, this basic antenna element consists of a very thin ($t \ll \lambda_o$) metallic strip (patch) placed a small fraction of a wavelength ($h \ll \lambda_o$) above a ground plane. The strip (patch) and the ground plane are separated by a dielectric substrate. The length L of the element is usually $\lambda_o/3 < L < \lambda_o/2$.

Figure 2.1 Rectangular patch microstrip antenna



(a) Microstrip antenna





2.1.2 Substrates Characteristics

There are many substrates that can be used for the design of microstrip antennas, and their dielectric constants (ε_r) are usually in the range of $2.2 \leq \varepsilon_r \leq 12$. Thick substrates are most desirable for antenna performance as their dielectric constants are in the lower end, which provide **better efficiency**, **larger bandwidth**, loosely bound fields for radiation into space (better radiation power). However, these are achieved at the expense of larger element size, increase in weight, dielectric loss, surface wave loss and extraneous radiations. Thin substrates with higher dielectric constants, on the other hand, are desirable for microwave circuitry because they require tightly bound fields to minimize undesired radiation and coupling, thus leading to smaller sizes. However, because of their greater losses, they are less efficient and have relatively smaller bandwidth [2].

Since microstrip antennas are often integrated with other microwave circuitry, a compromise has to be reached between good antenna performance and circuit design.

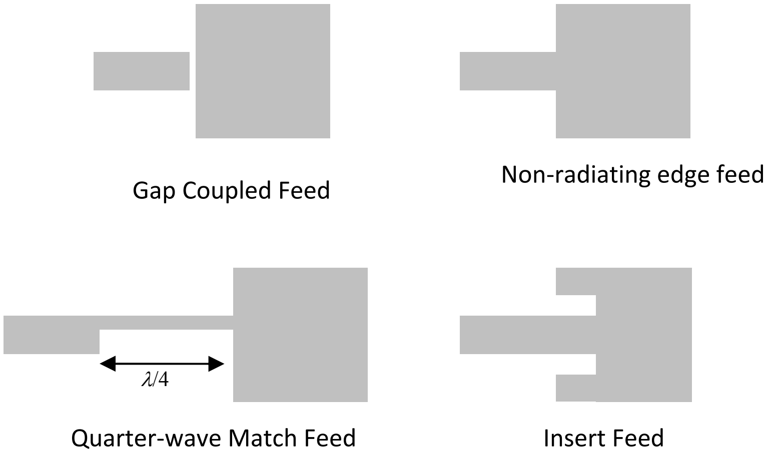
In summary, the differences in the thickness of the substrate are;

Thick substrate	Thin substrate
Low dielectric constant	High dielectric constant
Better efficiency	Less efficiency
Larger bandwidth	Smaller bandwidth
Larger element size	Smaller element size
Increase in weight	Lighter in weight
Increase in dielectric loss	Minimum dielectric loss

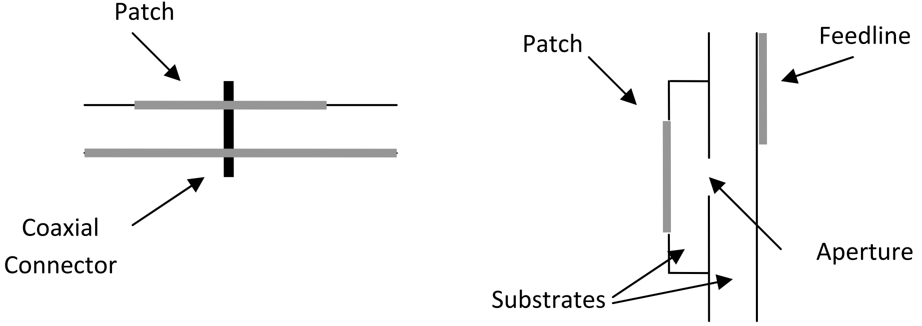
A rectangular patch antenna stops resonating for substrate thickness greater than $0.11\lambda_0$ ($\varepsilon_r = 2.55$) due to the inductive reactance of the probe feed. A low value of ε_r for the substrate will increase the fringing field at the patch periphery, and thus increase the radiation power. Therefore, substrates with $\varepsilon_r \leq 2.5$ are preferred. The four most commonly used substrate materials are honeycomb ($\varepsilon_r = 1.07$), Duroid ($\varepsilon_r = 2.32$), quartz ($\varepsilon_r = 3.8$), and alumina ($\varepsilon_r = 10$).

2.1.3 Feeding Methods

There are many techniques that can be used to feed microstrip antenna. The four most popular are the microstrip line feed, coaxial feed, aperture coupling and proximity coupling [2] as shown in Figure 2.2.

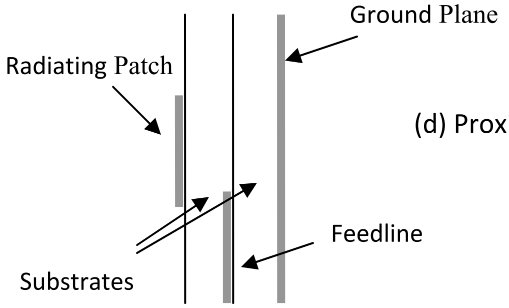


(a) Microstrip Line Feed



(b) Coaxial Feed

(c) Aperture Coupling



(d) Proximity Coupling

Figure 2.2 Typical feeds for microstrip antenna

a) Microstrip feed line. The microstrip feed line as shown in Figure 2.2a is a conducting strip of much smaller width compared to the patch. It is easy to fabricate, simple to match by controlling the inset position and rather simple to model. However, as the substrate thickness increases surface waves and spurious feed radiation, the usage limits the practical bandwidth (typically 2-5%).

b) Coaxial feed. The coaxial feed as shown in Figure 2.2b is an inner conductor of the coax and is attached to the radiation patch where the outer conductor is connected to the ground plane. It is easy to fabricate, match and it has low spurious radiation. The disadvantages are that it has a narrow bandwidth and more difficult to model especially for thick substrate ($h > 0.02\lambda_o$).

c) Aperture coupling. The aperture coupling as shown in Figure 2.2c is the most difficult of all four to fabricate and it also has narrow bandwidth. However, it is easier to model and has moderate spu**rious radiation. The aperture coupling 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. The ground plane between the substrates also isolates the feed from the radiating element and minimizes interference of spurious radiation for pattern formation and polarization purity.

d) Proximity coupling. The proximity coupling as shown in Figure 2.2d has the largest bandwidth, is easy to model and has low radiation but the fabrication is more difficult.

Both aperture and proximity coupling provide good polarization purity and no cross-polarised radiation in the principal planes, which can be found in microstrip and coaxial feeds.

2.2 Method of Analysis

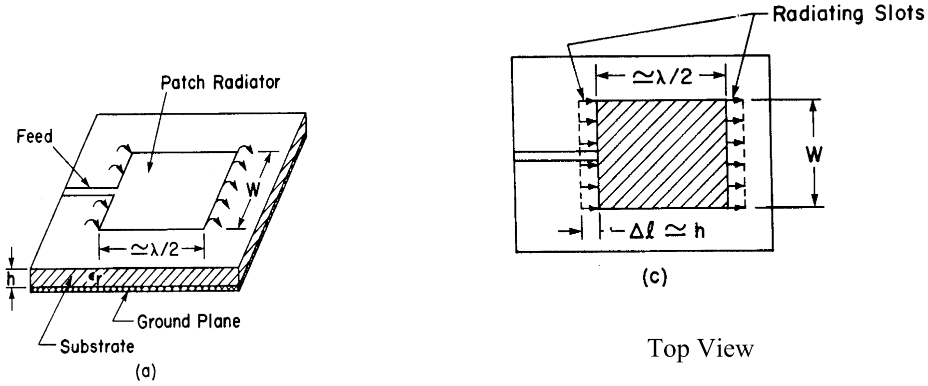
There are many methods of analysis for microstrip antennas. The most popular models are the transmission-line, cavity and full-wave.

The transmission-line model is the easiest of all, it gives good insight and it is adequate for most engineering purposes and requires less computation. However, it is less accurate and it is more difficult to model coupling. Comparing with the transmission-line model, the cavity model is more accurate but at the same time more complex. However, it also gives good physical insight, and is rather difficult to model coupling, although it has been used successfully. In general when applied properly, the full-wave models are very accurate, very versatile, and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements, and coupling. However, they are the most complex models and usually give less physical insight.

For the design of this project, the transmission-line model is selected as it provides a reasonable interpretation of the radiation mechanism while simultaneously giving simple expressions for the characteristics. In this model, a rectangular microstrip antenna is represented as an array of two radiating narrow aperture (slots), each of width W and height h, separated by a low impedance Z_C transmission line of length L.

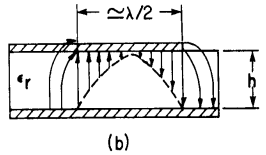
2.2.1 Radiation Mechanism

Radiation from microstrip antennas occurs from the fringing fields between the edge of the microstrip antenna conductor and the ground plane.



Top View

Rectangular Microstrip Patch Antenna



Side View

Figure 2.3 Rectangular microstrip patch antenna

As shown in Figure 2.3a [2], a rectangular microstrip patch is place a small fraction of a wavelength above a ground plane. Assuming no variations of the electric field along the width and the thickness of the microstrip structure, the electric field configuration of the radiator can be represented as shown in Figure 2.3b. The fields vary along the patch length which is about half a wavelength ($\lambda_g/2$). Radiation may be ascribed mostly to the fringing fields at the open-circuited edges of the microstrip antenna. The fields at the end can be resolved into normal and tangential components with respect to the ground plane. The normal components are out of phase because the patch line is $\lambda_g/2$ long, therefore the far field produced by them cancel in the broadside direction. The tangential components (those parallel to the ground plane) are in phase, and the resulting fields combine to give maximum radiated field normal to the surface of the structure, i.e., the broadside direction. Therefore, the patch may be represented by two slots $\lambda_g/2$ apart (Figure 2.3c) excited in phase and radiating in the half space above the ground plane.

The 2 slots are assumed to be lying flush and have component of slot aperture fields directed in both same direction. It is assumed that the slot width to be same as substrate thickness, h since $h \ll \lambda_o$. Hence, using the coordinate system in Figure 2.1c the total radiated field is the sum of the two-element array radiating in phase separated by $\lambda_g/2$ spacing. The far field of one slot is given as [2]

$$E_{FF\theta}(r) = j\frac{k_o e^{-jk_o r}}{2\pi r} P_Y \sin\phi \tag{1}$$

$$E_{FF\phi}(r) = j\frac{k_o e^{-jk_o r}}{2\pi r} P_Y \cos\theta \sin\phi \tag{2}$$

where $P_Y = E_o\, h \,\mathrm{sinc}(k_o \frac{h}{2} \sin\theta \cos\phi)\, W \,\mathrm{sinc}(k_o \frac{W}{2} \sin\theta \sin\phi)$ (3)

The array factor for the two elements of same magnitude and phase, separated by a distance of $\lambda_g/2$ along the y direction is

$$AF = 2\cos(\frac{\pi}{2}\sin\theta\sin\phi) \tag{4}$$

Hence, the overall radiation fields for the microstrip antenna consisting of 2 effective radiating slots can be found by multiplying 1 element's radiation fields by the array factor in (4). The principal E-plane is the XOY plane at $\phi = 90°$ is given as

$$E_{FF\theta}(r) = j\frac{k_o E_o h W e^{-jk_o r}}{2\pi r} \mathrm{sinc}(\frac{k_o h}{2}\sin\theta)\cos(\frac{\pi}{2}\sin\theta) \tag{5}$$

and the principal H-plane in the XOZ plane at $\phi = 0°$ is given as

$$E_{FF\phi}(r) = j\frac{k_o E_o h W e^{-jk_o r}}{2\pi r} \mathrm{sinc}(\frac{k_o h}{2}\sin\theta)\cos\theta \tag{6}$$

2.2.2 Radiation Conductance

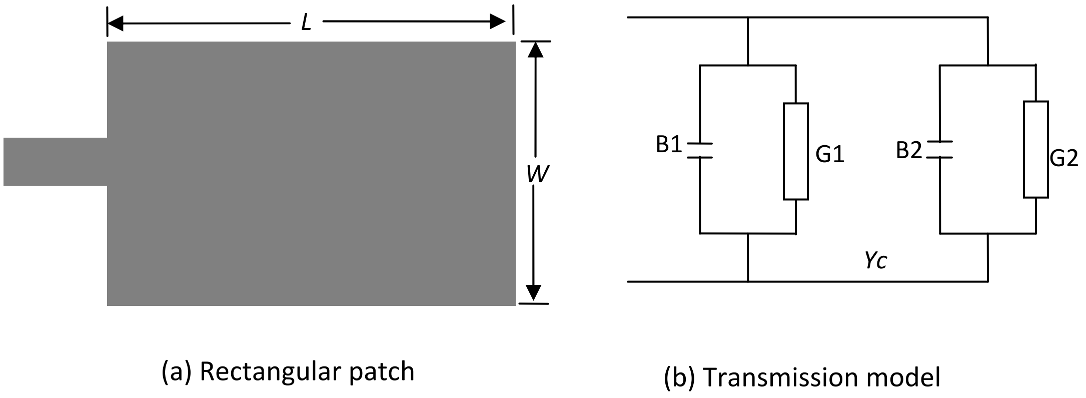
Each radiating slot is represented by a parallel equivalent admittance Y with conductance G and susceptance B as shown in Figure 2.4 [1]. The slots are labeled as #1 and #2. The equivalent admittance of slot #1, based on an infinitely wide, uniform slot is given by [1]

$$Y_1 = G_1 + jB_1 \qquad (7)$$

where for a slot of finite width W

$$G_1 = \frac{W}{120\lambda_o}\left[1 - \frac{1}{24}(k_o h)^2\right] \qquad \frac{h}{\lambda_o} < \frac{1}{10} \qquad (8)$$

$$B_1 = \frac{W}{120\lambda_o}\left[1 - 0.636\ln(k_o h)\right] \qquad \frac{h}{\lambda_o} < \frac{1}{10} \qquad (9)$$



(a) Rectangular patch (b) Transmission model

Figure 2.4 Rectangular microstrip patch and its equivalent circuit transmission model

Since slot #2 is identical to slot #1, its equivalent admittance is

$$Y_2 = Y_1, \qquad G_2 = G_1, \qquad B_2 = B_1 \qquad (10)$$

The conductance of a single slot as given in [1] are

$$G_1 = \begin{cases} \frac{1}{90}\left(\frac{W}{\lambda_o}\right)^2 & , W \ll \lambda_o \\ \frac{1}{120}\left(\frac{W}{\lambda_o}\right) & , W \gg \lambda_o \end{cases} \qquad (11)$$

2.2.3 Resonant Input Resistance

The total admittance at slot #1 is obtained by transferring the admittance of slot #2 from the output terminals to input terminals using the admittance transformation equation of transmission line. The separation of the two slots is slightly less than *λ/2*, thus the transformed admittance of slot #2 becomes

$$\widetilde{Y}_2 = \widetilde{G}_2 + j\widetilde{B}_2 = G_1 - jB_1 \tag{12}$$

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

$$\widetilde{Y}_2 = Y_1 + \widetilde{Y}_2 = 2G_1 \tag{13}$$

Hence the total input impedance is also real, or

$$Z_{in} = \frac{1}{Y_{in}} = R_{in} = \frac{1}{2G_1} \tag{14}$$

The resonant frequency is given by

$$f_r = \frac{v_o}{2L\sqrt{\varepsilon_r}} = q\frac{v_o}{2L\sqrt{\varepsilon_r}} \tag{15}$$

where v_o is the speed of light in free space and q is the fringe factor

The effective dielectric constant of a microstrip line is given approximately by

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \quad , \frac{W}{h} >> 1 \tag{16}$$

The effective dielectric constant is interpreted as the dielectric constant of a homogeneous medium that replaces the air and dielectric regions of the microstrip.

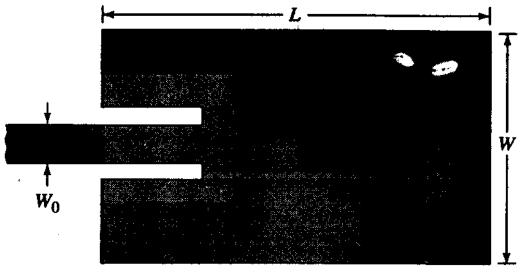
The characteristic impedance of a microstrip line feed to the patch antenna is given by [1]

$$Z_C = \begin{cases} \dfrac{60}{\sqrt{\varepsilon_{reff}}} \ln\left[\dfrac{8h}{W_o} + \dfrac{W_o}{4h}\right] & , \dfrac{W_o}{h} \le 1 \qquad (17a) \\ \dfrac{120\pi}{\sqrt{\varepsilon_{reff}}\left[\dfrac{W_o}{h} + 1.393 + 0.667 \ln\left(\dfrac{W_o}{h} + 1.444\right)\right]} & , \dfrac{W_o}{h} > 1 \qquad (17b) \end{cases}$$

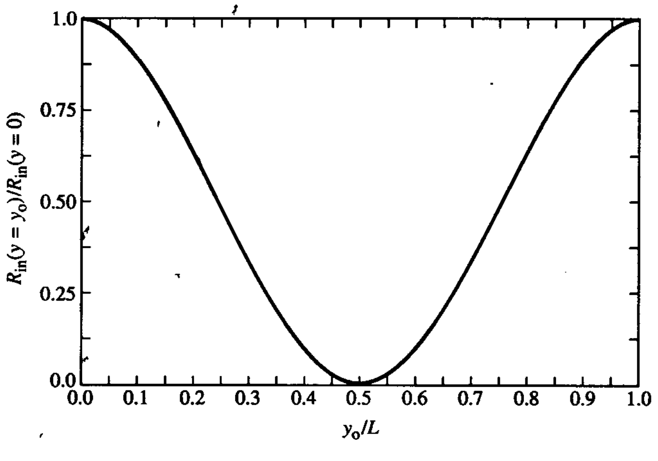
where W_o is the width of the microstrip line.

The resonant input resistance can be changed by using an inset feed, recessed a distance y_0 from slot #1, as shown in Figure 2.5a [1]. The inset feed point can be found using (18)

$$R_{in}(y = y_o) = R_{in}(y = 0)\cos^2\left(\frac{\pi}{L} y_o\right) \qquad (18)$$



(a) Recessed microstrip-line feed



(b) Normalized input resistance

Figure 2.5 Microstrip inset feed and variation of normalized input resistance

From (18) and Figure 2.5b, the maximum value occurs at the edge of the slot ($y_o = 0$) where the voltage is maximum and the current is minimum. The minimum value occurs at the center of the patch ($y_o = L/2$) where the voltage is zero and the current is maximum. Therefore the input resistance changes with the position of the feed point.

2.2.4 Directivity

The directivity of the antennas is defined as the ratio of the maximum power density in the main beam to the average radiated power density. The directivity of a microstrip antenna comprising two slots at a spacing *L* is expressed as [1]

$$D = \begin{cases} 6.6 = 8.2\text{dB} & , W << \lambda_o \\ 8\left(\dfrac{W}{\lambda_o}\right) & , W >> \lambda_o \end{cases} \tag{19}$$

2.2.5 *Q*-factor & Bandwidth

The quality factor is a figure of merit that is representative of the antenna losses. There are four loss mechanisms to be considered, namely, radiation, conduction (ohmic), dielectric and surface wave losses. The total quality factor is given by

$$\frac{1}{Q_t} = \frac{1}{Q_{rad}} + \frac{1}{Q_c} + \frac{1}{Q_d} + \frac{1}{Q_{sw}} \tag{20}$$

where Q_t = total quality factor

Q_{rad} = quality factor due to radiation (space wave) losses

Q_c = quality factor due to conduction (ohmic) losses

Q_d = quality factor due to dielectric losses

Q_{sw} = quality factor due to surface waves

For very thin substrates, the losses due to surface waves are very small and can be neglected. The approximate formulas to represent the quality factors of the various losses can be expressed as

$$Q_c = h\sqrt{\pi f \mu \sigma} \tag{21}$$

$$Q_d = \frac{1}{\tan\delta} \tag{22}$$

$$Q_{rad} = \frac{2\omega\varepsilon_r}{hG_t / l} K \tag{23}$$

where tan δ 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

$$K = \frac{\iint_{area} |E|^2 \, dA}{\oint_{perimeter} |E|^2 \, dl} \tag{23a}$$

For a rectangular aperture operating in the dominant TM$_{01}$ mode

$$K = \frac{L}{4} \tag{24a}$$

$$G_t / l = \frac{G_{rad}}{W} \tag{24b}$$

The Q_{rad} as represented by (23) is inversely proportional to the height of the substrate, and for very thin substrates is usually the dominant factor.

The bandwidth of a microstrip antenna of VSWR < s is given as [3]

$$BW = \frac{s-1}{Q_t\sqrt{s}} \tag{25}$$

Normally it is expressed as the percent bandwidth determined from the impedance data as

$$\%\ \mathrm{BW} = [(f_{r2} - f_{r1}) / f_r]\ 100 \text{ percent} \tag{25a}$$

where f_r is the resonant frequency, while f_{r2} and f_{r1} are the frequencies between the magnitude of the reflection coefficient of the antenna is less than or equal to 1/3. In general, bandwidth is proportional to the volume, which for a microstrip antenna at a constant resonant frequency can be express as

$$\mathrm{BW} \sim \text{volume} = \text{area x height} = \text{length x width x height} \tag{26a}$$

An empirical formula by Jackson and Alexopolus for the bandwidth (VSWR<2) is [1]

$$BW = 3.77[(\varepsilon_r - 1/\varepsilon_r^2)(W/L)(h/\lambda_0)] \tag{26b}$$

As stated in [1]-[3], the bandwidth increases as the substrate height increases. Increase in *h* will results in greater surface waves, spurious radiation and reduced directivity.

The radiation efficiency of an antenna is defined as the total power radiated over the net input power of the antenna. It is expressed in terms as

$$\eta = \frac{Q_t}{Q_{rad}} = \frac{P_{rad}}{P_{in}} \tag{27}$$

2.3 Design of Rectangular Microstrip Antenna

The lowest order mode TM_{01} resonates when the effective length of the rectangular patch is half wavelength. Radiation occurs from the fringing fields. For the principal *E*-plane, the dimensions of the patch along its length have been extended on each end by a distance ΔL, as show in Figure 2.3c, which is a function of the effective dielectric constant and the width-to-height ratio (*W/h*). The extension of length is given by [1]

$$\frac{\Delta L}{h} = 0.412 \frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \tag{28}$$

The actual length *L* of the patch is given as

$$L = \frac{\lambda}{2} - 2\Delta L \tag{29}$$

Hence the effective length of the patch is now

$$L_{eff} = L + 2\Delta L \tag{30a}$$

Or

$$L_{eff} = \frac{v_0}{2 f_0 \sqrt{\varepsilon_{reff}}} \tag{30b}$$

The width of the patch is given as

$$W = \frac{v_o}{2 f_0} \sqrt{\frac{2}{\varepsilon_r + 1}} \tag{31}$$

where v_o is the free space velocity of light.

2.4 Short Circuit Microstrip Antenna

2.4.1 Introduction

When a rectangular microstrip antenna is operating in the lowest mode, i.e. TM_{01}, a virtual short form through a plane centered between the two radiating edges. Thus, using half the patch and supplying the short circuit as shown in Figure 2.6 [3], a short circuit or quarter wavelength ($\lambda/4$) microstrip antenna can be fabricated. The resonant length is about a quarter wavelength in the dielectric of the substrate as given in (32).

$$\frac{L}{2} = \frac{\lambda}{4\sqrt{\varepsilon_{reff}}} - \Delta L \tag{32}$$

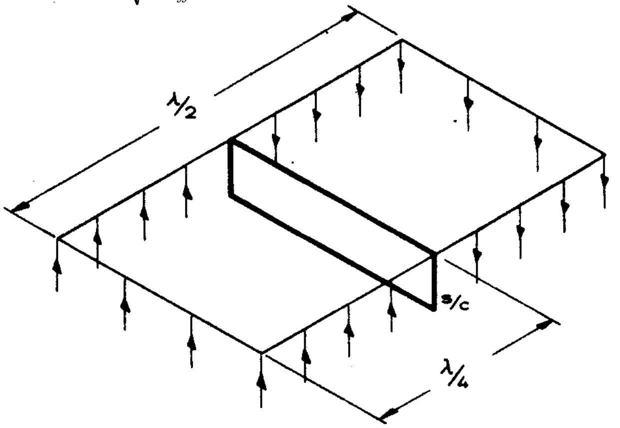


Figure 2.6 Short circuit microstrip antenna

The short circuit can be formed by using either a continuous sheet or by means of pins (via). The advantage of short circuit microstrip antenna is the increased *E*-plane beamwidth compared to the open circuit form on the same substrate material.

The length *L* of the rectangular microstrip antenna was reduced to a quarter wavelength using (32) and vias (short pins) were added to one of the radiating edge to form a short circuit microstrip antenna as shown in Figure 2.7.

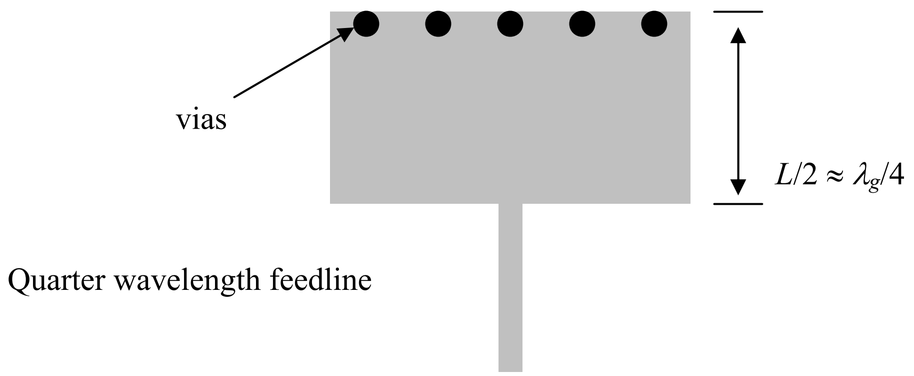


Figure 2.7 Short circuit microstrip antenna form using via (shorting pins)

2.4.2 Radiation Pattern

The increased in beamwidth is due to the fact that the fundamental mode *E*-plane pattern of the open circuit microstrip antenna has essentially the interferometer characteristics of a cophased pair of sources located at each end of the microstrip antenna. The half wave open circuit microstrip antenna operating in that mode has a zero voltage line across its center as shown in Figure 2.6. If a short circuit is added at this point and one half of the patch removed, the field structure within the resulting quarter wavelength short circuit is unchanged. The *E*-plane pattern then becomes that of a single magnetic current line source located at the high voltage edge, leading to an omnidirectional radiation pattern rather than one with a beamwidth of about 100°. The far field equation is thus reduce to [3]

a) the principal *E*-plane

$$E_\theta(\phi = 90^o) = -j\frac{2V_oWe^{-jk_or}}{2\lambda_o r} \tag{33}$$

b) the principal *H*-plane

$$E_\theta(\phi = 0^o) = -j\frac{2V_oWe^{-jk_or}}{2\lambda_o r}\cos\theta\frac{\sin\left(\frac{k_oW}{2}\sin\theta\right)}{\frac{k_oW}{2}\sin\theta} \tag{34}$$

Comparing to the far field equation of the open circuit microstrip antenna (5) and (6), the *H*-plane pattern is unchanged.

2.4.3 Bandwidth and Resonant Impedance

The impedance characteristics of the short circuit microstrip antenna are related to those of the corresponding open circuit microstrip antenna by the following two points:

a. Only one radiating slot is present, so the conductance is given by (11). Thus, the resonant impedance of a short circuit microstrip antenna is

$$Z_{in} = \frac{1}{Y_{in}} = R_{in} = \frac{1}{G_1} \tag{35}$$

This means that the input impedance of the short circuit patch at resonance is 2 times that the input impedance of the open circuit microstrip antenna.

b. With one radiating slot, the stored energy within the short circuit microstrip antenna is halved relative to the open circuit microstrip antenna. According to [1], the directivity of a single slot microstrip antenna is

$$D = \begin{cases} 3.3 = 5.2dB & ,W << \lambda_o \\ 4\left(\frac{W}{\lambda_o}\right) & ,W >> \lambda_o \end{cases} \tag{36}$$

2.5 Simulation Software

There are many electromagnetic simulation software like Ansoft, HP MDS, IE3D available to design and analysis of complicated microwave and RF printed circuit, antennas and other electronic components. However, in this project, Matlab R2007a software is used for the simulation of the microstrip antenna design. A basic software programme is written to calculate the dimension as well as the antenna bandwidth. The Matlab also has a radio frequency software toolbox to provide computational result for the designed antennas. RF Tool is a GUI that provides a visual interface for creating and analyzing RF components and networks. The RF Tool can be used as a convenient alternative to the command-line RF circuit design and analysis objects and methods that come with it. RF Tool provides the ability to create and import circuits, set circuit parameters, analyze circuits and display circuit S-parameters in tabular form and on X-Y plots, polar plots, and Smith charts

CHAPTER 3

RECTANGULAR MICROSTRIP PATCH ANTENNA & RESULTS

3.1 Design Specifications

There are three essential parameters for the designs of a rectangular Microstrip Patch Antenna are:

3.1.1 Frequency of operation (f_0): The resonant frequency of the antenna must be selected appropriately. The UHF antenna for this project uses the frequency range from 200-400 MHz. Hence, the antenna designed must be able to operate in this frequency range. The resonant frequency selected for this design is 300 MHz.

The propagation of the electromagnetic field is usually considered in free space, where it travels at the speed of light $v_0 = 3x10^8 m/s$

$$\lambda = \frac{v_0}{f_{(Hz)}} \tag{37}$$

λ, lambda is the wavelength, expressed in meters (m)

In UHF band, the following expression is used:

$$\lambda = \frac{300}{f_{(MHz)}}$$

Hence, the wavelength of the antenna when operating at 300MHz is 1m.

3.1.2 Dielectric constant of the substrate (ε_r): The dielectric material selected for this design is RT/Duroid 5880 which has a dielectric constant (ε_r) of. 2.2. A substrate with a low dielectric constant has been selected since it will increase the bandwidth of the antenna.

3.1.2 Height of dielectric substrate (*h*): For the microstrip patch antenna to be used in this project, it is essential that the height of the substrate and permittivity should satisfy the equation below as a lower limit on the height, below which the broad band operation is unlikely.

$$h \geq 0.06 \frac{\lambda}{\sqrt{\varepsilon_r}} \tag{38}$$

Hence, the height of the dielectric substrate is selected as **0.04 m** or **40 mm**.

3.2 Design Procedure

From the above, the essential parameters for the design are:

a. f_0 = **300MHz**

b. ε_r = **2.2**

c. h = **40mm**

3.2.1 Calculation of the Width (*W*): The width of the microstrip patch antenna is given by equation (31) as:

$$W = \frac{v_o}{2f_0}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

Substituting v_0=3x10^8m/s, ε_r =2.2 and f_0=300 Mhz,

W= **0.395m or 395.3 mm**

3. 2.2 Calculation of Effective dielectric constant (ε_{reff}): Equation (16) gives the effective dielectric constant as:

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

Substituting ε_r =2.2, *W*= 395.3 mm and *h*= 40 mm,

$$\varepsilon_{reff} = 2.0032$$

3.2.3 Calculation of the Effective length (L_{eff}): Equation (30b) gives the effective length as:

$$L_{eff} = \frac{v_0}{2 f_0 \sqrt{\varepsilon_{reff}}}$$

Substituting v_0=3x10^8m/s, ε_{reff}=2.0 and f_0=300 Mhz,

L_{eff}= **0.353 m** = **353 mm**

3.2.4 Calculation of the length extension (ΔL): Equation (28) gives the length extension as:

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

Substituting ε_{reff} =2.0, *W*= 395.3 mm and *h*= 40 mm,

ΔL = **0.0207 m** = **20.7 mm**

3.2.5 Calculation of actual length of patch (L): The actual length is obtained by re-writing equation (30a) as

$$L = L_{eff} - 2\Delta L$$

Substituting L_{reff} =353 mm, and ΔL = 20.7 mm,

L = **311.6 mm** or **0.3116 m**

3.2.6 Calculation of the ground plane dimensions (L_g and W_g): The transmission line model is applicable to infinite ground planes only. However, for practical considerations, it is essential to have a finite ground plane. The finite ground can be obtained if the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness all around the periphery. Hence, for this design, the ground plane dimensions would be given as:

$$L_g = 6h + L$$

$$W_g = 6h + W$$

Hence, the calculated L_g and W_g are **551.6 mm** and **635.3 mm** respectively.

3.2.7 Microstrip Patch Antenna Dimensions

Based on the calculation above, the L and W derived are 311.6 mm and 395.3 mm

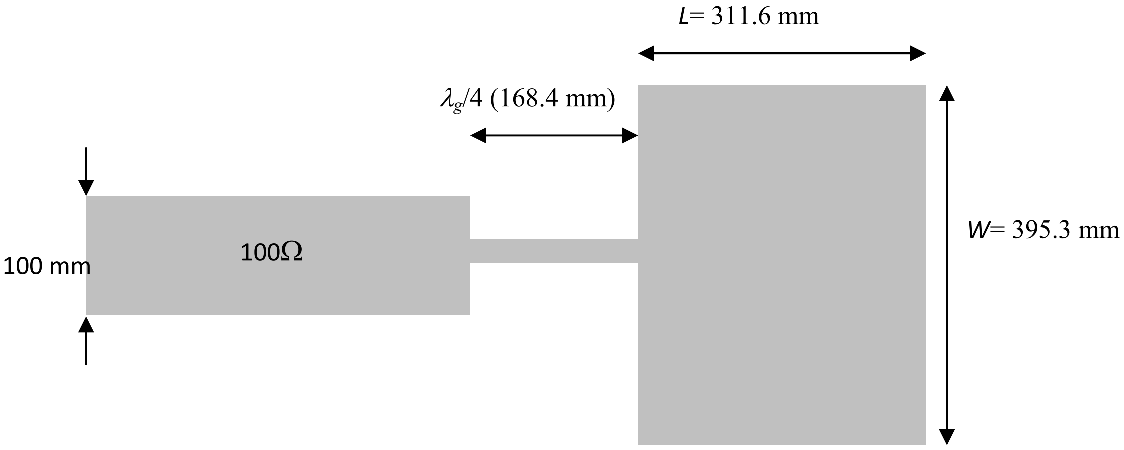


Figure 2.8 Single rectangular microstrip antenna

The design of the microstrip antenna array starts from a single rectangular microstrip antenna. The microstrip antenna is feed using microstrip feedline, the design specifications for this project is as follows

Frequency, $f_0 = 300$ MHz
Dielectric constant, $\varepsilon_r = 2.2$
Substrate thickness, $h = 40$ mm
Metallic strip thickness, $t = 0.1778$ mm
Conductivity of ground plane (Copper), $\sigma_g = 5.8 \times 10^7$ S/m
Effective dielectric constant, $\varepsilon_{reff} = 2.0$
Resonant input impedance, $R_{in} = 113.9\Omega$ using (11) and (14)

A 100Ω microstrip feedline was chosen because the width of the 50Ω feedline calculated was 201.3mm. It was rather thick which can cause spurious radiation and interfere with the radiation field of the microstrip antenna. The width of the 100Ω microstrip feedline calculated is 100mm using (17).

Using (26b) equation,

$$BW = 3.77[(\varepsilon_r - 1/\varepsilon_r^2)(W/L)(h/\lambda_0)]$$

The bandwidth for this microstrip patch antenna is **4.74%** and given that this project is to design a microstrip patch antenna that operates at a frequency from 200-400 MHz, the bandwidth requires is about 66.7%. Hence, this antenna bandwidth does not fulfill the requirement.

3.3 Matlab Simulation Results

Using the Matlab software, a programme is written to compute the microstrip patch antenna dimension by entering the required parameter such as dielectric constant and height of substrate.

a. When dielectric constant ε_r is increased to 2.2 and height increases to 50mm, the computed dimensions are;

Parameters	Computed Results
Width	0.3953
Minimum height	0.0405
Effective dielectric constant	1.9781
Effective length	0.3555
Length extension	0.0256
Actual length	0.3043
Bandwidth	6.07098%

It is observed that there is a slight increased in the bandwidth to **6.07%** when the height of the substrate is increased to 50mm. Hence, as stated in [1]-[3], the patch antenna's BW increases with the increase in the height of the substrate.

b. When dielectric constant ε_r is increased to 12 (Silicon substrate), and height is 17.3mm, the computed dimensions are;

Parameters	Computed Results(m)
Width	0.1961
Minimum height	0.0173
Effective dielectric constant	10.3322
Effective length	0.1556
Length extension	0.0072
Actual length	0.1412
Bandwidth	0.693027%

It is observed that a high dielectric constant will result in the width of the antenna to be almost half as compared with the width of a lower dielectric constant. However, the compactness of this antenna results in a much narrower bandwidth of **0.69%**, which is undesired for this project.

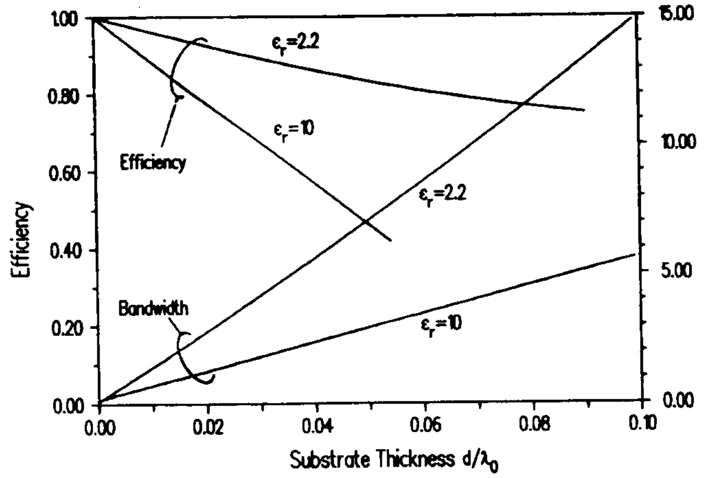


Figure 2.9 Impedance bandwidth (VSWR<2) and efficiency for a microstrip antenna element versus substrate thickness

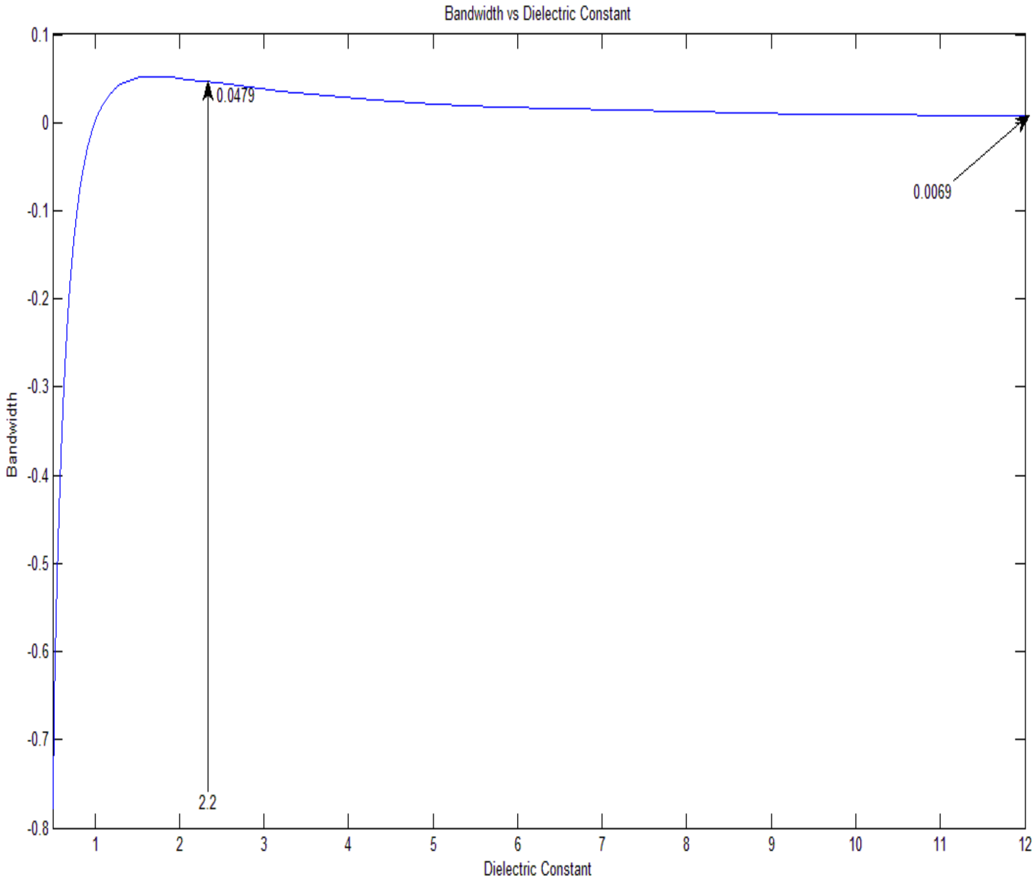


Figure 3.0 Bandwidth vs Dielectric constant

The graph shown in Figure 3.0 is extracted from the Matlab software, showing the relationship between the bandwidth and the dielectric constant (increasing). From this graph, it is observed that the bandwidth of the antenna is decreasing while the dielectric constant is increasing. This graph also verified with Figure 2.9.

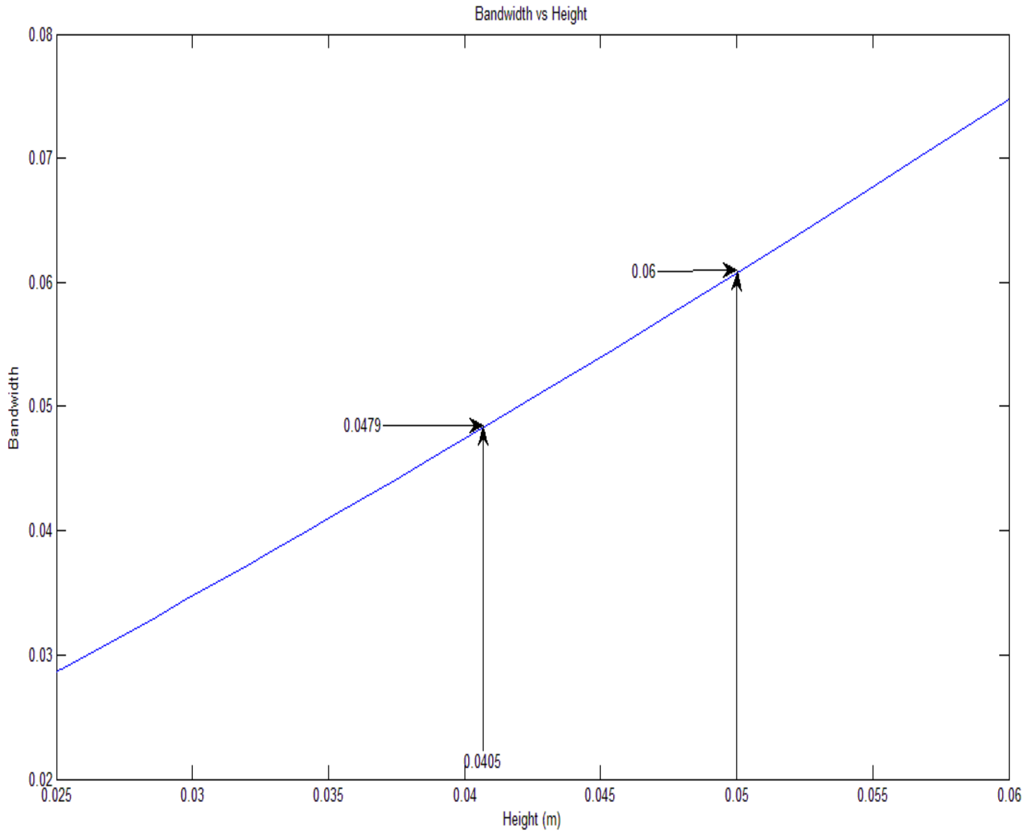


Figure 3.1 Bandwidth vs Height

The graph shown in Figure 3.1 is extracted from the Matlab software, showing the relationship between the bandwidth and the height of the substrate (increasing). From this graph, it is observed that the bandwidth of the antenna is increasing as the height is increased. This graph also verified with Figure 2.9.

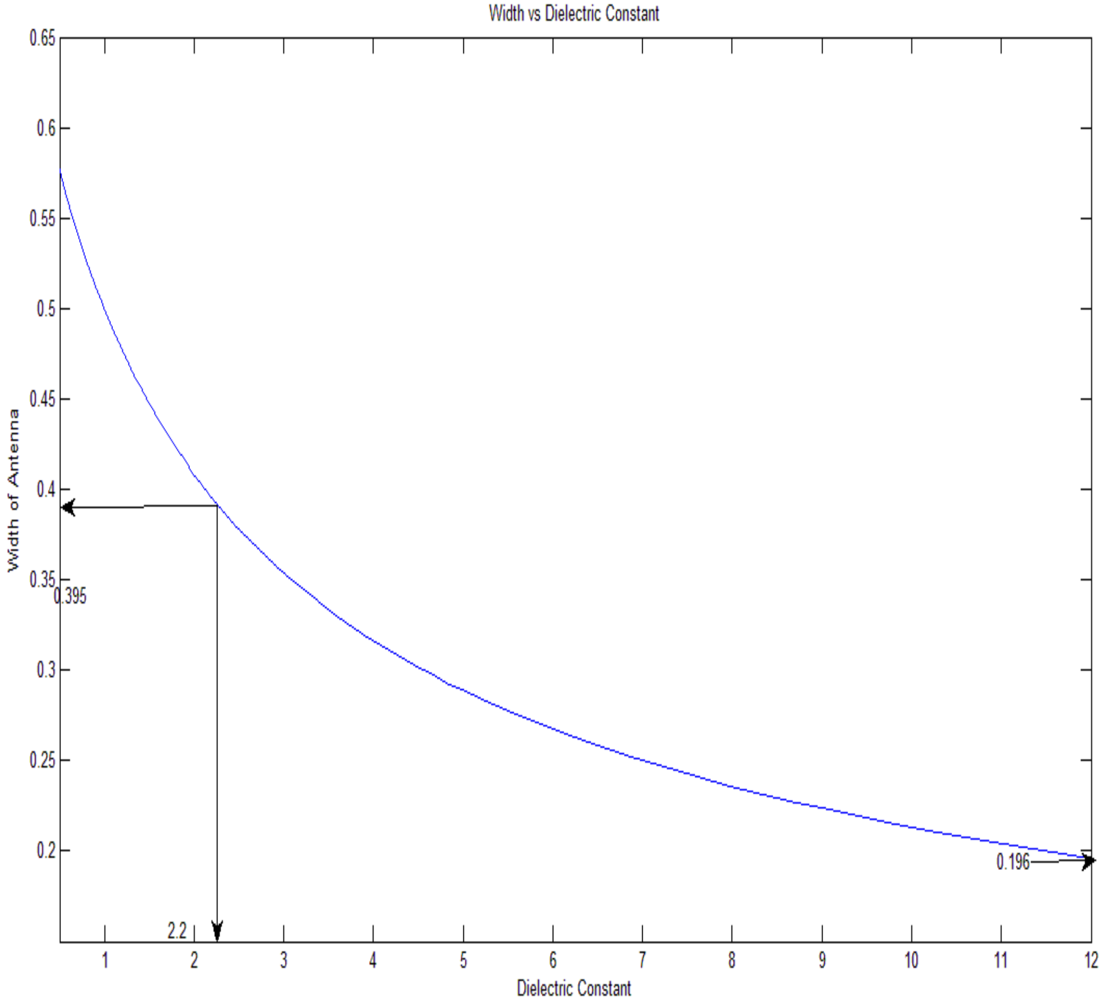


Figure 3.2 Width vs Dielectric Constant

The graph shown in Figure 3.2 is extracted from the Matlab software, showing the relationship between the width of the antenna and the dielectric constant (increasing). From this graph, it is observed that the antenna with the low dielectric constant has almost twice the width as compared with the antenna with high dielectric constant.

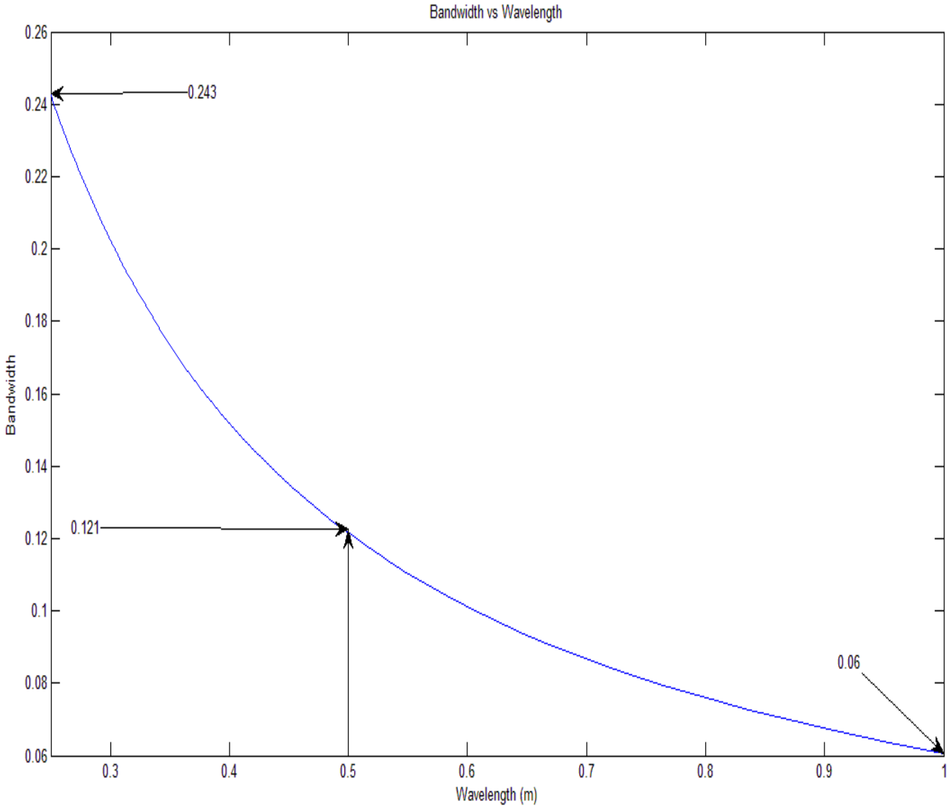


Figure 3.3 Bandwidth vs Wavelength

The graph shown in Figure 3.3 is extracted from the Matlab software, showing the relationship between the bandwidth of the antenna and various wavelengths (*λ,λ/2 and λ/4*). From this graph, it is observed that even if the antenna is designed to be a short circuit or quarter wavelength microstrip antenna (*λ/4*), the bandwidth computed is about **24.3%**. Hence, this will not meet the requirement of the project.

CHAPTER 4

DESIGN OF A RECTANGULAR U-SLOT MICROSTRIP PATCH ANTENNA

4.1 Introduction

In chapter 3, it is shown that microstrip patch antenna has a very narrow frequency bandwidth that precludes its use in our design specification which requires to operate at 200-400MHz. Hence, there is a need to study in broad banding of the microstrip patch antenna. In 1995, researchers presented an experimental study of a new kind of broad-band antenna with an impedance bandwidth of 47%. This new type of antenna was a probe-fed rectangular microstrip patch antenna on a unity permittivity substrate with an internal U-shaped slot as shown in Figure 3.4.

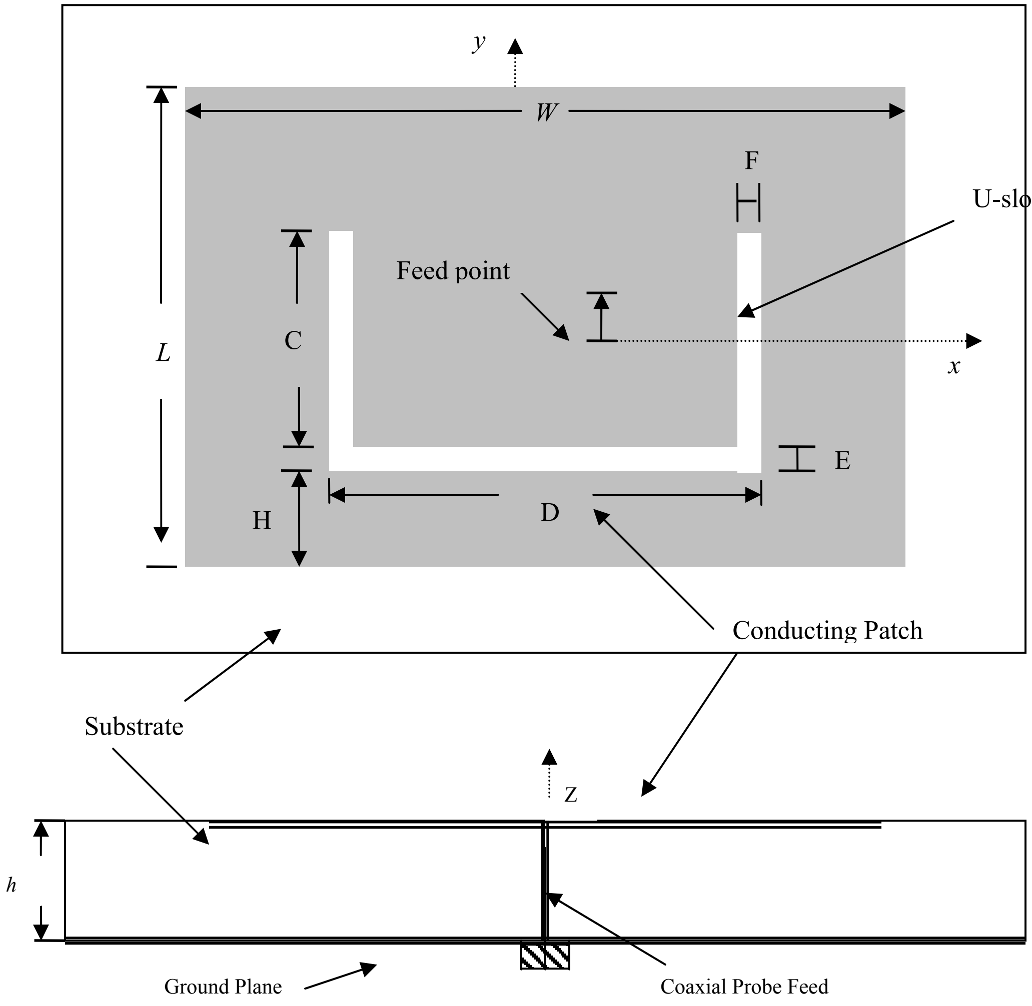


Figure 3.4 Geometry of the Rectangular U-Slot Microstrip Patch Antenna

4.2 Design Procedure

This design procedure is a set of simple design steps for the rectangular U-slot mircostrip patch antenna on microwave substrates [27]. These procedures provide antenna engineers with approximate rules that result in a good first-pass design with prescribed characteristics that requires only minimal tuning.

4.2.1 Determine centre frequency, f_0

Set center frequency as f_0 and the lower and upper frequency bounds of the bandwidth as f_{low} and f_{high}, respectively.

a. Center frequency, f_0 = **300 MHz**

b. Lower bound frequency, f_{low} = **200 MHz**

c. Upper bound frequency, f_{high} = **400 MHz**

4.2.2 Select a substrate permittivity ε_r and a substrate height

There is a lower limit on *h* below which broad-band operation is unlikely. Therefore, the substrate height and permittivity should satisfy the following equation (38)

a. The dielectric material selected for this design is RT/Duroid 5880 which has a dielectric constant (ε_r) of. 2.2.

b. The height of the substrate is 0.05m or 50mm

4.2.3 Calculation of the Width (*W*): The width of the microstrip patch antenna is given by equation (31) as:

$$W = \frac{v_o}{2f_0}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

Substituting v_0=3x10^8m/s, ε_r =2.2 and f_0=300 Mhz,

W= **0.395m or 395.3 mm**

4.2.4 Calculation of Effective dielectric constant (ε_{reff}): Equation (16) gives the effective dielectric constant as:

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

Substituting ε_r =2.2, *W*= 395.3 mm and *h*= 50 mm,

$$\varepsilon_{reff} = 1.9781$$

4.2.5 Calculation of the Effective length (L_{eff}): Equation (30b) gives the effective length as:

$$L_{eff} = \frac{v_0}{2f_0\sqrt{\varepsilon_{reff}}}$$

Substituting v_0=3x10^8m/s, ε_{reff}=1.9781 and f_0=300 Mhz,

L_{eff}= **0.3555 m** = **355.5 mm**

4.2.6 Calculation of the length extension (ΔL): Equation (28) gives the length extension as:

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

Substituting ε_{reff} =1.9781, W= 395.3 mm and h= 50 mm,

ΔL = **0.0256 m** = **25.6 mm**

4.2.7 Calculation of actual length of patch (L): The actual length is obtained by re-writing equation (30a) as

$$L = L_{eff} - 2\Delta L$$

Substituting L_{reff} =355.5 mm, and ΔL = 25.6 mm,

L = **304.3 mm** or **0.3043 m**

4.2.8 Calculation of slot thickness E and F: Using the equation below

$$E = F = \lambda / 60$$

Substituting λ = 1 m. Hence, $E = F$ = **0.0167 m** or **16.7 mm**

4.2.9 Calculation of slot width D:

$$D = \frac{v_0}{f_{low}\sqrt{\varepsilon_{reff}}} - 2(L + 2\Delta L - E)$$

Substituting v_0=3x10^8m/s, ε_{reff} =1.9781, f_{low}=200 MHz, L =0.3043 m, ΔL = 0.0256 m and E = 0.0167 m

D = **0.3888 m** or **388.8 mm**

4.2.10 Selection of C:

$$\frac{C_1}{W} \geq 0.3 \quad \text{and} \quad \frac{C_2}{D} \geq 0.75$$

Substituting W= 0.3953 m, C_1 = 0.11859 m

Substituting D = 0.3888 m and C_2 = 0.2916 m

4.2.11 Calculate the effective permittivity of the pseudopatch:

This pseudopatch of the upper bound frequency resonance has the effective patch width as *D – 2F*

$$\varepsilon_{reff(pp)} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{D - 2F}\right]^{-\frac{1}{2}}$$

Substituting ε_r =1.9781, *D* =0.3888 m, *h* = 0.05 m and *F* = 0.0167 m

$\varepsilon_{reff(pp)}$ = **1.9660**

4.2.12 Calculate the effective length of the pseudopatch:

This pseudopatch of the upper bound frequency resonance has the effective patch width as *D – 2F*

$$2\Delta_{L-E-H} = 0.4824h\frac{\left(\varepsilon_{reff(pp)} + 0.3\right)\left(\frac{D - 2F}{h} + 0.264\right)}{\left(\varepsilon_{reff(pp)} - 0.258\right)\left(\frac{D - 2F}{h} + 0.8\right)}$$

Substituting $\varepsilon_{reff(pp)}$ =1.966, *D* =0.3888 m, *h* = 0.05 m and *F* = 0.0167 m

$$2\Delta_{L-E-H} = 0.051m$$

4.2.13 Calculate *H*:

$$H \approx L - E + 2\Delta_{L-E-H} - \frac{1}{\sqrt{\varepsilon_{reff(pp)}}}\left(\frac{v_0}{f_{high}} - \left(2C + D\right)\right)$$

Substituting v_0=3x10^8m/s, f_{high} = 400 MHz, $\varepsilon_{reff(pp)}$ =1.966, C_1 = 0.1186 m, *D* =0.3888 m, *L* = 0.3043 m, *E* = 0.0167 m and $2\Delta_{L-E-H} = 0.051m$

H = 0.2502

4.2.14 Checksum

Check that the sum $C + E + H$ is less than L. If not, need to adjust value of C and H until the design is physically possible.

Using the calculated values of C, E and H, the total value exceeded the length of the antenna. Hence, the design is physically impossible. In order to make the design realisable, there is a need to change the initial lower, f_{low}, and upper bound frequency, f_{high}.

4.3. Matlab Simulation Results

Using the Matlab software, a programme is written to compute the U-Slot microstrip patch antenna dimension by entering the required parameter such as dielectric constant, height of substrate.

4.3.1 Parameters setting

Dielectric constant $\varepsilon_r = 2.2$, Height = 50mm,

Lower bound frequency, $f_{low} = 250$ MHz, Upper bound frequency, $f_{high} = 350$ MHz

The computed dimensions are;

Parameters	Computed Results	Parameters	Computed Results
Width	0.3953	E	0.0167
Minimum height	0.0405	F	0.0167
Effective dielectric constant	1.9781	D	0.1755
Actual length	0.3043	C1	0.1186
Effective $\varepsilon_{reff(pp)}$	1.8626	C2	0.1317
$2\Delta_{L-E-H}$	0.0474	H	0.0285
Bandwidth	33.333333%	Checksum	0.1768

It is observed that the U-slot microstrip antenna has an increased bandwidth almost 5 times of the initial microstrip patch antenna (6.07%) stated in Chapter 3.

4.3.2 Optimising parameters setting

Using the Matlab software, the user can set the lower bound and upper bound frequency to derive the bandwidth.Dielectric constant ε_r = 2.2, Height = 50mm, and no physical changes in patch antenna.

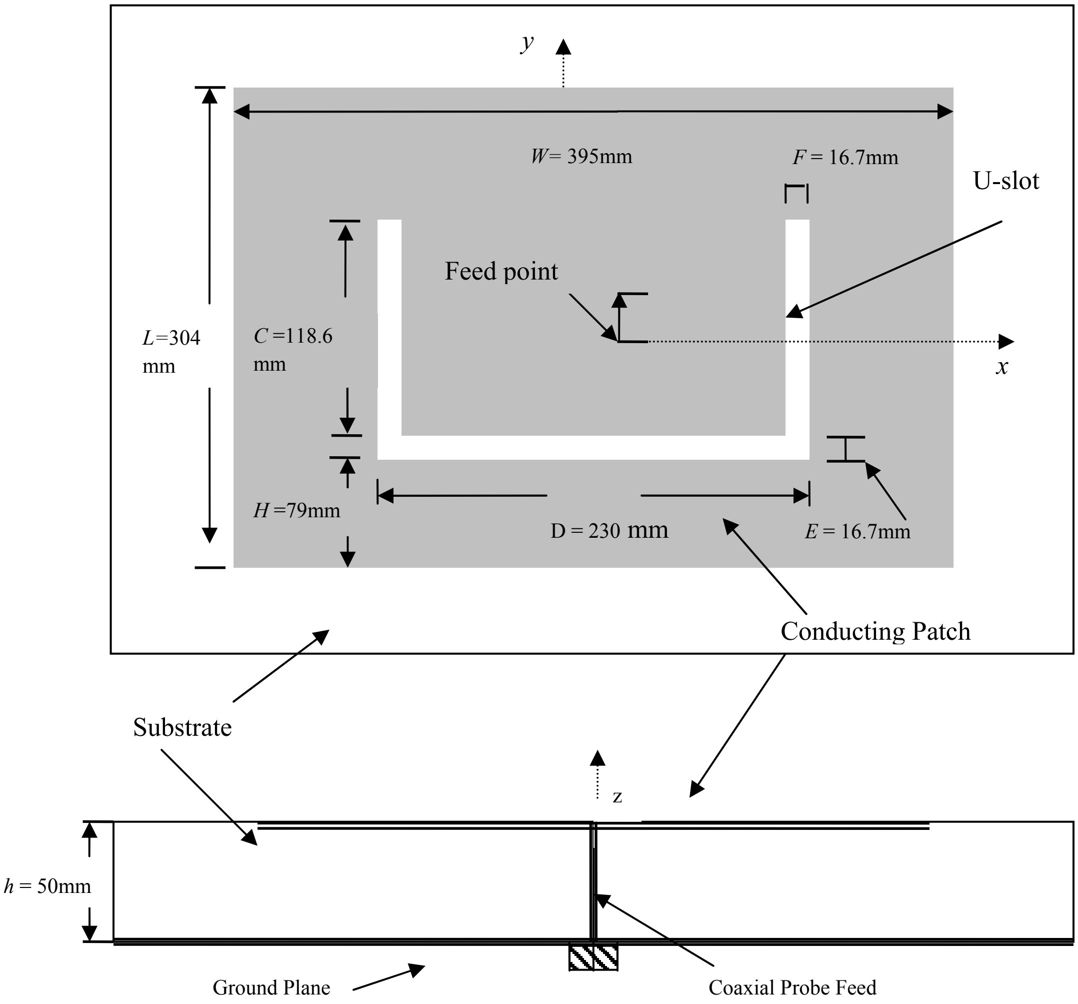
Hence, the optimised lower bound frequency, f_{low} = 235 MHz, upper bound frequency, f_{high} =365 MHz, is selected after going through various frequency values using the Matlab

The computed dimensions are;

Parameters	Computed Results	Parameters	Computed Results
Width	0.3953	E	0.0167
Minimum height	0.0405	F	0.0167
Effective dielectric constant	1.9781	D*	0.2300
Actual length	0.3043	C1	0.1186
Effective $\varepsilon_{reff(pp)*}$	1.8981	C2*	0.1725
$2\Delta_{L-E-H}$	0.0490	H*	0.0791
Bandwidth*	43.333333%	Checksum*	0.2144

Beside the increase in the antenna bandwidth, it is also observed that with the change in the frequency, the actual length and width of the microstrip antenna does not change in size and only a few slot dimensions will vary in size eg. D, C2 and H.

4.4 Final U-Slot Microstrip Antenna Dimenson



CHAPTER 5

CONCLUSION

5.1 Summary of Results Achieved in this Capstone Project

In this project, a rectangular microstrip patch antenna was selected to design a lightweight, low volume and low profile planar antenna in the application for a military band short range communication system (UHF), at a frequency range of 200 MHz – 400 MHz. Hence, this antenna requires a bandwidth of 66.7% in order to support for the wide broad band.

Through the initial rectangular microstrip patch antenna design, the Matlab results in a bandwidth of **4% - 6%.** The programme showed that a high dielectric constant will result in the width of the antenna to be almost half as compared with the width of a lower dielectric constant. However, the compactness of this antenna results in a much narrower bandwidth of **0.69%**, which is undesired for this project. By reducing the dielectric constant and increasing the substrate height will enhance the bandwidth, and this concurred with [1]-[3]. From the Matlab software, it showed that an antenna with the low dielectric constant has almost twice the width as compared with the antenna with high dielectric constant. It was known that a short circuit quarter wavelength type of microstrip antenna can realise the same resonant frequency, at less than half the size of a standard microstrip antenna however, the bandwidth computed is about **24.3%**. Hence, this will not meet the requirement of the project.

A U-slot microstrip patch antenna was later researched and studied as an alternate means to enhance the bandwidth of the antenna. A simple design procedure based on previous literature and theoretical analyses was used to formulate the model. While the design rules presented here are approximate and may not work in all situations, it does provide a good starting point for antenna designers as it gives better and timelier results than simply through guesses or cut-and-try techniques. Hence, using this set of calculation, an optimum U-slot microstrip patch antenna was designed with a bandwidth of **43%**, operating from 235 MHz to 365 MHz. This operating frequency range is approximately closed to the military UHF radio set, AN/ARC 164, which operates from 225 MHz – 399.975 MHz.

5.2 Future Work

Using Matlab for antenna design simulation is very challenging as it will take very complex programming to achieve the desire results and it is very time consuming. However, this can be easily solved by using RF simulation software like Zealand IE3D. If future work is to be carried out, it is recommended to use this advance software for the initial design and simulation and should there be facilities available, ie microwave anechoic chamber, hardware implementation and testing should be carried out.

A further study can be look into the design of a microstrip patch antenna array operating at UHF frequency. This will further improved the antenna with very directive characteristics or very high gains to meet the demands for long distance communication as well as providing a fixed beam of specified shape (shape beam) or a beam that scans in response to system stimulus. One of the applications is to use a UHF microstrip antenna array for Synthetic Aperture radar onboard an aerial platform.

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PART 2 CRITICAL REVIEW AND REFLECTIONS

It is not easy to juggle between work and a part time degree course. Having to juggle between work, family and a part time degree course is a real challenge for me. I have numerous deadlines to meet at work, family commitment and to attend evening classes. It has not been a smooth sailing journey but this learning process has certainly been enriching and has help to mould me into a stronger person.

I am a military personnel and I realized that most military aviation platforms are equipped with UHF communication system for their operational requirements. At UHF frequencies, the antenna configuration will increase. If microstrip antenna can replace the current ones, it will reduce or even eliminate antenna visual and radar signatures and increasing platform survivability significantly.

The initial preparation and planning was simple. I knew that I wanted to do design a light weight, low volume, low profile planar microstrip antenna in the application for a military band short range radio communication system (UHF), at a frequency range of 200MHz – 400MHz.

It was easy to draw a timeline on all the tasks required on the Gannt chart. What made it tricky was to follow the Gannt chart on the task that I have to complete by the deadline set by me. This requires lots of commitment and discipline

In the stage of exploring and researching, I find myself not adhering to the timelines. As I do not have the advantage of being a full time student, I really struggled to meet deadlines. In addition, not having the benefit to work regular hours and having to travel occasionally made it harder to achieve the targets.

Although I have my family's morale support to complete the course. It is my responsibility to care for my family and spend time with them. I will ferry my son to and fro daily except on days that I was overseas. We traveled from Sengkang (my home) to Woodlands (my mum's house) to Changi (my workplace). I have clocked an astonishing 30000km on mileage in a year.

Before I knew it, the original date for submission was just round the corner and my project was not near completion. However, I was very determined to complete the course. Hence I have requested for an extension and I told myself that I have to give my last shot and my best effort to finish the line.

The only chance I could get to the library was during weekends. As most books were under reference and not for loan, I had spent long hours there and chalked up hefty parking bills. Besides that I have also done extensive search on the internet on the relevant topics.

With only the foundation courses like Radio Frequency (TZS327) and Semiconductor Devices and Electronic Material (HESZ341) taught in UniSim, there is a lot of knowledge and skills require having a deeper understanding in microstrip antenna theories, and its mathematical relations. Hence, the first step was to find the relevant IEEE papers and books on this subject.

Not to my surprise, there are a lot of researches done in this area, and this did not help at all as I have somehow lost focus on what is desired, this is the typical information overload during the literature survey. During the meet up with Dr Shen, he always provides me with the relevant comments and valuable inputs with regards to my progress. Without the help of my dedicated tutor to guide me and to align the ideas, this project would not be completed. The paper design for the microstrip patch antenna was completed on time in accordance with the Gannt chart however, the bandwidth of the antenna is too narrow for my project application, and hence, there was a need to find a suitable technique to enhance the bandwidth. After some discussions with Dr Shen, we finalized on using a U-slot microstrip patch antenna to increase the bandwidth. The literature survey on this subject was to be researched all over again.

In the course of doing the project, I have self learnt and acquired some basic Matlab software programming to implement the simulation model. As I was not familiar with the software and this is not taught in UniSim, I have a few failed attempts during the design phase and eventually after many version of designing practicing. This was overcome. Being new to this software programming, I took more than the estimated time to complete it. This has caused delay to the completion. Moreover, time is required to travel to UniSim to have access to a comprehensive set of Matlab toolboxes for radio frequency simulation.

With the simulated results obtained from the model, I have evaluated and finalized the microstrip antenna design however I was unable to run simulation on the U-slot microstrip antenna as this requires complex programming skills.

Project management is also one of the necessary skills which I have picked up in this capstone subject. With the need for the planning of the numerous specific tasks with the available timeline and resources as well as the various projected deliverables, the progress of the project can be easily planned and tracked by using a Gantt's chart. The challenge was to follow it religiously.

Finally, the art of report writing is an essential skill that I have learnt for this project. This report writing is important as I must be able to capture the necessary learning points and challenges during the entire process of the capstone project.

Acknowledgement

Special thanks to Dr Shen (my Tutor) and Mr Stephen Low (Course Chair), who has given me valuable directions on how to complete the project. I also want to express my appreciation to Dr Venkata Ramanan who has given his consent for this project.