A 2.4GHz SLOT ANTENNA ARRAY

By

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DEDICATION

This project is dedicated to my loving parents Mr. and Mrs. Olewe whose words of encouragement and push for tenacity ring in my ears. My brothers Charles and Brian have never left my side and are very special.
ACKNOWLEDGEMENTS

First and foremost, I thank the almighty God for guiding me throughout my studies till the accomplishment of this project.

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ABBREVIATIONS AND ACRONYMS

HPBW- Half Power Beam Width
dB- decibels
MoM- Method of Moments
FDTD- Finite Domain Time Difference
HFFS- High Frequency Structure Simulator
ISM- Industrial, Scientific and Medical
3D- Three Dimension
VSWR- Voltage Standing Wave Ratio
RHCP- Right Hand Circular Polarization
LHCP- Left Hand Circular Polarization
CPW- Coplanar Waveguide
TEM- Transverse Electromagnetic
TM- Transverse Electric
TE- Transverse Magnetic
SMA- SubMiniature version A
FR4- Flame Retardant
FEM- Finite Element Method
In this study, a micro-strip fed slot antenna array for application in the 2.4GHz ISM band was implemented using the Ansoft HFSS software. Standard formulas were used to calculate different antenna parameters. The proposed antenna was designed to work at 2.4GHz frequency band. A HPBW of 57°. A bandwidth of around 7.7% was attained. This may have been brought about by poor impedance matching and a high level of surface waves. A way of improving the bandwidth would have been to use proximity coupling feeding method which offers the highest bandwidth and is somewhat easy to model and has low spurious radiation. However, its fabrication would have been more difficult. A directivity of 2.01 dB was achieved. This was a fairly high though directivity increase could have been studied through use of different substrate material and thickness. Adjusting length and width of narrow slot loop antenna will influence on the resonance frequency and bandwidth. By using HFSS software, the characteristics of antenna are investigated and analyzed, including VSWR, return loss and far field radiation patterns.
CHAPTER 1

1.1 INTRODUCTION

An antenna is a structure designed for radiating electromagnetic energy effectively in a prescribed manner. An antenna may be a single straight wire or a conducting loop excited by a voltage source, an aperture at the end of a waveguide, or complex array of these properly arranged radiating elements.

A slot antenna is a narrow-width opening in a conductive sheet which when excited by a voltage across the narrow dimension, it appears to radiate from an equivalent magnetic current flowing along the long dimension that replaces the voltage (or electric field) across it. Most slots have a finite length with either an open or short circuit at both ends. The voltage along the slot forms a standing wave.

This report presents the design and analysis of slot antenna array for the 2.4GHz ISM (industrial, scientific and medical) band which is largely license exempt and can be accessed freely for example, near field communication in devices, Bluetooth and wireless computer networks. The antenna will be designed with an aim of achieving high directivity and at least a 10% fractional bandwidth. The antenna will have a center frequency of 2.44 which is almost the same as the given ISM band center frequency. It was so chosen so as to have a bandwidth whose range falls within the 2.4 GHz band.

1.2 PROJECT OBJECTIVE

This project presents design analysis and fabrication of a slot antenna array for 2.4 GHz. Basic design specifications for a slot antenna were considered are center frequency and bandwidth. The specifications are given in the table below.

<table>
<thead>
<tr>
<th>Table 1 Antenna Specifications</th>
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<tbody>
<tr>
<td><strong>FEATURE</strong></td>
</tr>
<tr>
<td>Center Frequency</td>
</tr>
<tr>
<td>HPBW</td>
</tr>
<tr>
<td>Fabrication Technology</td>
</tr>
<tr>
<td>Circuit Board Material</td>
</tr>
<tr>
<td>Substrate thickness</td>
</tr>
<tr>
<td>---------------------</td>
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<td>Relative permittivity</td>
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### 1.3 PROJECT SCOPE

This project entails the following:

- Understand the design, fabrication and testing of 2.4 Slot antenna array developed by using a micro-strip.
- The results acquired through R & D process have been simulated, analyzed and verified by micro-strip technology, which were later, enhanced by various value-aided software tools such as PCB Express and HFSS (2013).
- Carry out comparative slot antenna analysis with the help of vector network analyzer, which gives the best choice for further analysis and development.
- Optimization of both experimental and analytical data acquired through the design, simulation, and fabrication and testing process of the slot antenna. Subsequent results demonstrate, through verification process, that the experimental results (measured) gives more or less same performance compare analytical one (calculated).
CHAPTER 2

2.1 LITERATURE REVIEW

An antenna is generally a bidirectional device, that is, the power through the antenna can flow in both directions, coupling electromagnetic energy from the transmitter to free space and from free space to the receiver, and hence it works as a transmitting as well as a receiving device, that is, by reciprocity. Transmission lines are used to transfer electromagnetic energy from one point to another within a circuit and this mode of energy transfer is generally known as guided wave propagation. An antenna can be thought of as a mode transformer which transforms a guided-wave field distribution into a radiated-wave field distribution.

2.1.1 Fundamental Antenna parameters

Lobes

Any given antenna pattern has portions of the pattern that are called lobes. A lobe can be a main lobe, a side lobe or a back lobe and these descriptions refer to that portion of the antenna pattern in which the lobe appears. In general, a lobe is any part of the pattern that is surrounded by regions of weaker radiation.

Radiation Pattern

A radiation pattern defines the variation of the power radiated by an antenna as a function of the direction away from the antenna. This power variation as a function of the arrival angle is observed in the antenna's far field. Antenna radiation patterns are taken at one frequency, one polarization and one plane cut. The patterns are usually presented in polar or linear form with a dB strength scale. Antenna radiation plots can be quite complex because in the real world they are three-dimensional. However, to simplify them a Cartesian coordinate system (a two-dimensional system which refers to points in free space) is often used. Radiation plots are most often shown in either the plane of the axis of the antenna or the plane perpendicular to the axis and are referred to as the azimuth or "E-plane" and the elevation or "H-plane" respectively. It is common, however, to describe this 3D pattern with two planar patterns, called the principal plane patterns. These principal plane patterns can be obtained by making two slices through the 3D pattern through the maximum value of the pattern or by direct measurement. It is these principal plane patterns that are commonly referred to as the antenna patterns.

Far-field
This is the region away from an antenna where the radiated wave essentially takes the form of a plane wave. A commonly used criterion is $2D^2/\lambda$, where $D$ is the maximum linear dimension of the antenna, and $\lambda$ is the operating wavelength. Radiation patterns are generally assumed to be in the far-field of the antenna.

**Azimuth and Elevation Plane (E and H plane)**

Characterizing an antenna's radiation properties with two principal plane patterns works quite well for antennas that have well-behaved patterns, that is, not much information is lost when only two planes are shown. Figure 2.1 shows a possible coordinate system used for making such antenna measurements.

![Antenna measurement coordinate system](image)

**Figure 2.1** Antenna measurement coordinate system

The term *azimuth* is commonly found in reference to the horizontal whereas the term *elevation* commonly refers to the vertical. When used to describe antenna patterns, these terms assume that the antenna is mounted (or measured) in the orientation in which it will be used. In the Figure, the $xy$-plane ($\theta = 90^\circ$) is the azimuth plane (E-plane). The azimuth plane pattern is measured when the measurement is made traversing the entire $xy$-plane around the antenna under test. The elevation plane (H-plane) is then a plane orthogonal to the $xy$-plane, say the $yz$-plane ($\Phi = 90^\circ$). The elevation plane pattern is made traversing the entire $yz$-plane around the antenna under test.

**Return Loss**

Return loss is a measure of the reflected energy from a transmitted signal. It is a logarithmic ratio measured in dB that compares the power reflected by the antenna to the power that is fed into the
antenna from the transmission line. The larger the value of return loss the less is the energy reflected. For good impedance matching resonant frequency must lie below $-10 \, dB$.

**Bandwidth**

Bandwidth is defined as the range between upper cut-off frequency ($f_U$) at -10 dB and lower cut-off ($f_L$) frequency at -10 dB. Bandwidth indicates range of frequency for which an antenna provides satisfactory operation.

**Half Power Beamwidth**

Also known as the 3-dB beamwidth is typically defined for each of the principle planes. The Half Power Beamwidth (HPBW) is the angular separation in which the magnitude of the radiation pattern decreases by 50% (or -3 dB) from the peak of the main beam.

**VSWR**

The parameter VSWR is a measure that numerically describes how well the antenna is impedance matched to the radio or transmission line it is connected to. The smaller the VSWR the better the antenna matched to the transmission line and the more the power delivered to the antenna. Higher values of VSWR indicate more mismatch loss. For the perfect matching VSWR = 1, there is no reflection. In the real system it is very hard to achieve a perfect match, so it is defined that having VSWR ≤ 2 is a good matching transmission line.

**Directivity**

It is a measure of how 'directional' an antenna's radiation pattern is. An antenna that radiates equally in all directions would have effectively zero directionality, and the directivity of this type of antenna would be 1 (or 0 dB).

**Efficiency**

Like other microwave components, an antenna may dissipate power due to conductor loss or dielectric loss, and so antenna efficiency can be defined as the ratio of total power radiated by the antenna to the input power of the antenna.

**Antenna Gain**

Gain is a measure of the ability of the antenna to direct the input power into radiation in a particular direction and is measured at the peak radiation intensity. Antenna gain is the product of directivity and efficiency and accounts for the fact that loss reduces the power density radiated in a given direction. It is standard practice to use an isotropic radiator as the reference antenna in
this definition. An isotropic radiator is a hypothetical lossless antenna that radiates its energy equally in all directions. This means that the gain of an isotropic radiator is \( G=1 \) (or 0 dB).

**Polarization**

The polarization of an antenna is the polarization of the electric field vector of the radiated wave radiated by the antenna in the far field. Typical polarizations include linear (vertical or horizontal), and circular (RHCP or LHCP). Some antennas are designed to operate with two polarizations. For optimum system performance, transmit and receive antennas must have the same polarization.

**Impedance**

An antenna presents a driving-point impedance to the source or load to which it is connected, and so impedance mismatch with a feed line can occur. This mismatch degrades antenna performance, and is dependent on the external circuitry which is connected to the antenna.

**Front-to-back ratio**

The Front-to-Back Ratio is a parameter used in describing directional radiation patterns for antennas. If an antenna has a unique maximum direction, the front-to-back ratio is the ratio of the gain in the maximum direction to that in the opposite direction (180 degrees from the specified maximum direction). This parameter is usually given in dB

### 2.1.2 Slot Antennas

A slot antenna consists of a metal surface, usually a flat plate, with a hole or slot cut out. When the plate is driven as an antenna by a driving frequency, the slot radiates electromagnetic waves in a way similar to a dipole antenna. The shape and size of the slot, as well as the driving frequency, determine the radiation distribution pattern. A slot antenna's main advantages are its size, design simplicity, robustness, mechanically robust when mounted on rigid surfaces, compatible with MMIC designs and convenient adaptation to mass production using PC board technology. Unique features of these antennas are horizontal polarization and omnidirectional gain around the azimuth. Slot antennas exhibit wider bandwidth which is approximately 10-20%, lower dispersion and lower radiation loss compared to micro-strip antennas. The slot antennas can be fed by micro-strip line, slot line or CPW. In this report, the design of slot antenna is fed by micro-strip line.

In a conventional micro-strip line-fed slot antenna, a narrow rectangular slot is cut in the ground plane and the slot is excited by a micro-strip feed line with a short or an open termination. With this feed configuration, a good impedance match has been achieved with a narrow slot, and a bandwidth of approximately 7.7% has been obtained. However, as the width of the slot increases, the radiation resistance of the slot antenna also increases proportionately. This, in turn, reduces the impedance bandwidth of the antenna, even though the size of the slot is larger. There is a possibility of increasing the bandwidth of a wide slot antenna by terminating the open end of the
feed line within the width of the slot, although substantial bandwidth improvement has not been achieved. The conventional feeding structures of conventional transverse slot antennas are center feeding and offset feeding. The center feed has a larger value of radiation impedance than an offset feed. It means that the bandwidth of a center feed antenna is less than for an offset fed antenna.

2.1.3 Basic Characteristics
Slot antennas, as shown in Figure 2.2, consist of a very thin width (t ≪ λg, where λg is the dielectric wavelength) on a ground plane. For a rectangular slot, the length L of the element is usually λg/3 < L < λg/2. The microstrip line and the ground plane are separated by a dielectric substrate.

There are numerous substrates that can be used for the design of microstrip antennas and their dielectric constants are usually in the range of 2.2 ≤ εr ≤ 12. The ones that are most desirable for good antenna performance are thick substrates whose dielectric constant is in the lower end of the range because they provide better efficiency, larger bandwidth, loosely bound fields for radiation into space, but at the expense of larger element size.

The radiating elements and the feed lines are usually photo-etched on the dielectric substrate. The radiating slot may be square, rectangular, circular, triangular, or any other configuration. Square, rectangular and circular are the most common because of ease of analysis and fabrication, and their attractive radiation characteristics, especially low cross-polarization radiation.

Figure 2.2 Slot antenna and coordinate system

There are many configurations that can be used to feed slot antennas. The most popular methods are the micro-strip line, coaxial probe, aperture coupling, and proximity coupling. The micro-
strip line feed 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 increases, which for practical designs limits the bandwidth.

There are various methods of analysis for slot antennas with the most popular models being the transmission-line, MoM and FTTD. The transmission-line model is the easiest of all, it gives good physical insight, but is less accurate and it is more difficult to model coupling.

2.1.4 Transmission–Line Model Analysis for a Rectangular Slot

2.1.4. a Fringing Effects

Micro-strip line is one of the most popular types of planar transmission lines primarily because it can be fabricated by photolithographic processes and is easily miniaturized and integrated with both passive and active microwave devices. The geometry of a micro-strip line is shown in Figure 3.25a. A conductor of width $W$ is printed on a thin, grounded dielectric substrate of thickness $d$ and relative permittivity $\varepsilon_r$; a sketch of the field lines is shown in Figure 2.3

![Figure 2.3 Diagram showing fringing effects on a micro-strip line](image)

The presence of the dielectric, particularly the fact that the dielectric does not fill the region above the strip ($y > d$), complicates the behavior and analysis of micro-strip line. The micro-strip has some (usually most) of its field lines in the dielectric region between the strip conductor and the ground plane and some fraction in the air region above the substrate. For this reason micro-strip line cannot support a pure TEM wave so a phase-matching condition at the dielectric–air interface would be impossible to enforce.

In actuality, the exact fields of a micro-strip line constitute a hybrid TM-TE wave. In most practical applications, however, the dielectric substrate is electrically very thin ($d \ll \lambda$), and so the fields are quasi-TEM. In other words, the fields are essentially the same as those of the static (DC) case.
2.1.5 Effective Length, Width, dielectric constant and characteristic impedance

The length of the slot, $L_s = \frac{\lambda_g}{2}$.

The width of the slot, $W_s = 0.1 \lambda_g$.

The effective dielectric constant of a micro-strip line is given approximately by:

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

For a given characteristic impedance $Z_0$ and dielectric constant $\varepsilon_r$, the $\frac{W}{d}$ ratio is approximated by:

$$\frac{W}{d} = 2 \ln \left[ B - 1 - \ln (2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r} \ln (B - 1) + 0.39 \frac{0.61}{\varepsilon_r} \right]$$

Where $B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}}$

2.1.6 Arrays and Feed Networks

Usually the radiation pattern of a single element is relatively wide, and each element provides low values of gain and directivity. In many applications it is necessary to design antennas with very directivity/gain to meet the demands of long distance communication. This can only be accomplished by increasing the electrical size of the antenna. Enlarging the dimensions of single elements often leads to more directive characteristics. Another way to enlarge the dimensions of the antenna, without necessarily increasing the size of the individual elements, is to form an assembly of radiating elements in an electrical and geometrical configuration. This new antenna, formed by multi elements which are driven by the same source, is referred to as an array. In most cases, the elements of an array are identical.

The total field of the array is determined by the vector addition of the fields radiated by the individual elements. This assumes that the current in each element is the same as that of the isolated element (neglecting coupling). This is usually not the case and it depends on the separation between the elements. To provide very directive patterns, it is necessary that the fields from the elements of the array interfere constructively (add) in the desired directions and interfere destructively (cancel each other) in the remaining space. Ideally this can be
accomplished, but practically it is only approached. In an array of identical elements, there are at least five controls that can be used to shape the overall pattern of the antenna. These are:

1. The geometrical configuration of the overall array (linear, circular, rectangular, spherical, etc.)
2. The relative displacement between the elements
3. The excitation amplitude of the individual elements
4. The excitation phase of the individual elements
5. The relative pattern of the individual elements

Arrays are very versatile and are used to synthesize a required pattern that cannot be achieved with a single element. In addition, they are used to scan the beam of an antenna system, increase the directivity, and perform various other functions which would be difficult with any one single element. The elements can be fed by a single line or by multiple lines in a feed network arrangement. The first is referred to as a series-feed network while the second is referred to as a corporate-feed network. The corporate-feed network is used to provide power splits of $2^n$ (i.e., n=2, 4, 8, 16, 32, etc.). This is accomplished by using either tapered lines, or using quarter-wavelength impedance transformers [1].

![Feed arrangements for micro-strip slot arrays](image)

**Figure 2.4** Feed arrangements for micro-strip slot arrays

Corporate-fed arrays are general and versatile. With this method the designer has more control of the feed of each element (amplitude and phase) and it is ideal for scanning phased arrays, multi-beam arrays, or shaped-beam arrays. The phase of each element can be controlled using phase shifters while the amplitude can be adjusted using either amplifiers or attenuators.

Those who have been designing and testing micro-strip arrays indicate that radiation from the feed line, using either a series or corporate-feed network, is a serious problem that limits the cross-polarization and side lobe level of the arrays. Both cross-polarization and side lobe levels can be improved by isolating the feed network from the radiating face of the array. This can be accomplished using either probe feeds or aperture coupling.
In slot arrays, mutual coupling between elements can introduce scan-blindness which limits, for a certain maximum reflection coefficient, the angular volume over which the arrays can be scanned. For micro-strip antennas, this scan limitation is strongly influenced by surface waves within the substrate. This scan angular volume can be extended by eliminating surface waves. One way to do this is to use cavities in conjunction with micro-strip elements. It has been shown that the presence of cavities, either circular or rectangular, can have a pronounced enhancement in the E-plane scan volume, especially for thicker substrates. The H-plane scan volume is not strongly enhanced. However the shape of the cavity, circular or rectangular, does not strongly influence the results.
CHAPTER 3

3.1 THE DESIGN METHODOLOGY

A rectangular slot was chosen as the basis of the design because of its ease of fabrication and analysis. The micro-strip line was used as the feeding method as it is easy to fabricate, simple to match by controlling the inset feed position and rather simple to model. The antenna was designed to work in the 2.4GHz ISM band which has a frequency range of 2.5-2.6GHz, a center frequency of 2.58GHz, a bandwidth of 100MHz and is freely available worldwide.

3.1.1 Design Procedure

The FR4 Glass Epoxy, whose loss tangent is 0.002, was chosen as the dielectric substrate.

To commence the design procedure assumes, specific information had to be included: dielectric constant of the substrate ($\varepsilon_r$), the resonant frequency ($f_r$) and the height of the substrate,$h$.

$$\varepsilon_r = 4.3, f_r = 2.4\,GHz, \, h = 1.6\,mm$$

For an efficient radiator, the practical width that leads to good radiation efficiencies is

$$W = 0.1\lambda g$$

$$W = 7\,mm$$

The initial values (at low frequencies) of the effective dielectric constant are referred to as the static values, and they were calculated as

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

$$\varepsilon_{reff} = 3.27$$

The actual length of the slot was determined by solving $L$ as,

$$L = 0.5\lambda g$$

$$L = 35\,mm$$
For efficient transfer of power from a transmission line to the slot antenna, the input impedance of the slot antenna needed to be matched to the characteristic impedance of the transmission line. It was observed that impedance seen by a transmission line attached to the radiating edge increased as one moved towards the center of the slot. Therefore, depending on the characteristic impedance of the transmission line, an appropriate point on the slot was chosen through calculation as the feed point. An off-the centre feed was used with distance from the edge calculated as:

\[ 0.05\lambda g = 3.5\, mm \]  \hspace{1cm} (3 - 4)

### 3.1.2 Ground Plane

As part of the antenna, the ground plane should be infinite in size as for slot antenna but in reality this is not easy to apply besides a small size of ground plane is desired. In practice, it has been found that the micro-strip impedance with finite ground plane width \((Z_o)\) is practically equal to the impedance value with infinite width ground plane \((Z_i)\), if the ground width \(W_g\) > 3*W.

The size of the ground plane was chosen as:

\[ 100\, mm \text{ by } 97.5\, mm \]  \hspace{1cm} (3 - 5)

### 3.1.3 Micro-strip Discontinuities

Surface waves are electromagnetic waves that propagate on the dielectric interface layer of the micro-strip. The propagation modes of surface waves are practically TE and TM. Surface waves are generally at any discontinuity of the micro-strip. Once generated, they travel and radiate, coupling with other micro-strip of the circuit, decreasing isolation between different networks and signal attenuation. Surface waves are a cause of crosstalk, coupling, and attenuation in a multi-micro-strip circuit. For this reason surface waves are always an undesired phenomenon [9].

A discontinuity in a micro-strip is caused by an abrupt change in geometry of the strip conductor, and electric and magnetic field distributions are modified near the discontinuity. The altered electric field distribution gives rise to a change in capacitance, and the changed magnetic field distribution to a change in inductance.

### 3.1.4 Micro-strip feed and distance between elements

For the 2-element array of figure 3.1(to be placed) to implement an even number of in-phase slot elements, the feed network needed to be carefully designed. The distance from the 50-ohm SMA source to each slot element needed to be identical or multiples of \(\lambda\). Unequal line lengths would
have produced phase shifts, which would yield fixed beams that would be scanned away from the broadside. The 50-ohm micro-strip line was fed using a 50-ohm SMA. In the design of an effective in-phase radiator, the distance between the slot elements needed to be optimized to yield a peak gain. A separation distance of $\lambda/2$ as providing the optimal gain. In the design, this separation was used as 35mm.

3.1.5 Matching of Micro-strip Lines to the Source

The characteristic impedance of a transmission line of the micro-strip feed was designed with respect to the source impedance. The characteristic impedance $Z_o$ of the transmission line from the source with respect to the source impedance $Z_s$ was

$$Z_o = Z_s \quad (3 - 6)$$

$$Z_o = 50 \text{ Ohms}$$

3.1.6 Quarter-wave Transformer

For the input impedance of a transmission line of length $l$ with a characteristic impedance $Z_o$ and connected to a load with impedance $Z_A$:

$$Z_{in}(-L) = Z_o \left[ Z_A + jZ_o \tan(\beta l) \right] \frac{Z_o}{Z_A + jZ_o \tan(\beta l)} \quad (3 - 7)$$

When the length of the transformer is a quarter wavelength;

$$Z_{in} \left( L = \frac{\lambda}{4} \right) = \frac{Z_o^2}{Z_A} \quad (3 - 8)$$

Hence by using a transmission line with a characteristic impedance of 50-ohms, the 50 ohm inset feed line was matched to

$$Z_o = \sqrt{50 \times 50} \quad (3 - 9)$$

$$= 50 \text{ ohms}$$

Where $Z_o =$ Characteristic impedance of the quarter-wavelength transformer

This ensured that no power would be reflected back to the SMA feed point as it tried to deliver power to the antenna.

The length of the quarter wavelength transformer was calculated as
\[ l = \frac{\lambda g}{4} \]  \quad (3 - 10) \\
\[ = 17.5\text{mm} \]

3.1.7 Simulation

The antenna array was designed using the Ansoft HFSS 13.0 software. HFSS is a 3D full wave electromagnetic field simulator. HFSS uses a numerical technique called the Finite Element Method (FEM). This is a procedure where a structure is subdivided into many smaller subsections called finite elements. The finite elements used by HFSS are tetrahedra, and the entire collection of tetrahedra is called a mesh. A solution is found for the fields within the finite elements, and these fields are interrelated so that Maxwell’s equations are satisfied across inter-element boundaries yielding a field solution for the entire, original, structure. Once the field solution has been found, the generalized S-matrix solution is determined. It can calculate and plot both the near and far field radiation and compute important antenna parameters such as gain and radiation efficiency. This software was used to vary the sizes of the slot. Figure 3.4 illustrates the HFSS antenna model.

![Figure 3.1 2 element slot antenna HFSS model](image)
3.1.8 Fabrication
As per the HFSS designs, masks for fabrication of the slot antenna and the ground plane were designed using PCB Express. The mask images were then transferred to transparent films before being photoengraved to a double sided PCB by exposure to UV light for 60 seconds. The PCB was then suspended in Sodium Hydroxide developer for a minute to develop photoresist. It was washed after which chemical etching done using a solution of iron chloride to create the slot antenna. The etched copper pattern was rinsed in water and again exposed to UV light for a minute. It was immersed in the developer to remove the photoresist and finally cleaned with water. After air drying, an RF RP-SMA connector (through-hole, Jack (male pin) right angle PCB mount connector) with solder post was soldered at the center of the PCB from the backside. An RG58/U cable was used to connect to the SMA connector. The other end of the cable was terminated to an N male connector. This was to be used as the connector to a spectrum analyzer.
Figure 3.3 Implemented 2-element slot antenna array
The designed antenna was tested for the centre frequency using a spectrum analyzer using a computer with Wi-Fi connectivity on and it picked a peak frequency of 2.428GHz. The radiation pattern, gain and directivity could not be measured because of lack of equipment in the laboratory. It was also late to take antenna parameter measurements at CAK.

Figure 3.8 N male to sma female cable
4. CHAPTER FOUR

4.1 HFSS SIMULATION RESULTS AND ANALYSIS

4.1.1 VSWR Plot

Figure 4.1 shows the VSWR plot for the designed antenna. The value of the VSWR should lie between 1 and 2. SWR is used as an efficiency measure for transmission lines, electrical cables that conduct radio frequency signals, used for purposes such as connecting radio transmitters and receivers with their antennas.
4.1.2 Smith Chart

The smith chart is a graphical representation of the normalized characteristic impedance. It provides the information about the impedance match of the radiating slot. The smith chart for the designed slot antenna array showed an input impedance of 50.78+10.5i ohms at resonant frequency 2.58 GHz. The magnitude of the input impedance was 51.85 which showed that accurate matching was not achieved. This was due to shifting of the inset feed position away from the edge of the ground plane.

4.1.3 Reflection Coefficient and Bandwidth
Figure 4.3 shows the reflection coefficient $[S_{11}]$ of the proposed antenna in dB. $S_{11}$ gives the reflection coefficient at the inset feed position where the input to the micro-strip slot antenna was applied. It should be less than -10dB for an acceptable operation. It shows that the proposed antenna had a frequency of resonance of 2.58GHz.

The simulated impedance bandwidth of about 200MHz (2.5022-2.7023 GHz) was achieved at $-10dB$ reflection coefficient (VSWR≤2). The reflection coefficient value that was achieved at this resonant frequency was equal to -15.33 dB. This reflection coefficient value suggested that there was good matching at the frequency point below the -10dB region.

### 4.1.4 Variation of slot length and width

Dimensions calculated in the design procedure were used to create a 2 element slot antenna array. The antenna, however, did not produce acceptable results. In order to shift the $S_{11}$ minima towards the desired center frequency, the length and width of the slot were varied.

#### Table 4.1 Simulation results of slot antenna by adjusting width

<table>
<thead>
<tr>
<th>Width(mm)</th>
<th>Resonance Frequency(GHz)</th>
<th>Return loss $S11$ (dB)</th>
<th>Bandwidth (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td>2.71</td>
<td>-10.5</td>
<td>165</td>
</tr>
<tr>
<td>5.5</td>
<td>2.68</td>
<td>-14.9</td>
<td>173</td>
</tr>
<tr>
<td>6.0</td>
<td>2.64</td>
<td>-25.5</td>
<td>188</td>
</tr>
<tr>
<td>6.5</td>
<td>2.62</td>
<td>-18.74</td>
<td>195</td>
</tr>
<tr>
<td>7.0</td>
<td>2.58</td>
<td>-15.33</td>
<td>200</td>
</tr>
</tbody>
</table>
At designed frequency of 2.58 GHz, the width of slot antenna is varied in five values beginning from 5.0 mm to 7.0 mm by step up 0.5 mm, and length is adjusted for match impedance. The simulation results of return loss $S_{11}$, resonance frequency and bandwidth are tabulated in Table 1. It shows that the changing in width of slot antenna will affect on the resonance frequency. When the width of slot is increased, the resonance frequency will decrease and bandwidth is wider. Therefore, if we increase the width of slot, the length of slot should be decreased in order to achieve the same resonance frequency and wider bandwidth.

**4.1.5 Radiation Pattern**

![Radiation Pattern 2](image1)

**Figure 4.4 Radiation pattern of E-total at 2.58 GHz xz plane ($\Omega=0^\circ$)**

![Radiation Pattern 4](image2)
4.1.6 Other antenna parameters

The table 4.2 shows a summary of the antenna parameters from the HFSS software. The directivity $D$ and efficiency $\eta$ were 2.0109 and 62.5%, which gave a gain $G = \eta D$ of the antenna as 1.25. The front to back ratio was 1.2224.

![Antenna Parameters Table]

Table 4.2 Antenna parameters

![E-Plane and H-Plane patterns in rectangular coordinates]

Figure 4.6 E-Plane and H-Plane patterns in rectangular coordinates
The Figure 4.5 shows that the antenna had two main lobes which were 180° out of phase with each other. It was used to determine the half-power beam widths for the radiation patterns as the peaks and 3 dB points below them could easily be picked.
CHAPTER 5

5.1.1 Conclusion

A printed modified wide length slot fed by a 50Ω microstrip line was presented in the project. In addition, the size of the implemented antenna array can be increased. Moreover, the two rectangular slots are embedded on the ground plan to increase antenna gain. With optimized antenna geometry, the implemented antenna offers a bandwidth of 7.7%. By properly calculating slot dimensions and tuning the dimension parameters with simulation software, the implemented design, improvements can be made on the gain, bandwidth and radiation pattern. The implemented antenna is feasible for use as a low profile, low cost antenna for wireless applications in the ISM band.

6.0 REFERENCES

4. ANSYS HFSS. ver. 14.0.0, ANSYS, Canonsburg, PA, USA, 2011[Online].