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USKUDAR UNIVERSITY

INSTITUTE OF SCIENCE

DEPARTMENT OF ELECTRICAL ELECTRONICS ENGINEERING
MASTER'S DEGREE PROGRAM OF ELECTRICAL ELECTRONICS ENGINEERING
MASTER'S DEGREE THESIS

**PERFORMANCE OPTIMIZATION OF RECTANGULAR
MICROSTRIP PATCH ANTENNAS**

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Thesis Advisor

Prof. Dr. Gökhan APAYDIN

ISTANBUL-2023

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ABSTRACT

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Regarding communication systems engineers, microstrip patch antenna is the ideal option due to their performance and benefits including low weight, low profile, and low cost. They can integrate with applications like mobile devices, WLAN applications, navigation systems, and many others.

In this scientific study, the performance of “Rectangular microstrip patch antennas” has been improved, which is the most used in Wi-Fi and applications for wireless local area networks (Wireless Lan), due to their ease of manufacture and low cost with their lightweight and small size to be placed inside wireless communication devices with some disadvantages, the most important of which is narrow bandwidth.

The design focuses on increasing the bandwidth to achieve impressive performance over a broad frequency range at the frequency of 2.45 GHz. This rectangular microstrip patch antenna design is presented using a coaxial-line feed with a dielectric substrate type (*Rogers RT5870*) with the use of additional microstrip resonators or extra patch introduction and a modification in the design parameters as dielectric height, patch width and length) to get better results in rectangular microstrip patch antenna performance compared to the actual design parameters in terms of directivity of the radiation pattern, gain, bandwidth, VSWR, and return loss.

Utilizing computer simulation technologies (CST STUDIO, MATLAB) have been used to construct and simulated the suggested rectangular microstrip patch antennas, the proposed antenna matches the specifications and exhibits outstanding as well as favorable radiation patterns and properties in many frequency bands, pertinent WLAN connections, according to the developed antenna simulation results.

Keywords: Bandwidth, frequency, insulating substrate, wireless communication

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Special thanks to my honorable mother, may God prolong her life, for encouraging me and praying for me to achieve my ambition and reach the highest scientific ranks.

Finally, to my dear family, thank you sincerely for your constant giving and encouragement.

FORM OF DECLARATION

Herewith I declare, that I obtained all the information and documents in this study within the framework of academic rules, presented all visual, auditory, and written information and results by scientific ethics did not falsify the data I used, referred to the sources I used in accordance ways, that my thesis was original except in the cases cited, produced by me and written by the Thesis Writing Guide of Uskudar University Institute of Sciences.

09/01/2023

Abdalfahed Salem

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LIST OF ABBREVIATIONS AND SYMBOLS

CST: Computer System Technology

dB: decibel

dBi: decibel isotropic

VSWR: Voltage Standing Wave Ratio

WLAN: Wireless Local Area Network

ITU: International Telecommunication System

IEEE: Institute of Electrical and Electronics Engineers

RF: Radio Frequency

MSA: Microstrip Antenna

RH: Right Hand

LF: Left Hand

Wi-Fi: Wireless Fidelity

GPR: Ground Penetrating Radar

RFID: Radio Frequency Identification

PTFE: Polytetrafluoroethylene

G.P: Ground Plane

MICs: microwave integrated circuits

Q: the quality factor

c: Speed of light (3×10^8 m/s)

λ : Wavelength

ϵ_r : Dielectric-constant of Substrate

h : height of the dielectric

w: width the Patches

Z_c : impedance

L : length the Patches

ϵ_{reff} : Dielectric-constant effective

RT Duroid: glass-reinforced microfiber

SWE: efficiency of surface wave

ω_r : angular resonant frequency

w_T : total energy stored in the patch at resonance.

$\tan \delta$: loss tangent of the dielectric

Δ : skin depth of the conductor

h : height of Substrate

P_r : power radiated from the patch.

AR: axial ratio

SWE: surface wave efficiency

TE: transverse electric waves

TM: transverse magnetic waves

TEM: transverse electromagnetic waves

1. INTRODUCTION

There is a growing need in today's mobile, satellite, and wireless communication systems for smaller, less expensive, reconfigurable antennas that are simple to integrate into packaging structures. Because they preferred certain operating frequencies, patterns, and polarization, reconfigurable microstrip patch antennas attracted a lot of attention in wireless communication systems (Chung k et al., 2006).

Antennas are among the most significant parts in the formation of any wireless communication device and the development of low-cost and small-sized antennas to work efficiently within a wide frequency range in communication devices is an important topic that requires a lot of research and study.

In the past few years, the issue of inventing microwave antennas using microstrip patch antennas has attracted increasing attention, this antenna is one of the modern antennas since it was originally applied in the 1970s.

Researchers have been interested in this type of antenna due to its good specifications and wide use in the field of communications, the development of high-efficiency, low-cost, compact, multiband, and broadband antennas that can be incorporated into wireless products is in high demand.

In this research, we will deal with a study to improve the performance of among the widespread kinds, which is the antenna “rectangular microstrip patch antennas” in terms of increasing the bandwidth, directivity, gain, and some other characteristics through improving the design and choosing the best parameters for the antenna design.

Microstrip patch antennas in a rectangular shape are one of the shapes and have become one of the most popular antennas for their ease of analysis and installation, as well as for their small size with several types of feeding methods (John D. Kraus, 1992).

This antenna usually uses frequencies in the level greater than 1 GHz and is used in many applications such as telephone and satellite devices as well as in aircraft and can operate WLAN with rectangular microstrip patch antennas WLAN is an IEEE 802.11b-compliant broadband wireless technology that operates with a frequency of 2.45 GHz, and provides a rich set of features with great flexibility in terms of diffusion options and streaming services.

2. GENERAL INFORMATION

2.1. Geometry and Structure of a Microstrip Antenna

2.1.1. Introduction

The traditional and simple shape of the printed microchip antenna consists of a metal piece of different shapes (rectangular - square - circular - triangular - oval - etc.) fixed (printed) on a piece of a small thickness insulating material called Substrate, and the other side of the insulating material It is covered with a metal layer that is considered as the ground surface, displayed in Figure 2.1.

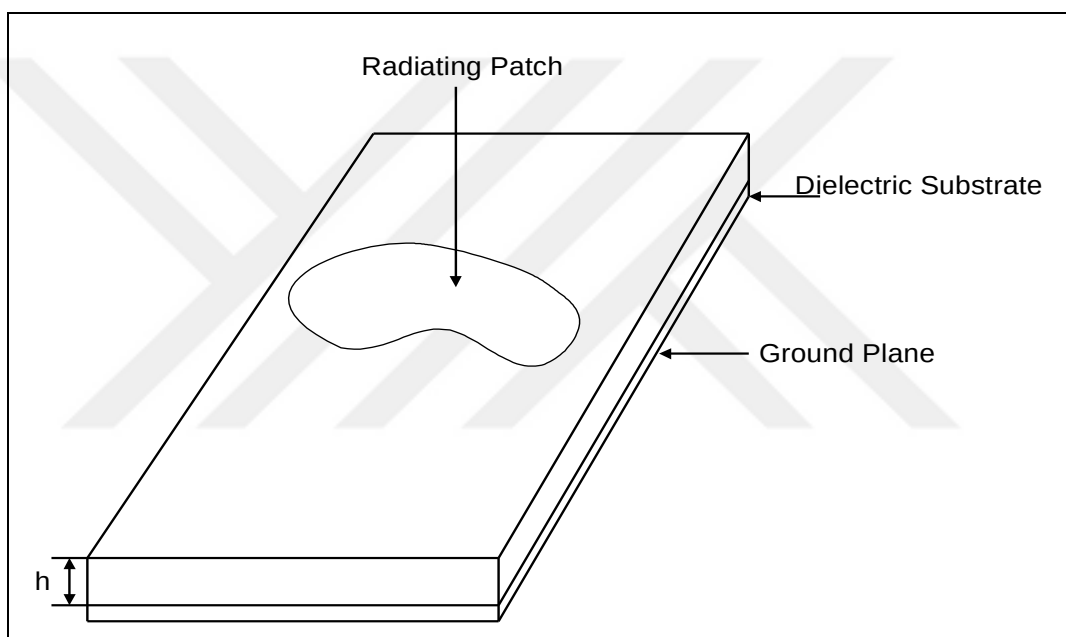


Figure 2.1: Configuration of an arbitrary shape microstrip antenna

The rectangular microstrip patch antenna is comprised of two layers of a well-conductive material, such as copper or gold, separated by an electrically insulating substrate layer, with the first layer acting as a patch and the second as a ground surface, as displayed in Figure 2.2. One of the most significant aspects affecting antenna performance “rectangular microstrip patch antenna” is the shape, area, and type of the patch material.

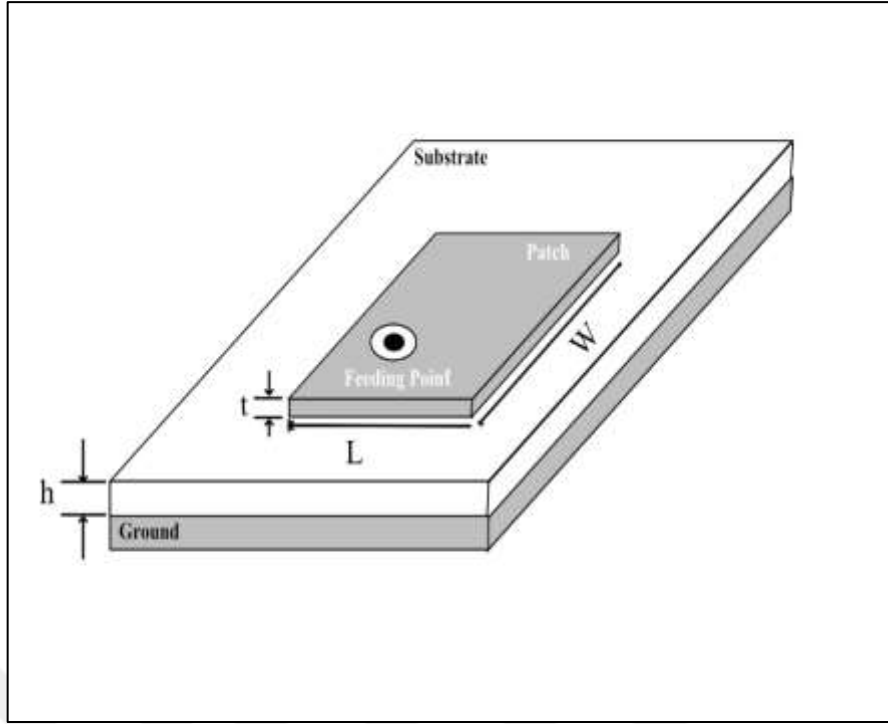


Figure 2.2: Microstrip patch antennas a rectangular shape

For rectangular patches, the patch length L is typically $(0.3333 \lambda_o < L < 0.5 \lambda_o)$, where λ_o is the wavelength in free space. The patches are chosen to be very thin such that $(t \ll \lambda_o)$, where t is the thickness of the patches.

The height h of the dielectric substrate is typically $(0.003 \lambda_o \leq h \leq 0.05 \lambda_o)$. The dielectric-constant (ϵ_r) of the substrate is typically in the range $(2.2 \leq \epsilon_r \leq 12)$.

The kind of substrate material and its thickness have an impact on the antenna's size, radiation range, gain rate, and directivity, the dielectric-constant of the substrate is determined, and the size of the patches installed in the antenna. The various techniques for creating the insulating layer are depicted in Figure 2.3.

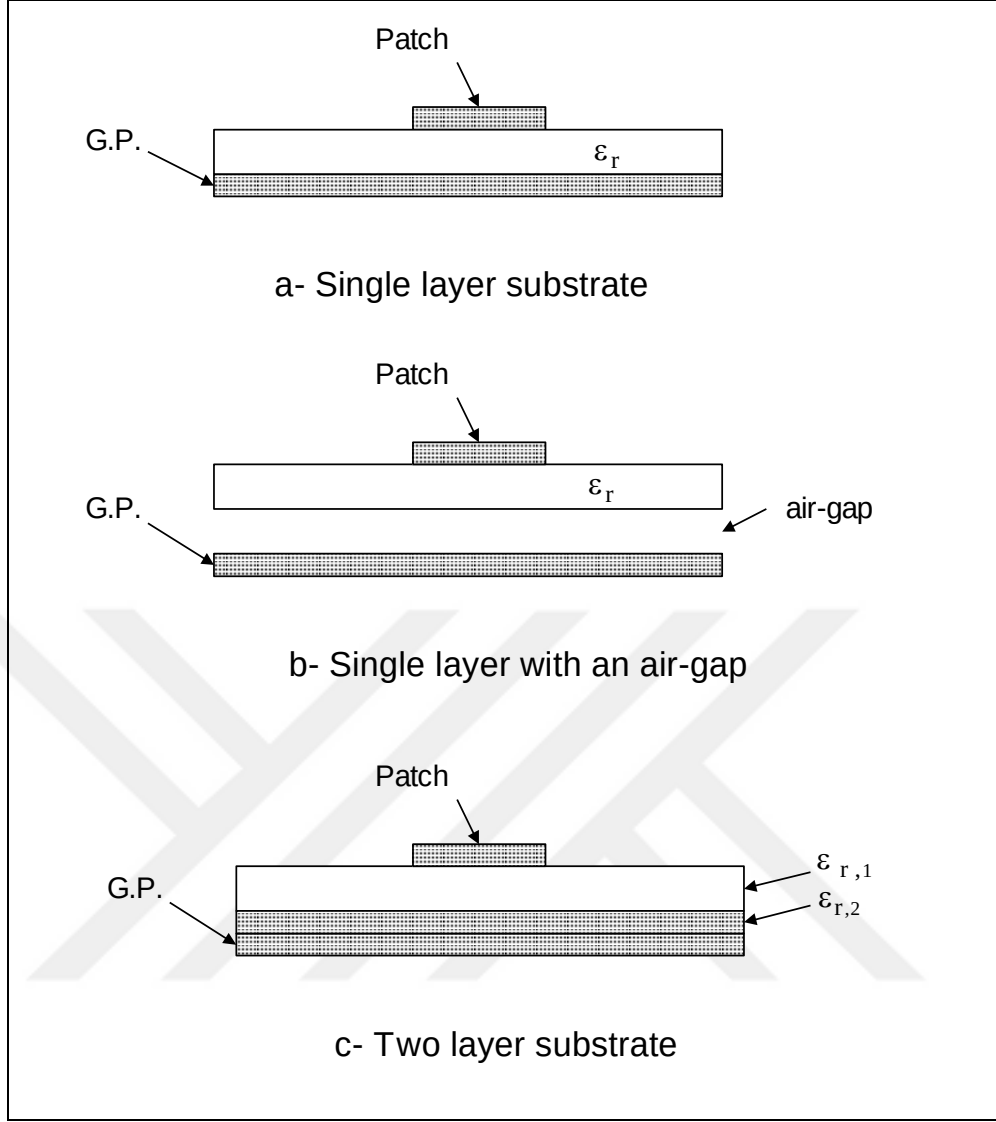


Figure 2.3: Different dielectric configurations

Copper can be used as a good conductor for the manufacture of the radioactive patch and the ground layer G.P.

Table 2.1 shows the properties of some insulating materials that can be used to manufacture the separating layer between the patch and the ground layer, which are used in the design of some models of microstrip-patch-antenna.

In this research, we will adopt the study of the traditional rectangular microstrip patch antennas with a monolayer from (RT Duroid 5870) insulating layer, as RT Duroid is a glass-reinforced microfiber PTFE (polytetrafluoroethylene) compound produced by Roger Corporation (E Aravindraj et al., 2017:1447).

The RT Duroid 5870 substrate has a low shadow loss and a small dielectric-constant compared to the rest of the insulators, as the dielectric-constant of a substrate affects, the performance and size of the antenna, and a substrate with a low dielectric constant gives better radiation than a substrate with a high dielectric, in addition to showing excellent resistance to chemicals, including solvents and reagents used in printing and painting, easy to fabricate, cut and cut, machined and environmentally friendly.

Table 2.1: Properties of microstrip dielectric materials, (Anubhuti Khare et. al.,2010; E Aravindraj et. al., 2017:1447)

Properties	Rogers RT5870	Taconic TLC	FR4 Glass Epoxy	Bakelite
Dielectric-constant	2.33	3.20	4.36	4.78
Loss-tangent	0.0004	0.002	0.013	0.03045
Water-absorption	0.02 %	< 0.02 %	< 0.25 %	0.5-1.3%
Tensile - strength	450MPa	-	< 310 MPa	60 MPa
Volume-resistivity	2×10^7 Mohm.cm	1×10^7 Mohm.cm	8×10^7 Mohm.cm	3×10^{15} Mohm.cm
Surface-resistivity	3×10^7 Mohm.cm	1×10^7 Mohm.cm	2×10^5 Mohm.cm	5×10^{10} Mohm.cm
Density	2200 kg/m ³	-	1850 kg/m ³	1810 kg/m ³

2.2. Advantages and Disadvantages

The traditional rectangular microstrip patch antenna is characterized by easy manufacture, low cost, tiny size, and lightweight weight. It is conjointly a flat antenna with a skinny profile, and it will be created per the form of the surfaces it covers will be created conformal, like on the roofs of craft, missiles, ships, etc., and does not need special Free-Standing Radomes, as is the case for many alternative kinds of antennas. Another advantage of this kind of antenna is that it will be simple and simply factory-made at the side of the effective solid-state parts and therefore the remainder of the electronic circuit parts that power this Monolithic Integration with Circuits,

It supports each linear and circular polarization, is integrated into microwave integrated circuits (MICs), and is automatically strong once mounted on arduous surfaces, (Balanis, C.A,2005), (Kumar. G et al.,2003).

Of these higher options have created this kind of antenna fashionable researchers since the seventies, and it is employed in numerous communication applications within the microwave radar system, telecommunication, remote sensing, navigation, Wi-Fi and wireless native space networks wireless applications, and mobile communication, like cellular phones, pagers, etc.,

Nevertheless, standard microstrip patch antennas square measure superior to traditional antennas in terms of low directionality, slender information measure, low potency, low gain, spurious emissions from feeds and junctions, low power handling, and surface wave excitation. It is several shortcomings compared to nomenclature. Microstrip patch antenna has a high antenna quality issue (Q), the standard issue represents the loss related to the antenna, and an oversized letter ends up in a slender information measure and low potency. The letter will be reduced by increasing the thickness of the stuff substrate.

However, because the thickness will increase, an associated increasing proportion of the entire power delivered by the supply is regenerated to surface waves. This surface undulation contribution will be counted as associate spare power loss because it can eventually be scattered by the stuff bends and causes degradation of the antenna performance. However, surface waves will be decreased by the mistreatment of photonic band gap structures (Qian. Y et al., 1999).

Some of these disadvantages will be addressed, for instance, by mistreatment of antenna arrays to extend the directive characteristic and scale back the radiation beam width to suit the application. However, one last purpose that must be mentioned is the issue of theoretical analysis of this kind of antenna ensuing from the interaction between the material and therefore the air at the surface of the radiated patch.

Therefore, we discover that their square measure several analytical ways within the scientific literature that are wont to study this kind of antenna, and most of them target the analytical side. These ways dissent among themselves in terms of accuracy and speed in calculations and complexity in theoretical analysis.

2.3. Methods of Analysis

Microstrip antenna analysis can be done in many ways the most widely used techniques:

- Transmission line model.
- Cavity model.
- Full-wave model.

The transmission line model, the cavity model, and the full-wave model (Balanis, C. A., 2005) (using the integral equation/moments method) are the three most used models for studying microstrip patch antenna. Transmission line models are the simplest and provide physical insight but are less accurate.

Cavity models are more accurate and provide physical insight but are inherently more complex. The full-wave model is highly accurate and versatile and can manage single elements, finite and infinite arrays, stacked elements, arbitrarily shaped elements, and couplings. These are less insightful and much more complex in nature than his two models above.

2.3.1. The Model of a Transmission Line

In this study, we use a relatively simple method in the analysis, which is the (transmission line method) and the radiation in the far region resulting from an assumed magnetic current around the circumference of the effective edge of the rectangular patch to find the antenna radiation model, and the modified transmission line equivalent model to find and calculate the impedance Input to the antenna assuming the type of feed used is a Coaxial Feed Probe. The study also reviews the possibility of designing to obtain specific antenna specifications along with a detailed analysis of the resulting antenna properties in radiation and directional models, efficiency, gain, quality coefficient, bandwidth, and input impedance.

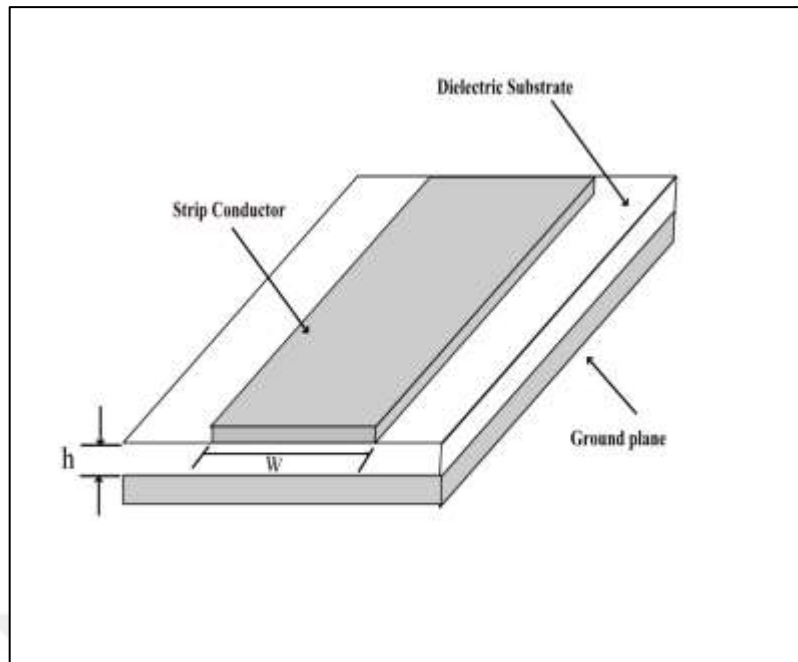


Figure 2.4: Microstrip line

This model represents the antenna as two slots separated by a width (w) and a height (h) by weak impedance (Z_c) is the transmitting line of length (L) antenna microstrip antenna is heterogeneous due to the presence of two dielectrics, the insulator present in the antenna as well as the air in Figure 2.4.

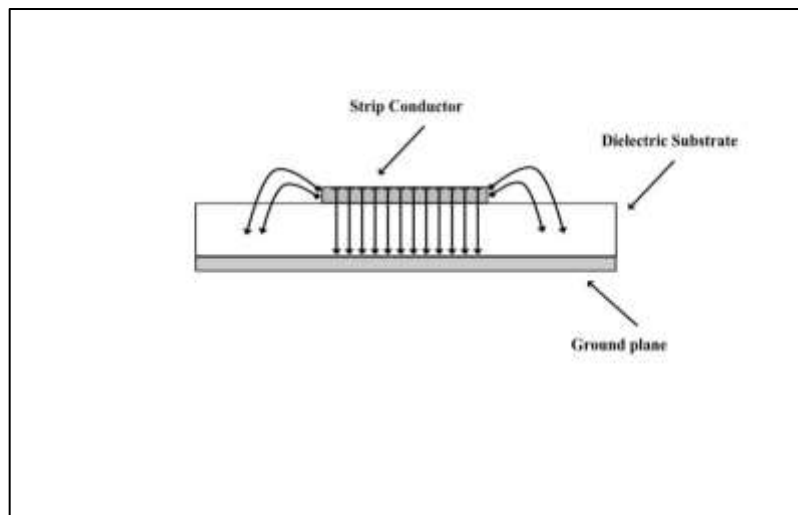


Figure 2.5: Lines of an electric field

Because all the electric field originating from the patch returns to the insulator Figure 2.5, the part of this field returns to the insulator after passing through the air, and because of that it will be a small difference in the dielectric-constant and the dielectric-constant will

be the dielectric-constant in the insulator, taking into account the air dielectric-constant, so that the dielectric-constant is (ϵ_{reff}).

The important dimensions we have in this analysis are the length the patches L , the width of patch w , and the height of Antenna h where we can assume that the slab length is in the x direction and its width is in the y direction, and the height of the antenna is z direction, as displayed in Figure 2.6.

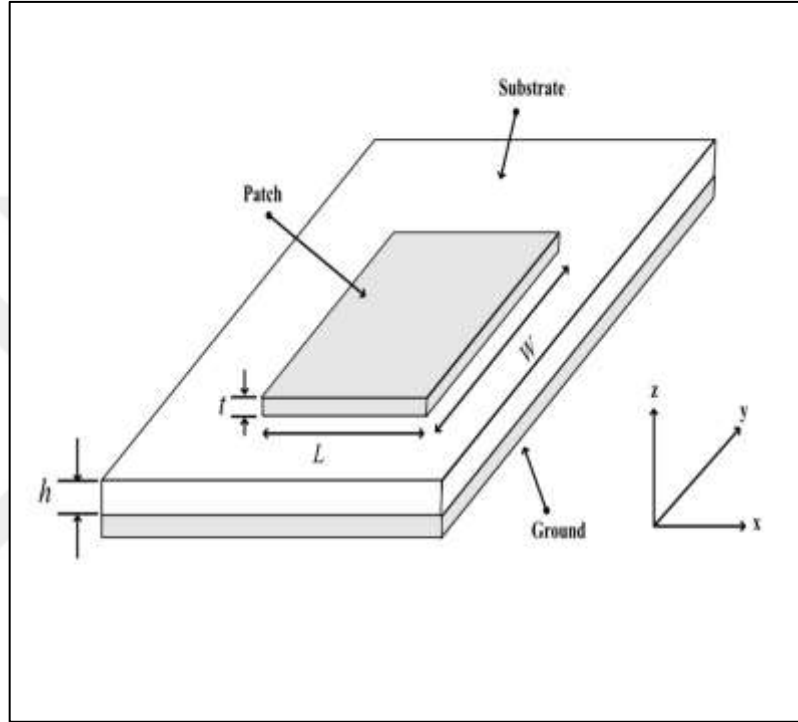


Figure 2.6: Microstrip-patch-antenna

- According to (James et al. 1989), the antenna's width of the patch is the following calculation:

$$w = \frac{c \sqrt{2/\epsilon_r + 1}}{2f_r} \quad (2.1)$$

where c represents the speed of light in space

- According to (Pozar et al. 1995), the following formula can be used to determine the length of the patches:

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + 12 \frac{h}{w} \right]^{-1/2} \quad (2.2)$$

where ϵ_{reff} = effective dielectric-constant.

ϵ_r = Dielectric-constant of the substrate.

h = Height - substrate.

w = Width - the patch

the dimensions of the patches are limited by the width and length of the patches, the fields at the edges of the patches become fringed, as displayed in Figure 2.7 due to the fringing field, the extension of patch length (ΔL) provided by (Ramesh et al., 2001):

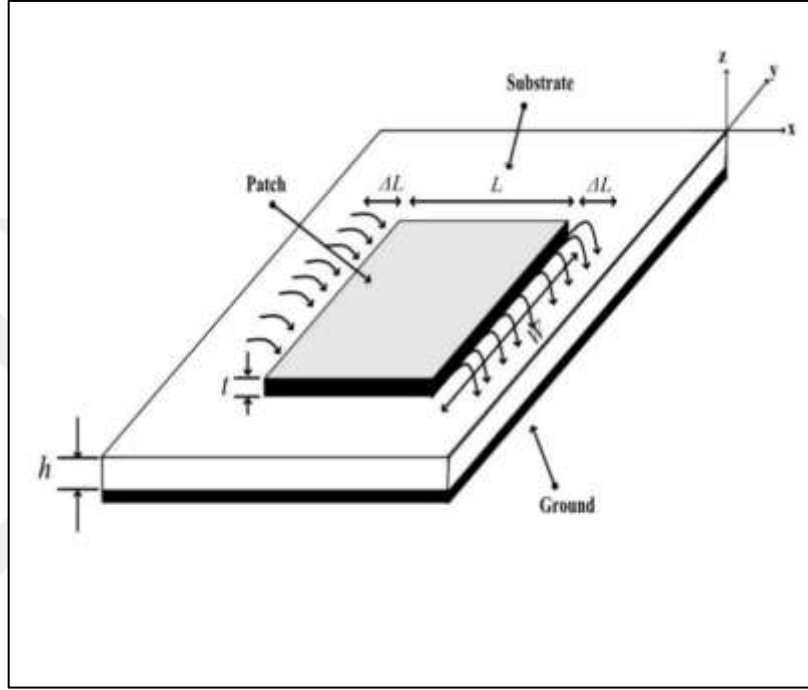


Figure 2.7: Physical and effective length of a rectangular microstrip patch

$$\Delta L = 0.412h((\epsilon_r + 0.3)*(\frac{w}{h} + 0.246))/((\epsilon_{reff} - 0.258)*(\frac{w}{h} + 0.8)) \quad (2.3)$$

$$L_{eff} = L + 2\Delta L, L = \frac{\lambda_0}{2} - 2\Delta L \quad (2.4)$$

$$L_{eff} = \frac{c}{2f_r \sqrt{\epsilon_{reff}}} \quad (2.5)$$

- Ground plane:

A conductive patch on the opposite side of the board acts as a ground plane and is often endless like a monopole antenna. However, in practice, a small ground plane is required as displayed in Figure 2.7. Microstrip antenna radiation is produced by stray electric fields that exist between patches and ground planes (Huang, Y., and K. Boyle, 2008).

For substrate and ground plane structure, the length and width of the antenna were estimated (Huang, 1983), (Thomas, 2005).

$$L_g = L + 6h \quad (2.6)$$

$$W_g = w + 6h \quad (2.7)$$

where L_g is the ground plane's and substrate's length, W_g substrate, ground plane, and its width.

2.3.2. Cavity Model

When studying microstrip antennas, the cavity model assumes that the space between the microstrip patch and the ground plane is defined by domain walls at the top and bottom of the conductor and along the edges of the conductor, as displayed in Figure 2.8. Assume it is an enclosed resonant cavity show.

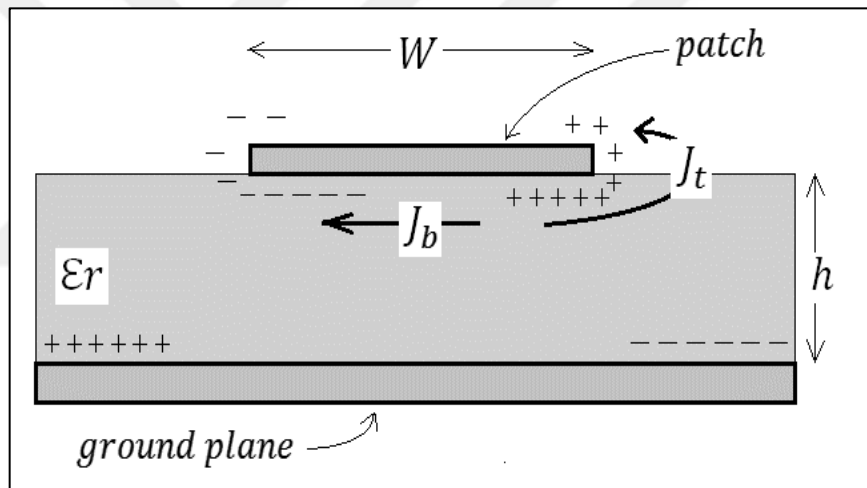


Figure 2.8: A microstrip antenna's charge distribution and current density

The interior of the dielectric substrate is displayed as a cavity surrounded by electrical walls at the top and bottom. The basis for this assertion is the following observation for thin substrates ($h \ll \lambda$) (Garg, R., 2001).

Due to the thinness of the substrate, the electric field inside varies little in the z-direction perpendicular to the patch. In the area enclosed by the patch metallization and ground plane, the electric field is only in the z direction and the magnetic field contains only opposite components H_x and H_y . This observation explains the upper and lower electrical walls.

In Figure 2.8, when powering the microstrip patch, the charge distribution on the top and bottom faces the patches as well as the underside of the ground plane, can be seen. As (Richards, 1988) discussed, this charge distribution is regulated by two mechanisms: an attractive mechanism and a repulsive mechanism.

Mechanism of attraction between opposite charges on the underside of the patches and the ground plane, which helps to maintain the charge concentration at the bottom of the patches. Repulsion occurs between identical charges on the bottom surface of the patches, causing certain charges to push from the bottom to the top.

Current flows on the upper and lower surfaces of the patches due to this charge movement. The cavity model assumes that the height-to-width ratio (i.e., the height of the Substrate to the width of the patches) is very modest so that the gravitational mechanism dominates and causes most of the charge and the current concentration lies below the patch. face. The current that will flow on the top surface of the patches will be much less, and as the aspect ratio decreases further, the current on the top surface of the patches will be almost zero, preventing any generation of components. any tangential magnetic field at the edges of the patches.

Thus, the four side walls are represented as fully conductive surfaces. This means that the magnetic field and electric field distribution under the patch will not be affected. However, in practice, there will be a finite aspect ratio, which will not result in completely zero tangential magnetic fields, but since they are so small the side walls can be considered perfectly conductive. (Balanis, C.A., 2005).

Since the cavity walls and the material contained therein are lossless, the cavity does not radiate, and its input impedance is simply reactive. Therefore, to account for the radiation and the loss process, the radiation resistance, and the loss resistance R_L , must be given. An attenuation cavity is now represented by an antenna, and the loss is calculated by the effective loss tangent δ_{eff} , (Stutzman, 1998), which is given by:

$$\delta_{eff} = \tan \delta + \frac{\Delta}{h} + \frac{P_r}{\omega_r w_T} \quad (2.8)$$

where:

ω_r : the angular resonant frequency.

w_T : total energy stored in the patch at resonance.

$\tan \delta$: the dielectric's loss tangent.

Δ : the skin depth of the conductor.

h : the height of the Substrate.

P_r : the power radiated from the patch.

As a result, the equation above (2.8), describes the microstrip-patch-total antenna's effective loss tangent.

2.3.3. Full-wave Model

The method of moments is one method that provides a full-wave analysis of microstrip patch antennas. This method uses surface currents to model the microstrip patches and bulk polarization currents to simulate the electric field in the dielectric slab. (Newman, 1981) showed how to obtain these unknown current integral equations and how to convert these electric field integral equations to matrix equations using the method of moments.

2.4. Surface Waves

Surface waves of type TE&TM can propagate in the Substratum beyond the surface of the emissive patch, and they are attenuated in a direction perpendicular to the surface of the patches and have a true propagation constant in this direction. The phase velocities of these modes depend on the dielectric permeability constant (ϵ_r) and substrate thickness (h).

If the propagation speed of one of the propagating surface waveforms reaches values asymptotic to the propagation speed of the Quasi TEM waves originally generated and scattered along the radiation array, then There is a strong coupling between the waves mentioned and this is a problem that needs to be considered. TE_n & TM_n in the equation below (J. R. James et al., 1986).

$$f_c = \frac{nc}{4h\sqrt{\epsilon_r - 1}}, \text{ where } n = 1,3,5,\dots \text{ for TE}_n \text{ mod es, and}$$
$$n = 2,4,6,\dots \text{ for TM}_n \text{ mod es.}$$

where c is the propagation speed of light in free space. ($c = 3 \times 10^8$ m/s). The TM₀ pattern has no cutoff frequency, it always propagates even if the Substrate is very thin, and therefore it represents the biggest problem compared to the rest of the patterns. Surface waves of higher degrees, (Dr. Anubhuti Khare et al.,2010).

found that the surface wave problem becomes effective for values of ($\epsilon_r \cong 2.3$) when an insulator with thickness $h/\lambda_0 > 0.09$, and for values of ($\epsilon_r \cong 10$) when $h/\lambda_0 > 0.03$, where

λ_0 represents the length of Wavelength in free space ($\lambda_0 = c/f$, where f is the propagating wave's frequency).

2.5. Feeding of Microstrip Patch Antennas

There are various methods in the scientific literature for feeding this type of antenna. Some methods use direct feeding, where the feeding tube connects physically to the radioactive patch and other methods that use indirect feeding, capacitively coupled. This second type leads for example to improving (increasing) the frequency response bandwidth of the antenna. Traditional direct methods, adopts microstrip line feeding and coaxial probe feeding (Balanis, C.A,2005).

In Table 2.2, The characteristics of the various feeding strategies are summarized here. It is also possible to use two separate feeding points so that two propagation modes that are perpendicular in the vacuum and differ from each other by phase angle $\pi/2$ can be generated, which can generate a propagating wave by polarization circular.

Table 2.2: Comparison of different feeding methods (Balanis, C.A, 2005).

Characteristics	Microstrip-Line Feed	Coaxial-Feed	Aperture-coupled Feed	Proximity-coupled Feed
Spurious-feed radiation	More	Less	Less	Minimum
Reliability	Better	Poor due to soldering	Good	Good
Ease of fabrication	Easy	Soldering drilling needed	Alignment - required	Alignment-required
Impedance-Matching	Easy	Easy	Easy	Easy
Bandwidth. (Through-impedance matching)	2.0-5.0%	2.0-5.0%	2.0-5.0%	13.0%

2.5.1. Microstrip Line for Feeding

This type of feed connects the conductive strip directly to the edge of the microstrip patch, as displayed in Figure 2.9. Conductive strips are narrower than patches and this type of feed configuration has the advantage that the feed can be etched on the same substrate to give a planar structure, (Ndujiuba, Oloyede 2015).

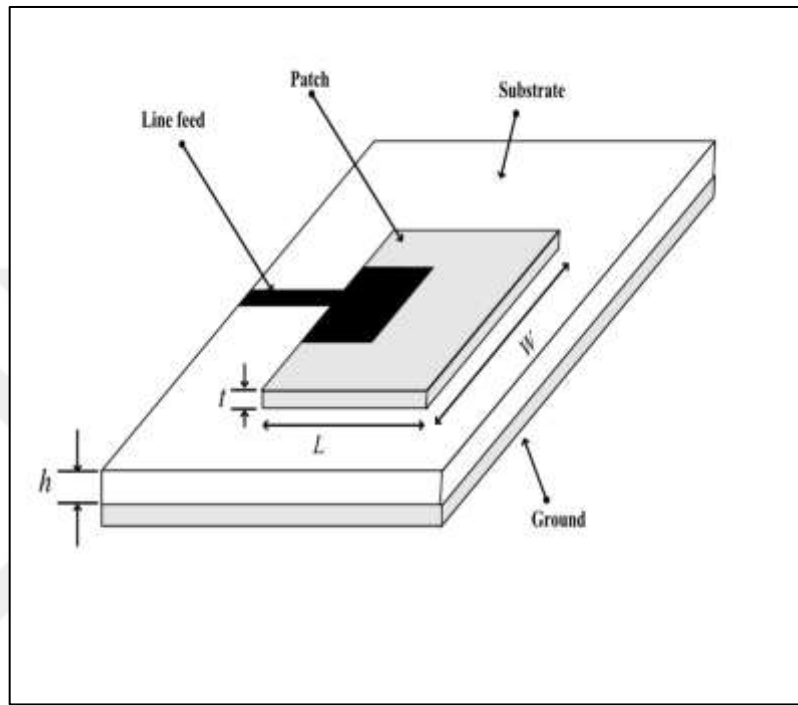


Figure 2.9: A microstrip-patch-antenna with line feed

2.5.2. Feeding Using a Coaxial Cable

Coaxial probe feeding is a common method of feeding microstrip patch antennas. As displayed in Figure 2.10, the inner conductor of a coaxial cable runs through the dielectric and is soldered to the radiating metal pad, while the outer conductor connects to the ground plane. The advantage of this feed approach is that the feed can be placed anywhere on the patch to match the cable impedance to the antenna input impedance. (Baranis, Calif., 2005).

The main purpose of tube feeding is to increase muscle mass (Ndujiuba, Oloyede 2015). Figure 2.10 shows the use of coaxial feeders assumed in this study. A coaxial feed allows the input impedance of the antenna to be adjusted at the resonant frequency, from maximum to low values of the radiating patch impedance.

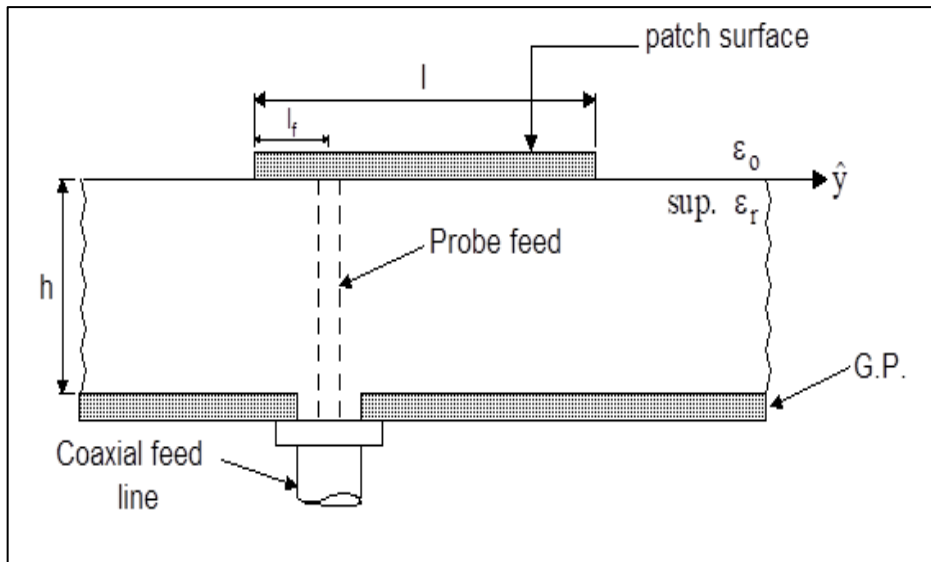


Figure 2.10: A microstrip patch antenna coaxial feed

2.5.3. Proximity Coupling

As illustrated in Figure 2.11, the electromagnetic coupling system uses two diverse types of substrates to send energy to a radiating area. The feed line is located between the two substrates, and the radiating area is on top of the upper substrate.

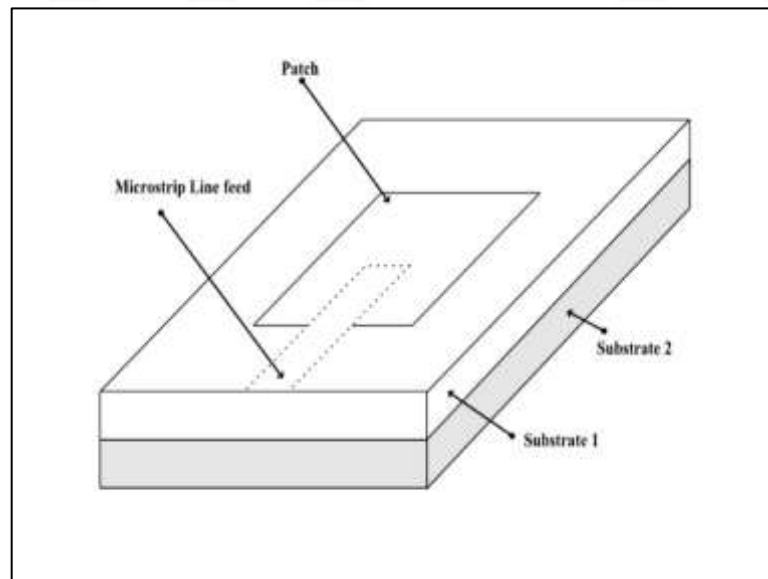


Figure 2.11: A microstrip patch antenna with feed through proximity coupling

The fundamental advantage of this feed approach is that the overall thickness of the microstrip-patch antenna is increased, thus providing much higher bandwidth (up to 13%) while reducing spurious feed emissions.

2.5.4. Aperture - Coupled Feed

In this type of feed technique, the ground plane acts as a barrier between the microstrip feed line and the radiating patch. As displayed in Figure 2.12, the ground plane has slots or openings that connect the patch and the feed line.

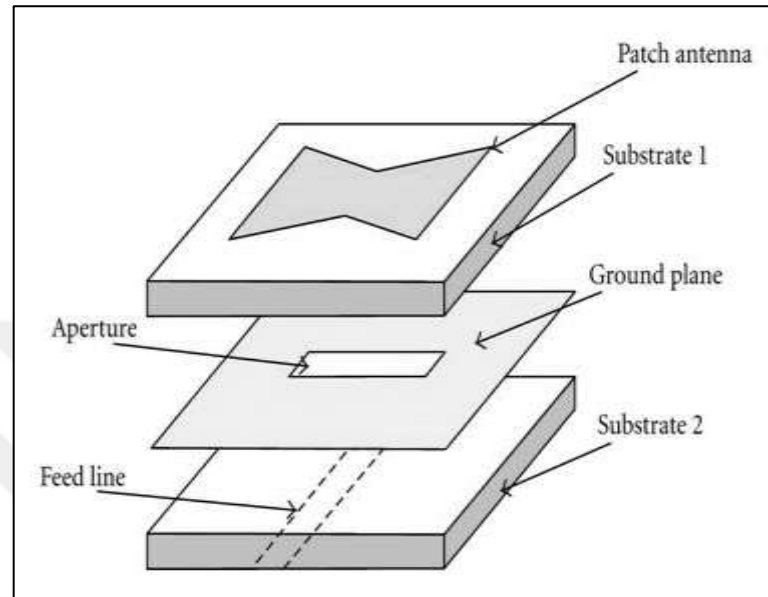


Figure 2.12: A microstrip patch antenna with aperture-coupled feed

The ground plane separates the radiation patch and the microstrip feed line in this type of feed technology, as displayed in Figure 2.12, the patch is coupled to the feed line through a slot or hole in the large plane.

Due to the symmetry of the design, the articulating aperture is usually centered below the patch, resulting in less cross-polarization. The shape, size, and position of the opening control the amount of coupling between the feed line and the patch. The background plane separates the patch and the path, reducing stray radiation.

To optimize patch radiation, a material with a high dielectric is used for the underlying substrate, and a thick material with a low dielectric constant is used for the upper substrate (Balanis, 2005). The main disadvantage of this feed technology is that it is difficult to fabricate due to the many layers, which increases the thickness of the antenna. This power method also has limited bandwidth.

2.6. Impedance Matching

Antenna impedance matching techniques are designed to transfer maximum power to the antenna so that the element can radiate strongly. When matching the impedance of an antenna, the input impedance at the end of the antenna feed line matches the characteristic impedance of the feed line.

Figure 2.9 shows the changes in current (magnetic field) and voltage (electric field) along the patch. The voltage (electric field) is zero at the center, maximum at the left edge, and minimum at the right edge, while the current is maximum at the center and minimum near the left and right edges.

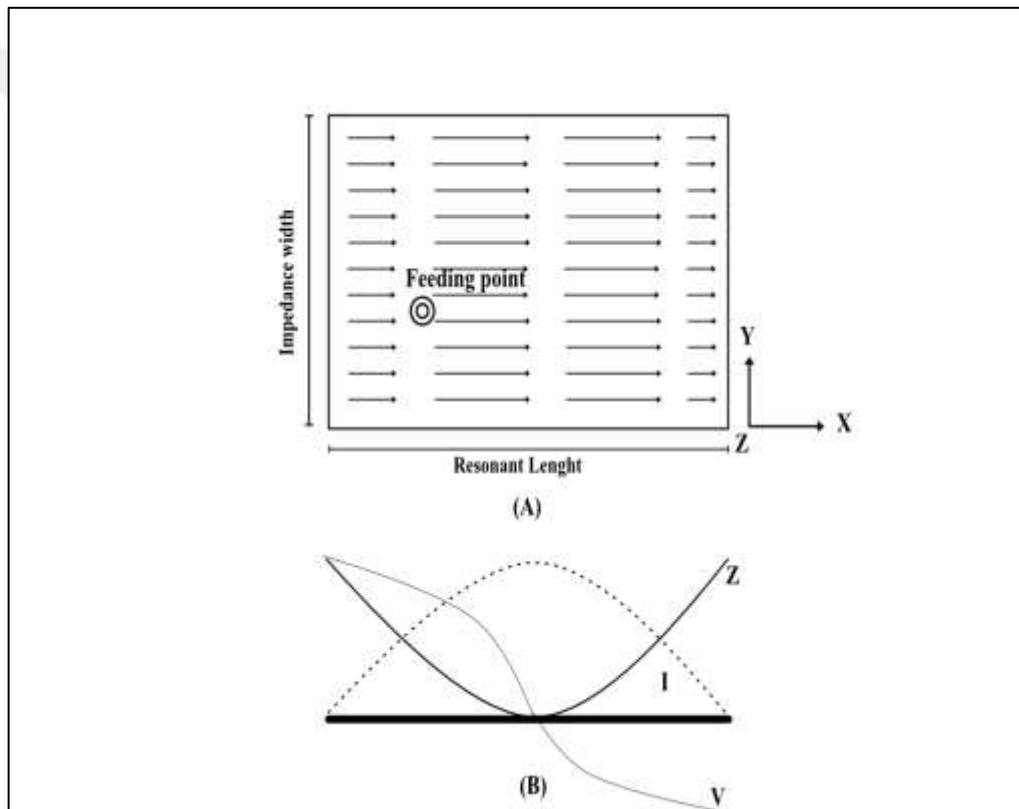


Figure 2.13: (A) Distribution of current across the patch surface. (B) Distribution of voltage (V), current (I), and impedance ($|Z|$) along the resonant length of the patches

From the amperage and voltage, we can prognosticate that the impedance is the lowest (theoretically zero Ω) in the middle of the patches and the largest (around 200 Ω) near the edges, therefore, the electric field is zero at the center of the patches, outside (positive) on one side, and minimum (negative) on the other side.

The maximum and minimal continuously change sides depending on the immediate phase of the applied signal. along the reverberate length, there is a point where the impedance is 50Ω .

This point is used to couple the electromagnetic input or affair the patches, known as the feed point. The electric field does not stop suddenly at the fringe of the patches as in a depression, the electric field extends to the fringe. These field extensions are called border fields and beget the patch to radiate. The border fields between the fringe of the patches and the ground airplane produce radiation from the microstrip antenna. To ameliorate edge fields from the patch, the range of the patches is increased, ϵ_r is reduced, or the consistency h of the Substrate is increased. In general, h is taken to be lesser than or equal to 1.59 mm (Chungk et al., 2006).

3. METHODS TO OPTIMIZE PERFORMANCE

3.1. Introduction

In their usual form, the microstrip patch antennas are narrow band bias. The range of their impedance is 1 to 2. This can be credited to two effects the antenna's bitsy consistency, which is lower than $0.05\lambda_0$ microns, and it reverberates design, which allows it to transmit effectively only across a limited range of frequency, preliminarily, we knew that the narrow bandwidth and weak gain and directivity are among the most important problems the affecting performance microstrip patch antennas.

This disadvantage of standard microstrip patch antennas renders these ineffective in a variety of operations requiring broad-spectrum frequency. As a result, several investigations have been conducted over many years to solve this constraint, and various ways had been suggested. As a result, in this Chapter, a range of styles will be provided and described based on proposed processes published in scientific literature to boost the spectrum frequency of blockish microstrip patch antennas. And gain and directivity with applicable values to give the antenna more effective, which allows it to be used in different operations.

Then we will bandy the principle of antenna work for each system that is used to increase the effectiveness of antenna performance, and describe the advantages and disadvantages of each system, also choose one of the styles that we will expand on in explaining it. And designing its distances and opting its parameters using (MATLAB) program and antenna simulation Blockish microstrip patch antennas using one of the computer programs (CST), to reach the return loss, gain, directivity, power and bandwidth at 2.45 GHz.

3.2. Substrate Specification

The substrate thickness of a microstrip patch antenna can be increased or decreased to increase the single-layer live feed bandwidth. The dielectric constant of the substrate for an antenna (the value of permittivity approaches one), as well as the bandwidth trends of monolayer microstrip patches related to platform permeability and height, are shown. This observation is supported by Figure 3.1.

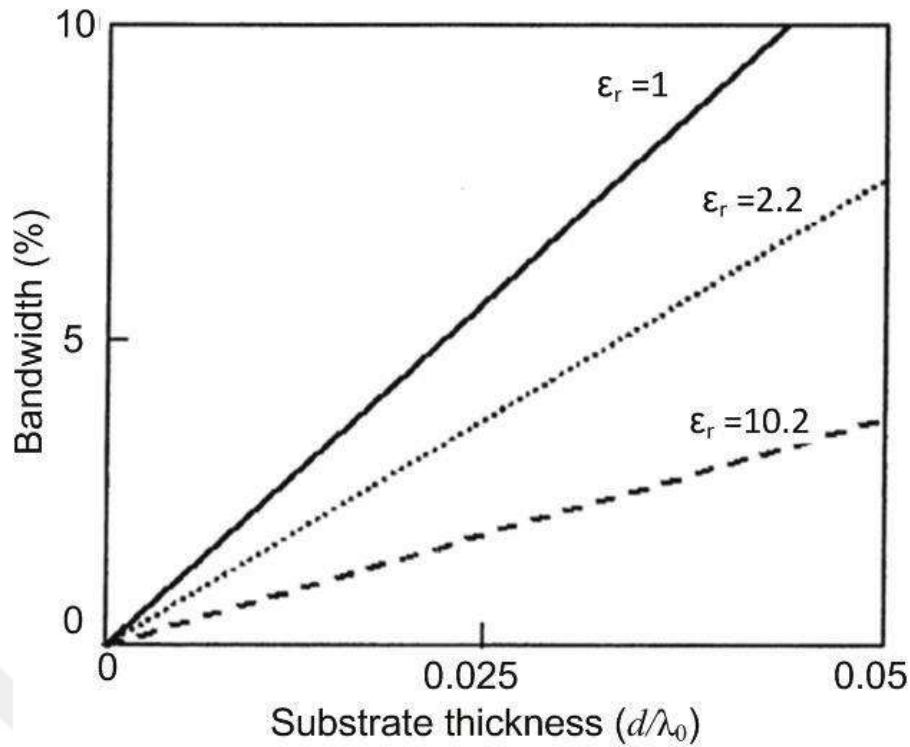


Figure 3.1: Direct broadband trends feed microstrip patches with substrate dielectric-constant and thickness (Waterhouse RB, 2003)

In fact, by making the thickness thicker of the base of the radiation patch, the area of the aperture using which the field radiates place may be improved, making it easier to match the resistance of the antenna's aperture, and improve antenna spectrum frequency.

The reflectance at the antenna's aperture is decreased by decreasing the dielectric of the platform (bringing it nearer to the dielectric of air), which makes it simpler to modify the impedance to provide more range over the air.

It needs to be noticed that the patch size reduces, and the gain drops as the substrate's thickness rises and the dielectric constant rises. Additionally, the supply network's radiated energy rises, resulting in a greater amount of cross-polarization and false radiation.

Furthermore, when the s - waves become more agitated, the antenna's ability to radiate decreases. Apart from the fact that standard commercial substrates have thickness and dielectric constant constraints, extending the frequency band via the substrate specification technique is restricted to 10%. (Kumar. G et al., 2003) is still insufficient for certain applications, such as L-band sonar, which requires 19% spectrum (1.4 GHz to

1. 7 GHz), or C-band Satellite TV, which requires a 12.5% frequency (3.7 GHz to 4.2 GHz). As a result, extra approaches, such as those described below, should be utilized to boost broadband.

3.3. Techniques of Feeding

The radiated field is fed with a contactless supply network and the antenna structure is simulated in layers in each of the suggested feed types mentioned in this text. By introducing a meshing medium between the supply network and the patch, a resonance similar to the patches is formed. If the feeder networks and patch are properly connected, the antenna's bandwidth may be increased.

3.3.1. Feed of Proximity-Coupled

Figure 3.2 shows feeding by proximity coupling. In this nutrient medium, open-ended microstrip feed lines routed to the lower subcaste excite radiant spots in the upper subcaste (radiating subcaste) (feeding subcaste). There is no direct contact between the supply lines and the radiation field. The open end of the tail is therefore used to join the panel to the patch.

Antenna bandwidth can be increased by adjusting the position of the open end of the feed line relative to the patch to achieve optimal coupling between the two. With this method, it is possible to achieve a frequency band in the 8% range.

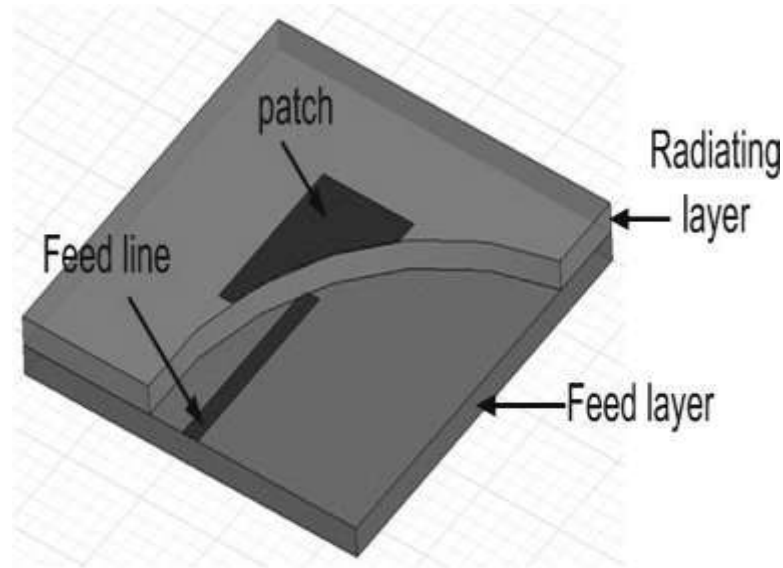


Figure 3.2: Proximity in coupled feed

To further expand the bandwidth, the radiating subcaste's consistency can be improved. However, as a result, power coupling from the feed line to the patch is now more difficult. To solve this problem, the feed substrate can be made thicker. While additional power is connected to the patch in this scenario via an open loop end, the feed channel's false radiation is also getting worse, which could lower the antenna's performance effectiveness.

Applying a straightforward matching structure to the feed line, like a quarter- surge motor, is another option for resolving this problem. The bandwidth can be increased in this mannerism, by employing thicker laminate for the radiating subcaste in addition to applying the corresponding circuit to the feed network (Waterhouse RB, 2003). One illustration of this problem is displayed in Figure 3.3, (Waterhouse RB, 2003). The bandwidth might be increased from 8 to 14 in this illustration by twofold the consistency of the subcaste propagating and operating a simple resistance motor at the coax cable.

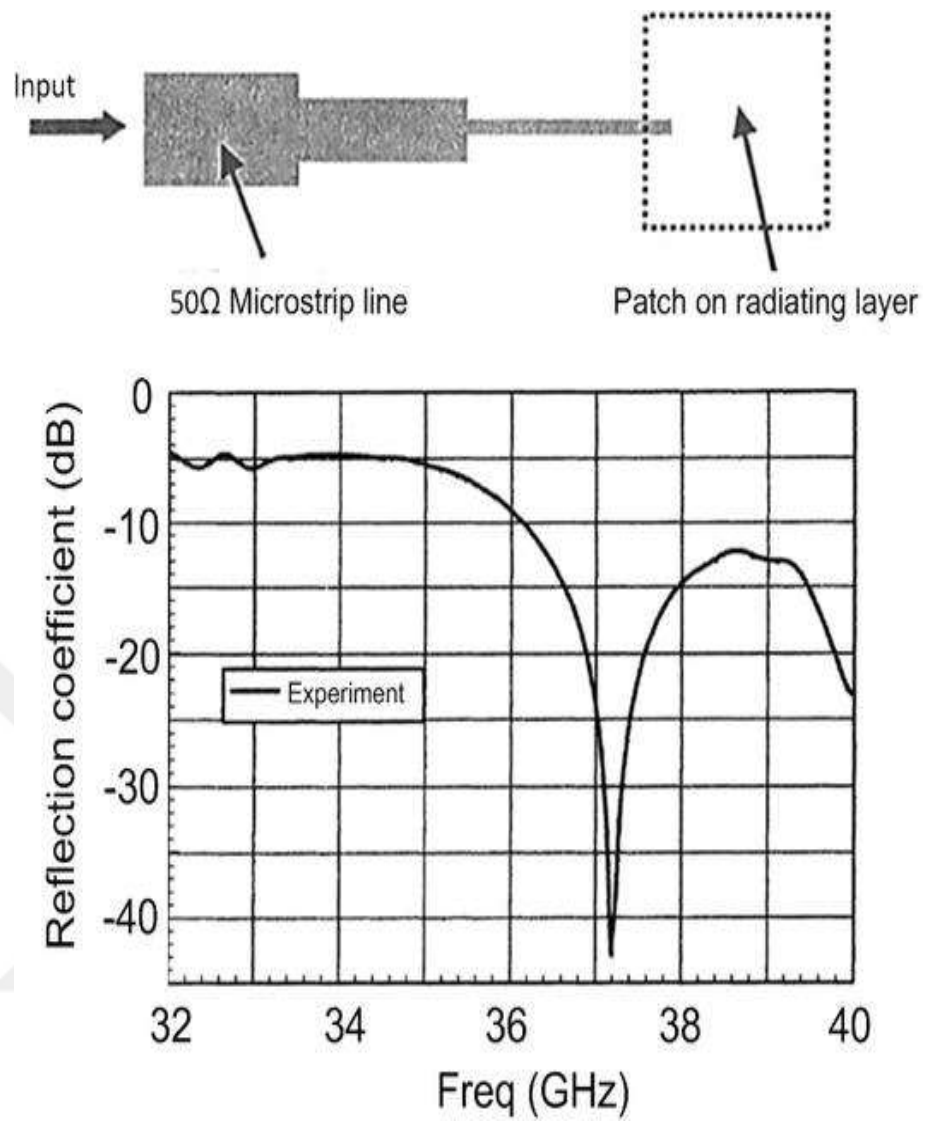


Figure 3.3: Proximity-coupled microstrip patch antennas (Waterhouse RB, 2003).
as S11

3.3.2. Feeding of Aperture-Coupled

Thus, an aperture/coupled feed is in Figure 3.4. Here, the feed mechanism, which is a Through perforation (slot) etched in the ground surface of the emissive layer, the microstrip line placed on the bottom layer (feed layer) stimulates the radiation field.

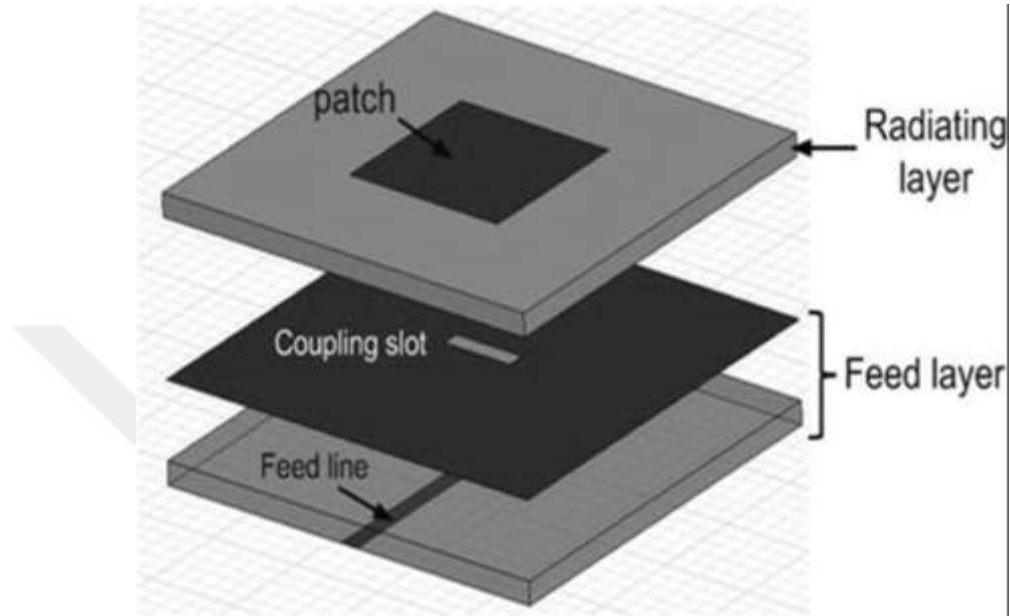


Figure 3.4: Aperture coupled supplied microstrip-patch-antenna in three dimensions

This structure offers two resonances. One through patches and one through slots. Proper connection of these two radiators brings the two corresponding resonances closer together, increasing the antenna bandwidth. By adjusting the dimensions of the slit, a proper bond between the slit and the patch can be achieved. This method can record bandwidth in the range of 20-30%.

In reference (Waterhouse RB, 2003), a sample with an operating frequency of 1.9 GHz, a spectrum frequency of (27%), and a gain of 9 dBi is intended for use in cellular base station applications, using a thick dielectric as the radiating layer, can be further extended with bandwidth. A larger slot size is required in this situation to ensure that power is properly connected to the patch. Using this simple method, we obtained 40% bandwidth (Zürcher JF, 1988:1433).

This method, the size and shape of the coupling slot, and the resulting antenna bandwidth and efficiency can significantly affect the coupling performance. In general, a thicker

substrate can be used for the radiating layer, resulting in a band bandwidth for impedance as the coupled power is increased by changing the slot geometry. As opposed to that, a smaller slot area reduces back radiation, which is due to the slot and improves antennae performance. In practice, using the slot submission format, we aim to offer the greatest coupling with the minimum slot area achievable. As a result, the bandwidth can be improved by thickening the emitting layer or lowering the dielectric constant, while ensuring optimum efficiency.

A thin rectangle is one of the most popular coupling slot designs as it allows for strong coupling with a plain design (Figure 3.5(a)). However, making it longer or wider can lead to stronger coupling (as in Figure 3.5) (b - c). Because the magnetic field strength in a rectangular patch varies sinusoidally, an "H" formed looped slot (Figure 3.5 (d - e)) can offer better coupling than a rectangular slot. Stronger couplings can be achieved by combining "H"-shaped and loop-shaped slits to provide a more uniform electric field distribution across the slit. This results in the hourglass-shaped slit illustrated in Figure 3.5(f), is realized (Kumar. G et al., 2003), (Rathi V. et al., 1996).

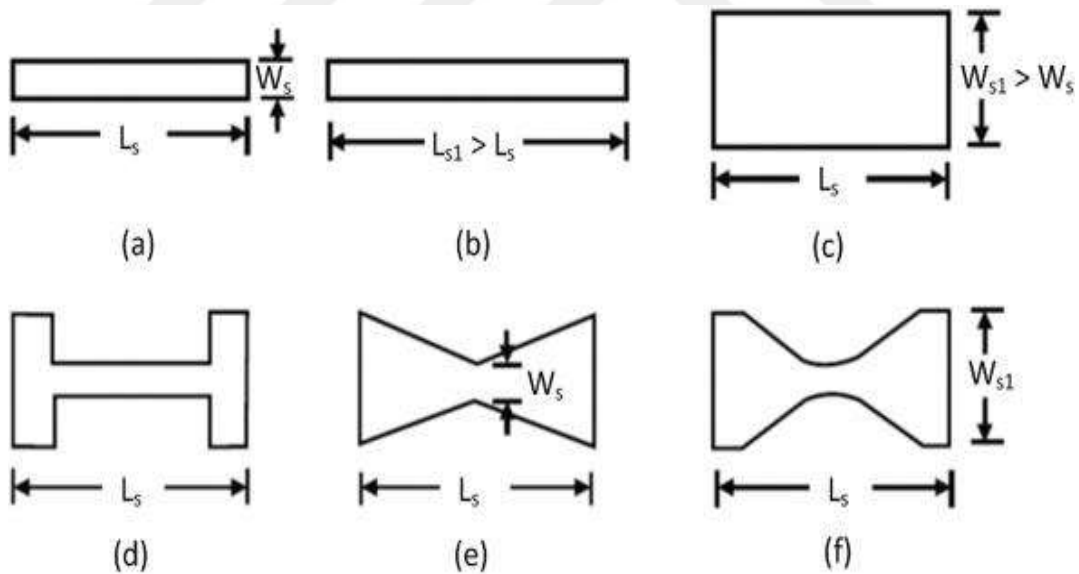


Figure 3.5: The connection slot comes in several shapes: (a) long, lean rectangle (b) longer, (c) wider rectangle (d) 'H'-shaped, (e) form of a bowtie and (f) form of an hourglass (Kumar. G et al.,2003),(Rathi V et al.,1996)

3.4. The Single Layer with Parasitic Components

If a second horizontal coupling patch is added next to the base patch on the same substrate, and the coupled element's resonance frequency is slightly different from the base patches, this technique can increase the antenna's overall bandwidth. The entire frequency response is displayed in Figure 3.6. In other words, it is a combination of the two patches' respective frequency responses.

This method places the base and the parasite patch on the same layer, streamlining the construction of the antenna. The huge overall dimension of the antenna would be method's main drawback.

Select an appropriate sort of substrate with a certain thickness and a low dielectric constant of substrate to overcome this issue. The size of the antenna is decreased by lowering the dielectric constant. There are four ways to implement this strategy, which are detailed below.

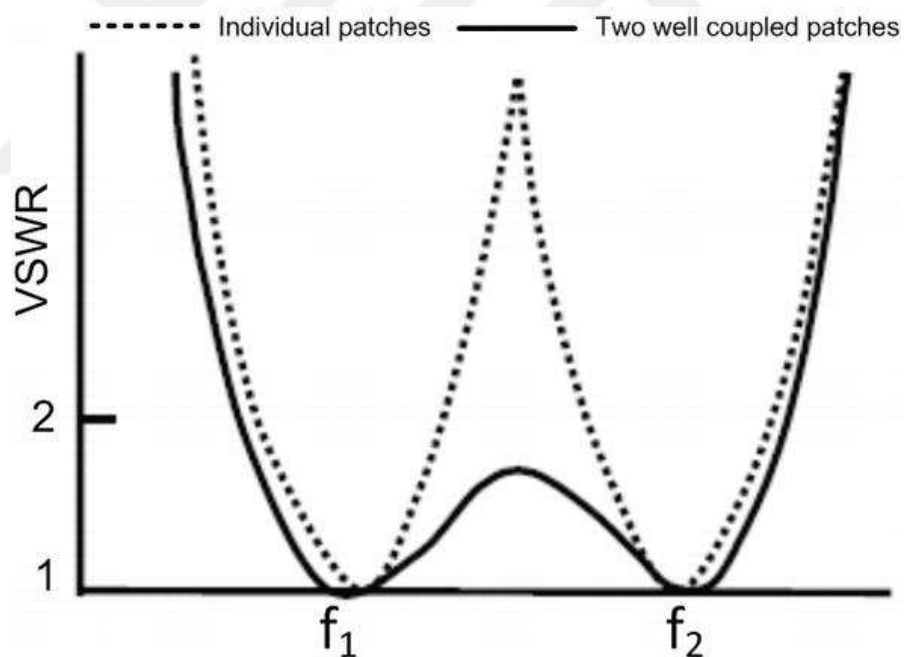


Figure 3.6: When the resonant frequencies of the two patches are noticeably different, a fake patch connected to the base patch can be added to enhance the bandwidth (Kumar. G et al., 2003)

3.4.1. Using Radiating Edges to Couple

At the radiation layer, two unequal parasitic components are used, a microstrip patch antenna is displayed in Figure 3.7(a), (Kumar. G et al.,2003), (Kumar G et al.,1985:173). In the suggested antenna, two dummy patches are positioned on either side of the basic patch, which is fed by a probe. Through the basic patches radiating edges, the parasitic patches in this structure are connected to the basic patch. There are three distinct resonances offered by the patches' vastly differing sizes. The spacing between the patches can be modified by changing how the antenna's impedance matches them.

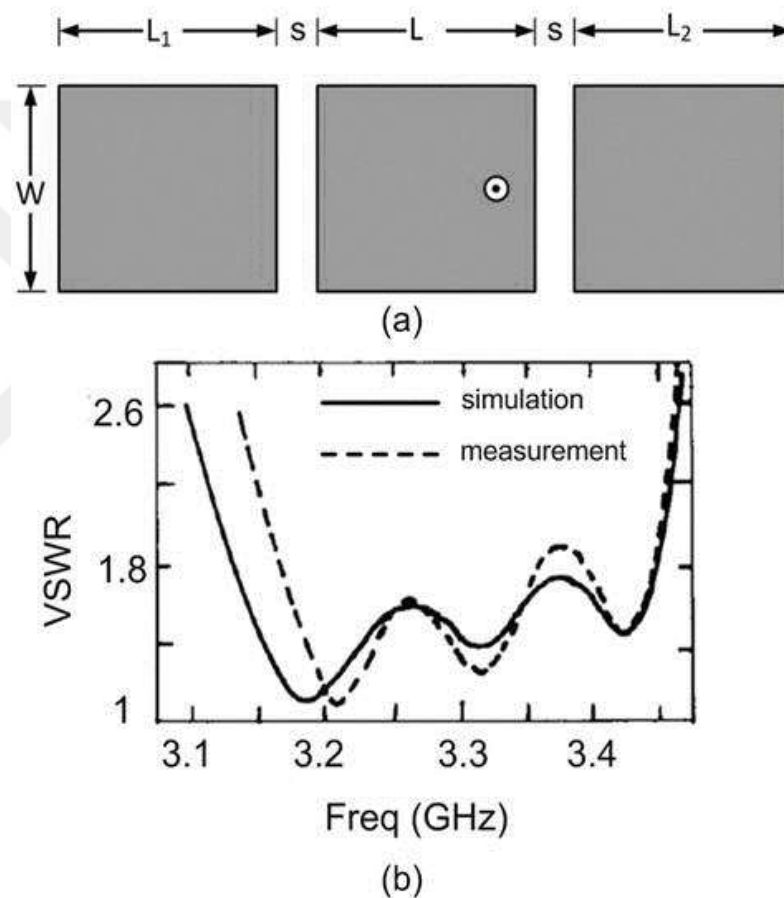


Figure 3.7: Radiating edges connect microstrip patch antennas to two parasites in the emissive layer (a). antenna design (b). The plot of the VSWR for a sample created in (Kumar G et al.,1985:173)

This method can be used to obtain a bandwidth of around 20% (Kumar. G et al.,2003). The frequency response of the sampling plan, provided in Reference (Kumar G et al.,1985:173) is displayed in Figure 3.7(b), Three closely spaced, well-coupled

resonances that have increased antenna bandwidth are visible in this picture. The resulting bandwidth is 10.6% of the center frequency (3.1–3.45 GHz).

3.4.2. Coupling via Edges

In this approach, two unequal parasitic elements are positioned on either side of the basic patch, similar, to Figure 3.7. However, in this instance, as seen in Figure 3.8(a), the basic patch's non-radiating edges are used to connect the parasitic patches to the basic patch. In contrast to the radiating edge's uniform field, the field of the non-radiating edge is not uniform, hence the coupling between the base patch and the parasitic element is lower than in the prior circumstance when the coupling was provided by the radiating edge. increase. As a result, the space between the base patch and the parasitic element should be narrower in this case than in the preceding scenario.

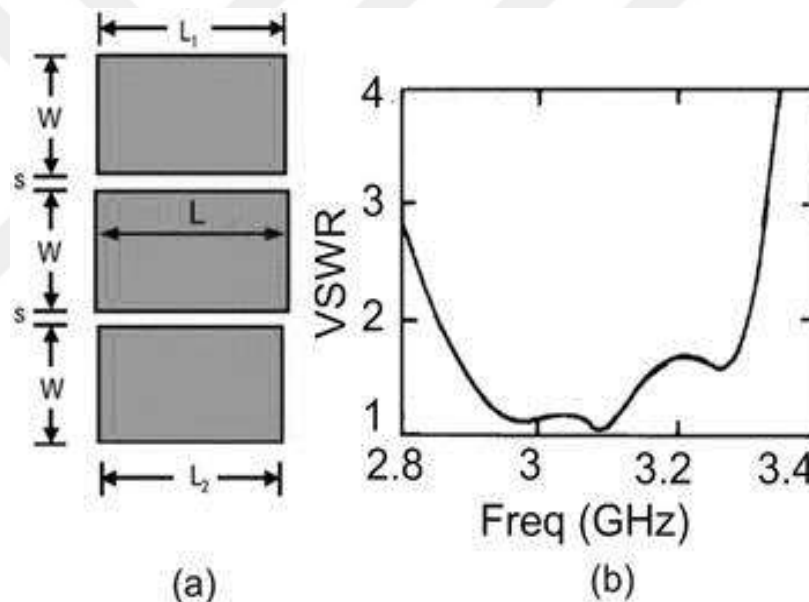
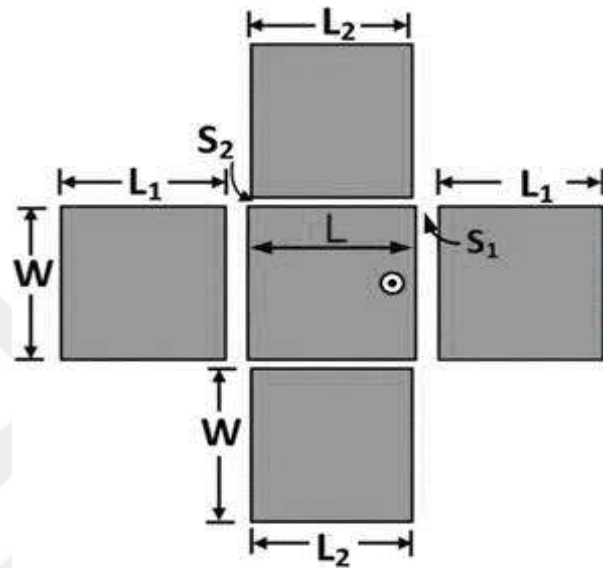


Figure 3.8: Using the quasi edges, a Microstrip Patch Antenna is connected to two parasite patches at the emission layer. (a) settings for the patch, and (b) A VSWR graph for an example antenna is displayed in (Kumar. G et al.,2003)

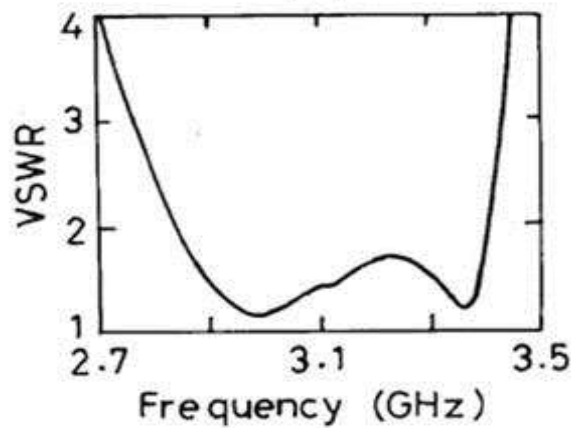
Using this method, you can get bandwidth at a rate of about 20%. The frequency response of the example design described in the reference, (Kumar. G et al., 2003) is displayed in Figure 3.8(b). Antenna bandwidth was increased due to the three closely spaced, well-coupled resonances seen in this image. This gives 14.5% of the bandwidth at the center frequency (2.8-3.3 GHz).

3.4.3. Using Four Edges to a Couple

Using the two procedures above in combination, Increased gain and broadband can be achieved by placing four patches around the base patch and connecting them by emitting and quasi edges, as displayed in Figure 3.9, (a). This approach yields 18.2% bandwidth (Kumar G et al.,1985:173). The resonant frequency of the item is displayed in Figure 3.9, (b), (Kumar G et al.,1985:173).



(a)



(b)

Figure 3.9: On both emitting and non-emitting sides, four parasite elements are connected to microstrip patch antennas at emissive layers. (a) Patch configuration and (b) A representative antenna's VSWR graph is displayed in (Kumar G et al., 1985:173)

3.4.4. Shorted Patch with An Annular Ring Loaded

Using an annular ring as the loading source, Figure 3.10, shows a circular shorted microstrip patch. A circular patch connected to the ground plane is the basic component of this arrangement, and the annular ring that surrounds it is the parasitic component.

To produce a solid coupling between the shorted patch and the ring, both of their dimensions must be precisely defined. The coupling can then be reduced, and the bandwidth can be expanded by widening the distance between them. A sample of this antenna that achieves 8.4 dBi gain and 6.6% bandwidth is designed in Reference (Chew W.C, 1982).

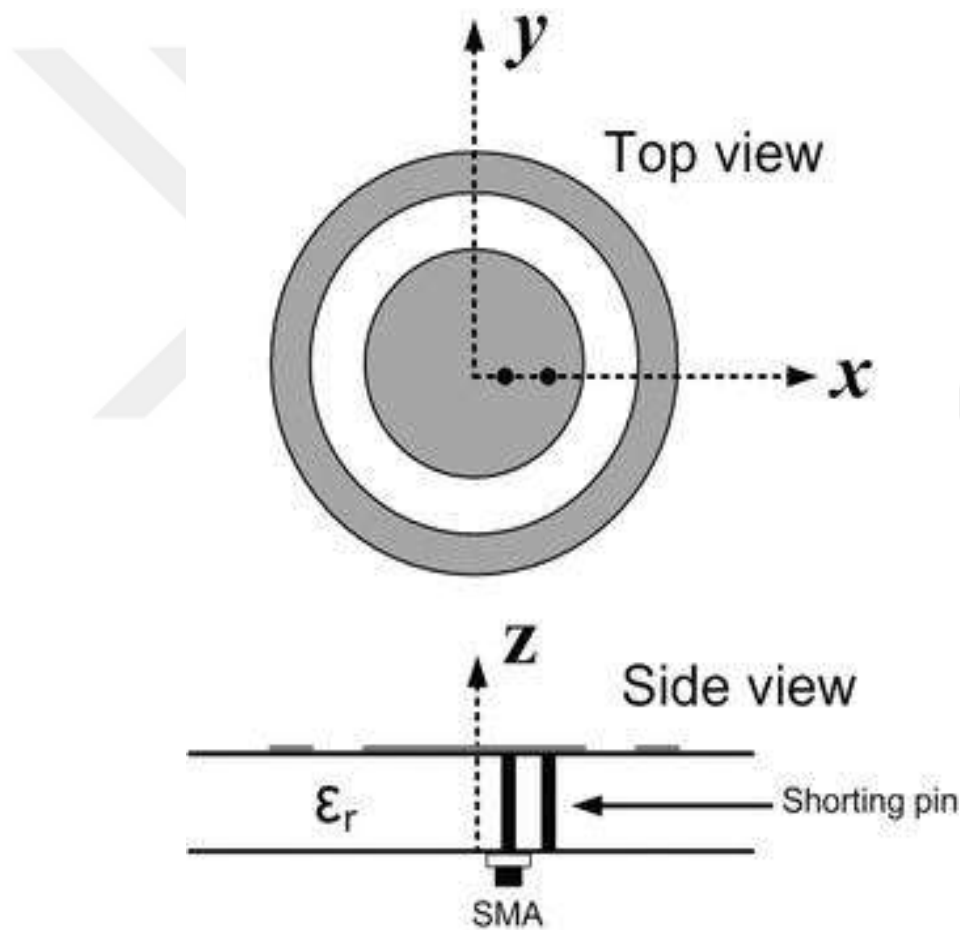


Figure 3.10: A loaded patch with an annular ring (Chew W.C,1982)

3.5. Stacked Patches

3.5.1. Configuration

Stacking is the process of connecting a main patch of a microstrip-patch-antenna vertically to another patch. When an array of antennas is employed, the issue of grating lobes can be resolved using this technique.

You do not run into the big planar area issue antennas (this is the antenna problem discussed in the previous part). established horizontally between the parasitic and main patches). The fabrication process for this technique is more difficult than the single-layer antenna displayed in the previous part, but the antenna structure has two layers. Using this strategy, you can obtain bandwidth at a rate of 20%. Figure 3.11 shows a typical rectangular stacked patch-antenna fed by a probe. This is a two-level structure with the primary patch printed on the bottom level and bonded to the parasitic patches on the top.

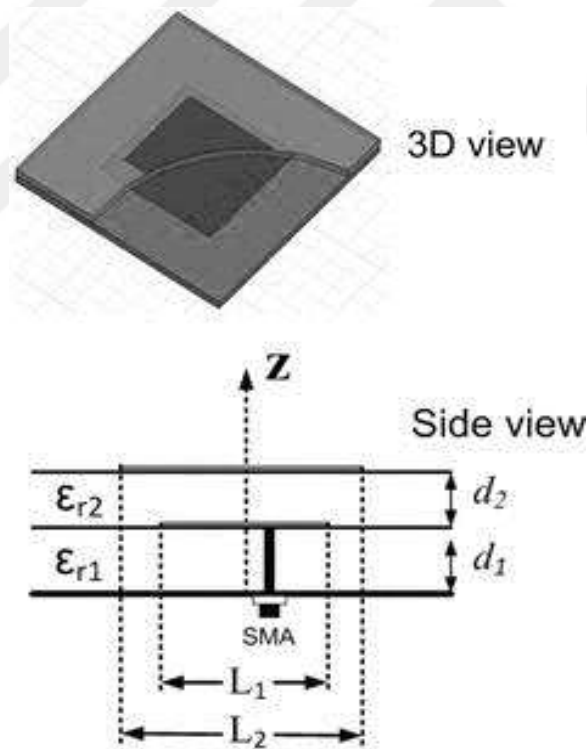


Figure 3.11: Stacking as a notion. a stack of rectangular patches

Typically, rectangular patches are used in this configuration, although annular and circular patches can also be utilized in the same way. The extra degree of freedom that rectangular and angular stacked patches has over circular stacked patches allows for

greater matching of impedance at a marginally lower bandwidth cost (Waterhouse RB, 2003).

In ref., a VSWR diagram of an antenna sample was constructed (Kumar. G et al., 2003) The bandwidth improvement is 18.8% when utilizing the strategy illustrated in Figure 3.12. (VSWR 2).

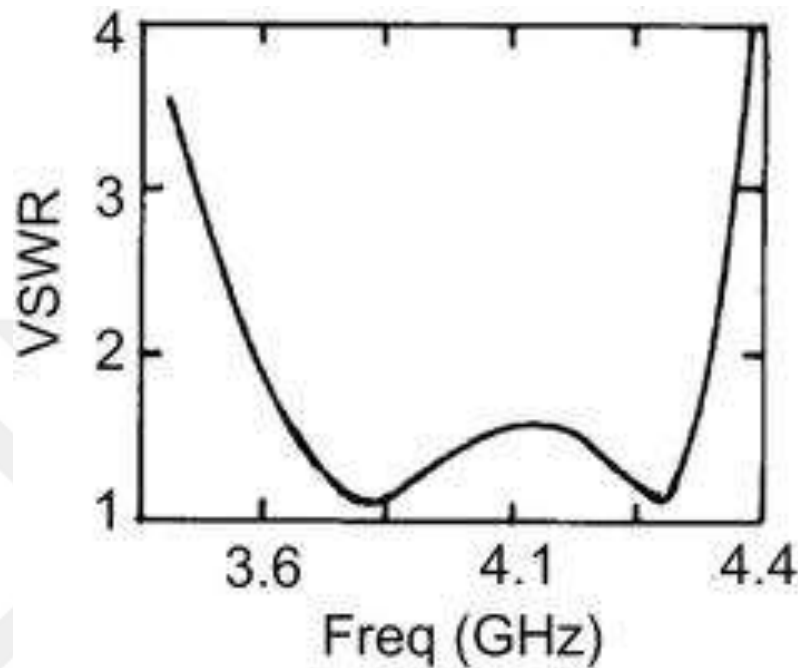


Figure 3.12: A typical antennae's VSWR graph (Kumar. G et al., 2003)

The exhibited design contains two reflectors, one for the main patches and one for the parasite patch. In Figure 3.11. To ensure that patches resonate at the same frequency, the size of each patch is selected throughout the design process. The dimensions of the two patches vary because they are made from two distinct substrates with various dielectric-constants (ϵ_{r1} , ϵ_{r2}).

It is possible to expand the bandwidth by shifting the two resonances relative to one another because of the mutual coupling between patches, which also creates a mutual resonance. To obtain the right coupling between the two resonances and increase bandwidth, the thickness and permittivity of substrates must be carefully chosen. By employing high permittivity, the coupling can be decreased to produce a larger bandwidth for impedance by using permittivity is low, like 1, for the top substrate and high permittivity, like 10, for the bottom substrate (Chung k et al.,2006).

Doing this high efficiency of surface wave is also attained, which improves the performance of the antenna as a radiator. The parasitic elements technique described in Chapter 3.4 can also be implemented using the stacking concept, which places the main bottom layer's patch and parasitic patches on the up layer. In (Kumar. G et al.,2003), 30% bandwidth could be attained by placing on top, there are five-parasitic rectangular areas. of the top layer and a single rectangle on the base coat to serve as the main path, the setup and its frequency response are displayed in Figure 3.13,

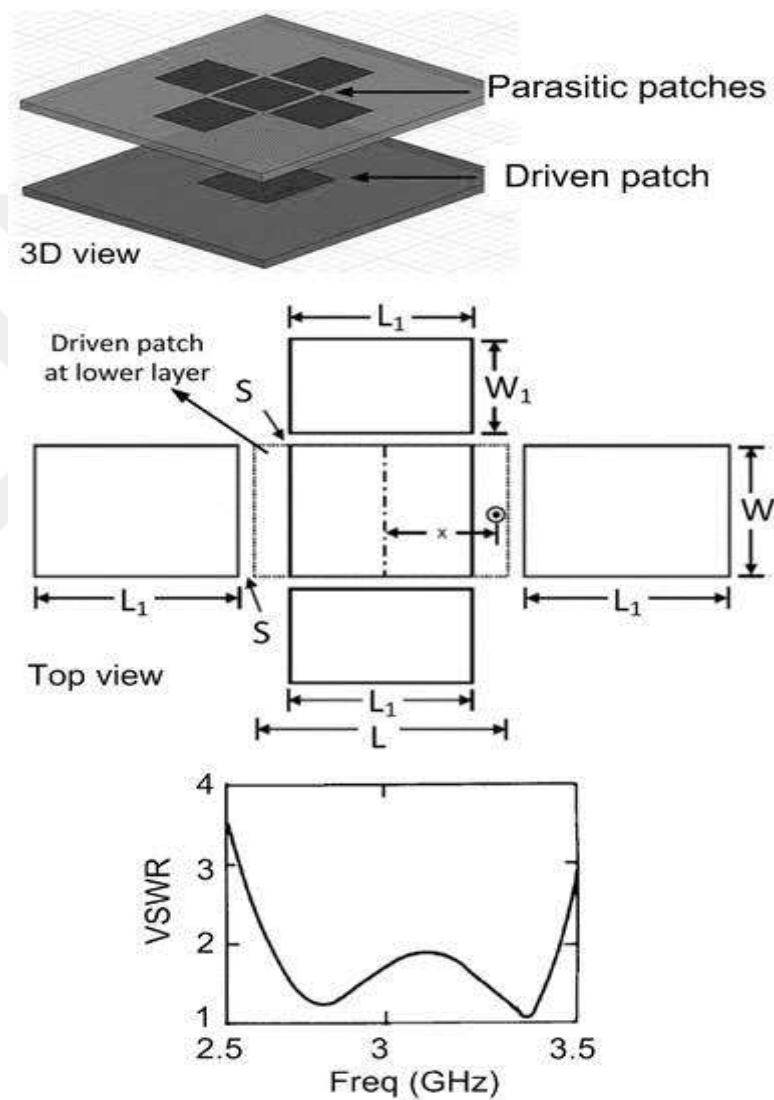


Figure 3.13: Configuration of the antenna and frequency response are displayed in (Kumar. G et al.,2003). the approach for parasitic elements described in Chapter 3.4, is used with the stacking notion

3.5.2. Fundamentals of Substrate Permittivity

The largest bandwidth for impedance and the lowest efficiency of surface wave (SWE) are displayed in Figure 3.14 (Waterhouse RB,2003) utilizing several laminates for the lower layer and foam with a proportional permittivity of 1.07 as a substrate for the top layer, to ensure the highest efficiency of surface wave and bandwidth attained by tweaking ϵ_{r1} , it should be emphasized that the upper layer's relative permittivity is chosen to be near 1. We can see that with $\epsilon_{r1} > 15$, it is possible to get broad bandwidths for impedance (greater than 25%) and excellent efficiency (greater than 80%), however, when ϵ_{r1} exceeds 15, the efficiency of the surface wave starts to decline, which impairs the antenna's ability to radiate. The bottom patch's surface wave is more well connected to the top patch, and, as a result, with radiant fields when ϵ_{r1} is reduced, increasing antenna efficiency. Higher ϵ_{r1} consequently results in decreased efficiency of the surface wave.

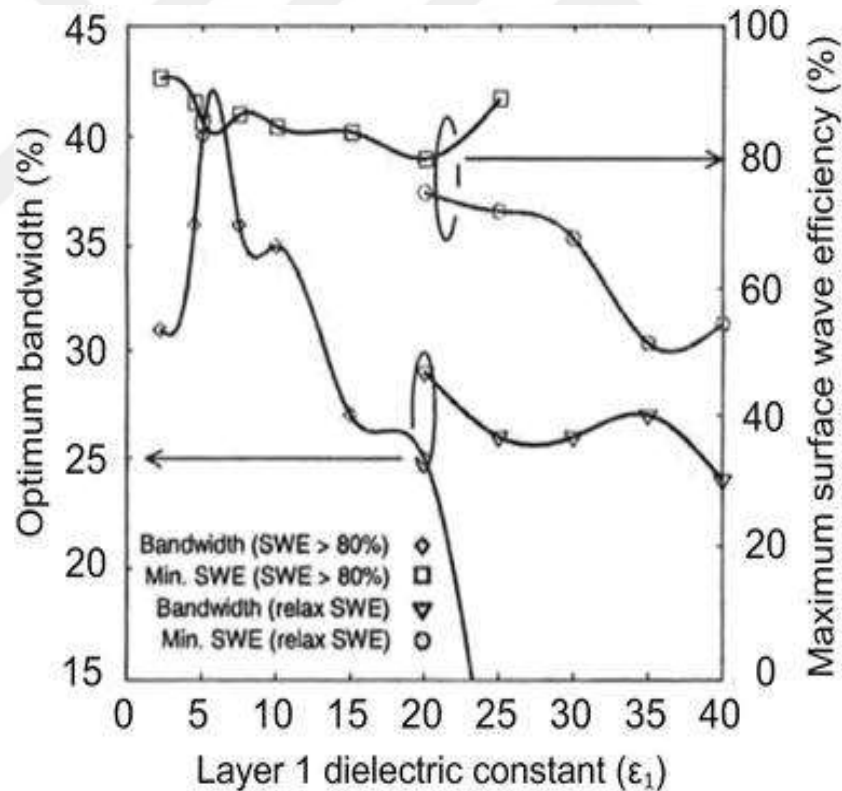


Figure 3.14: Efficiency of surface wave (SWE) and bandwidth for impedance about the bottom layer dielectric-constant ϵ_{r1} , the upper layer with permittivity is 1.07 (Waterhouse RB,2003)

3.6. Layered Aperture Patches

Multi-layer structures called hole-stacking stacking patches can achieve a frequency band in the 50–70% range. The general design of an opening stacking patch antenna is depicted in Figure 3.15. It is made up of a ground plane with etched coupling apertures, commonly known as slots, two patches, and an N dielectric layer. This configuration widens the bandwidth of impedance and includes an additional connecting method (in between the feed line and the main patch) in comparison to the conventional stacked patch depicted in Figure 3.11.

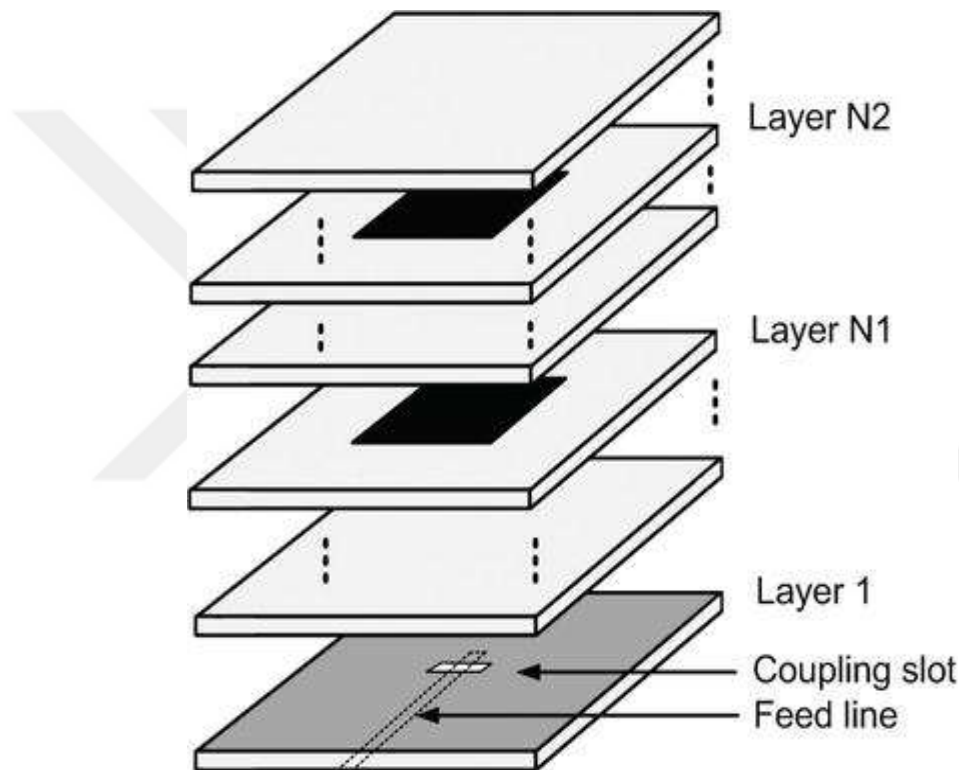


Figure 3.15: An Aperture stacked patch antenna's general configuration

Figure 3.16 shows the coefficient of reflection S_{11} of the three-level aperture stacking patch-antennae used in the K-band reference (Waterhouse RB, 2003). An impedance bandwidth of over 46% is achieved concerning the center frequency. The designed antennae gain exceeds six dBi in the frequency range of 26-40 GHz. Note the stacked patch antennas in (Waterhouse RB, 2003) is supported by a hole that improves gain and the front-and-back ratio.

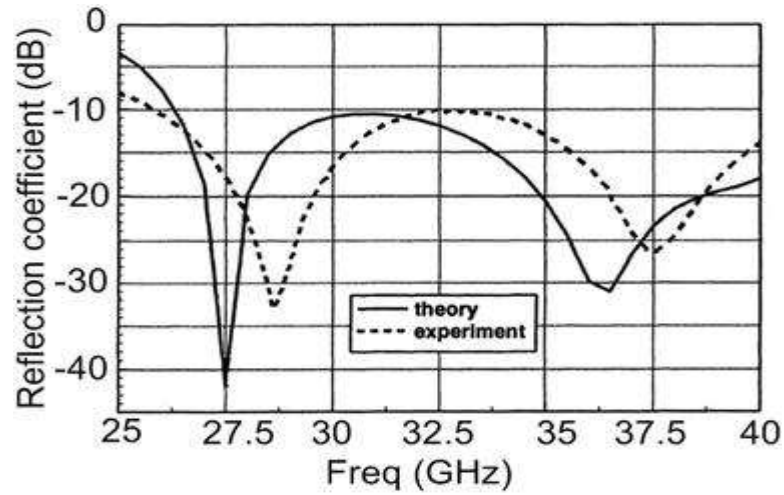


Figure 3.16: The slot stacking antennae's coefficient of reflection (S11)

Figure 3.17 shows the geometric size of a slot stack patch antennae. In this design, two offset feeds can be used to excite the slots to further control the coupling performance. A power divider connects the two-feeding strip line, and the 100 lines are reached by the 50 lines.

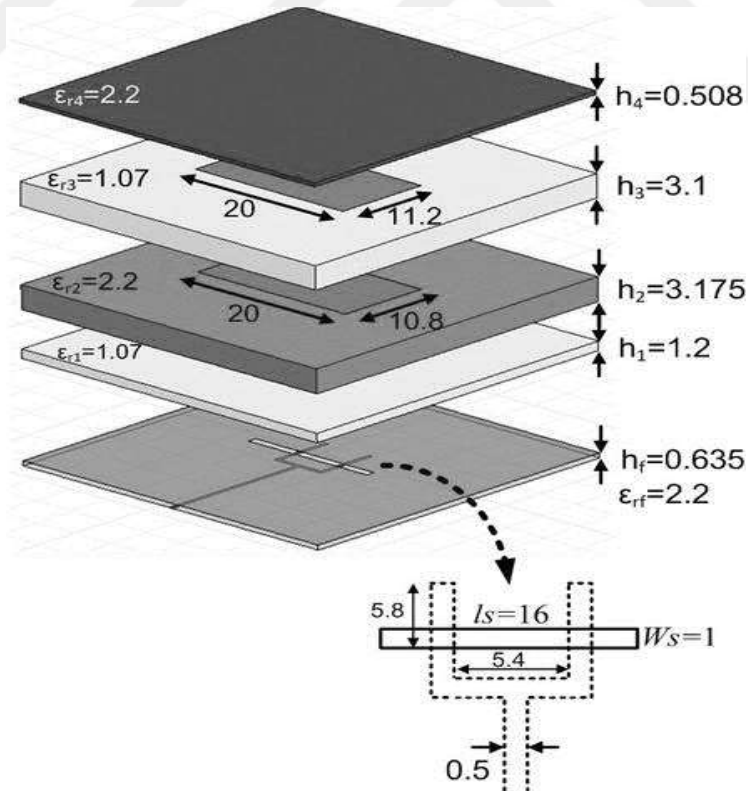


Figure 3.17: The Aperture stacked patch-antenna layout and dimensions

Figure 3.18 (Waterhouse RB, 2003), (Targonski SD et al., 1998) shows the suggested antennae's S11 contemplation value. We can see that, around the center frequency, the fractional bandwidth is around 67.0%. The planned antennae gain is approximately 7.0 dBi over the working bandwidth.

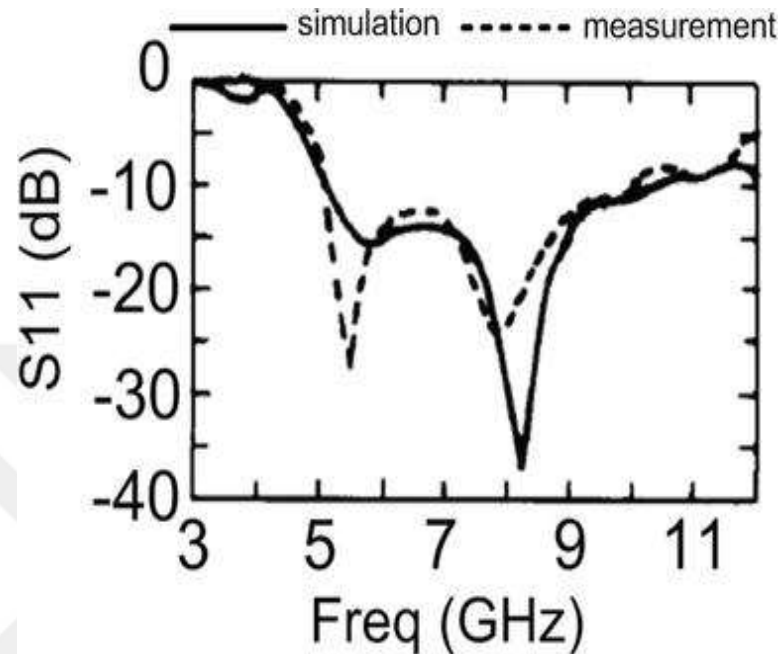


Figure 3.18: Aperture stacked patch-antenna coefficient of reflection

3.7. Broadband Circular Polarization Techniques

Linearly polarized broadband techniques were discussed in the previous part. However, circular polarization is necessary for various applications, including radar and guidance systems (Kumar G et al., 2003). A typical microstrip patch antenna has an axial ratio (A-R) frequency of about 1%, which is quite small for many applications. Therefore, it should be facilitated through a variety of strategies. In this paragraph, we briefly describe some configurations that produce broadband circularly polarized radiation.

3.7.1. On a Single Layer, Parasitic Elements

This approach extends the bandwidth in the same way as in Chapter 3.4 but increases the A-R bandwidth because the main patch is circularly polarized. Figure 3.19 (Reddy KTV et al., 2000) shows a doubly fed, square-connected, circularly polarized microstrip patch antennas. The main patch contains two perpendicular ports that are separated by a 90° phase shift and are circumferentially polarized. on all four ends, joined to four parasite

spots. As a result, two perpendicular rows of parasite patches are connected to two systems and operations of drive patches. As a result, the A-R frequency is increased, and the two perpendicular modes are impedance matched across a larger frequency range than they would be without the parasite patch. The distance between the main patch and all four of her parasite patches must be equal because the amplitude of her 2D mode in the main patch is the same. incorrect.

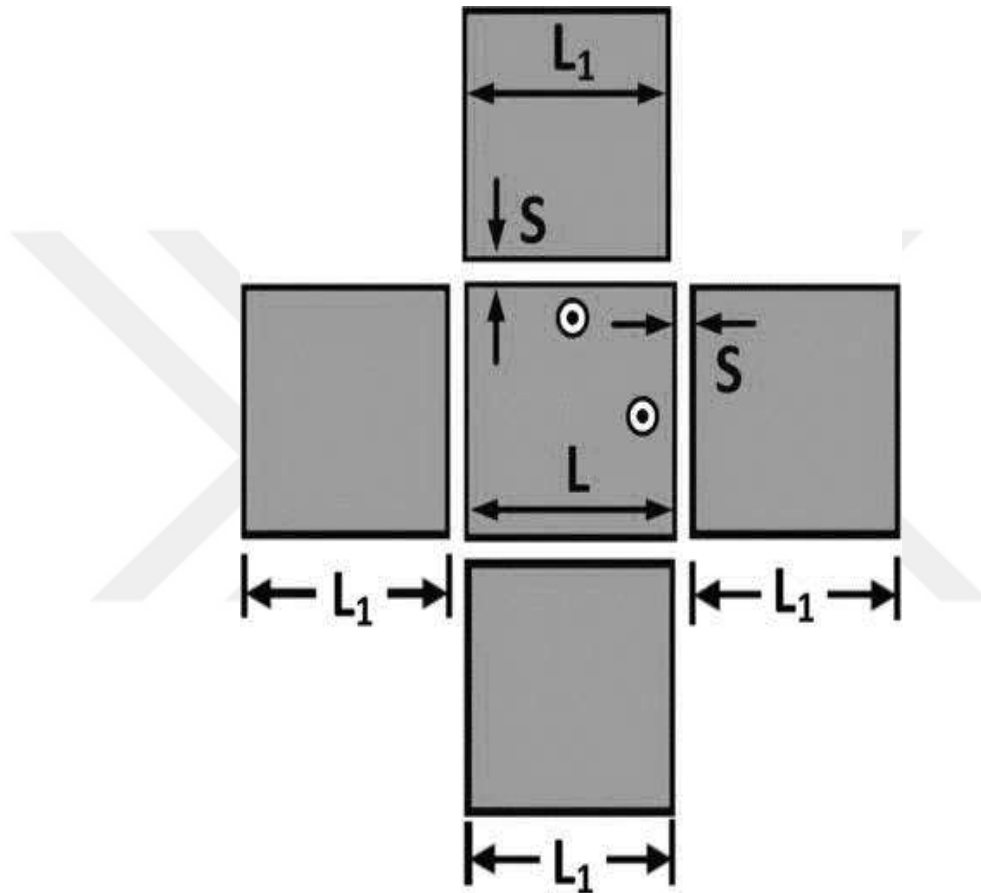


Figure 3.19: A circular polarized microstrip-patch-antenna with four edges that are doubly supplied and connected

In this case, it should be emphasized that all parasitic arrays should be equal with the same shape and area in keeping the gain, spectrum, and A-R improved by balancing the magnitude of the perpendicular radiation modes. The parasitic patch must likewise be square because the patch itself is squared. With just one layer, 10% A-R throughput is possible.

3.7.2. Stacking

In this case, stacking techniques can be used to increase the A-R bandwidth, as described in Chapter 3.5. Figure 3.20 shows a circularly polarized, doubly fed, the main patch is doubly fed and circularly polarized. The main patch creates two perpendicular modes that are perpendicularly connected to the parasite patch and excites the two perpendicular modes in it. In situation, two perpendicular modes in the lesser patch are connected to two perpendicular modes in the upper patch. In a conclusion, these dual quadrature types are resistance paired on a broader frequency bandwidth than without the parasite patch, resulting in a larger A-R bandwidth. An example antenna based on the arrangement in Figure 3.20 is constructed in (Reddy KTV et al., 2001), and an A-R bandwidth of 18% is achieved. Both primary and parasite spots are squared in (Reddy KTV et al., 2001).

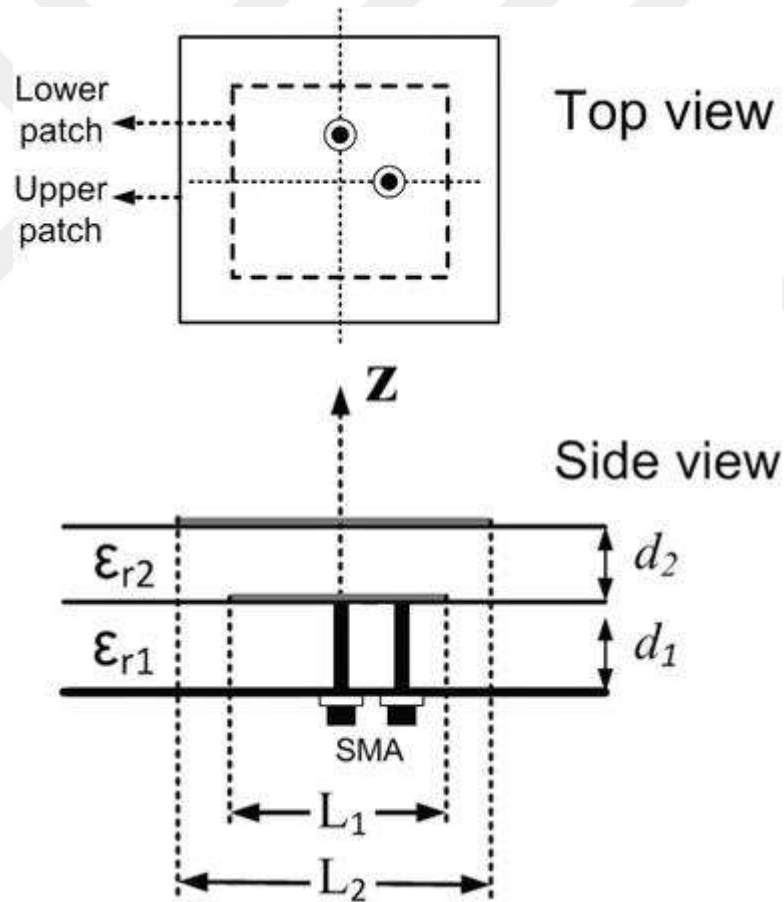


Figure 3.20: A-R bandwidth expansion using the stacking approach

3.7.3. Aperture Coupling

Obtaining circularly polarized radiation with increased A-R bandwidth with varying the slit patch geometry in the hole connecting approach outlined in Chapter 3.2 (Huang CY et al., 1999) -(Huang CY et al., 1998). Figure 3.21 shows a hole-connected square patch antenna with cross-over-formed connecting slots. In this setup, the two perpendicular modes created with the cruciform slot couple to his two perpendicular modes the patches, increasing the range frequency of every mode, resulting in an increased A–R bandwidth. In ref. (Huang CY et al., 1999), a sample antenna was constructed with the arrangement displayed in Figure 3.21, achieving A-R bandwidth of 1.4%.

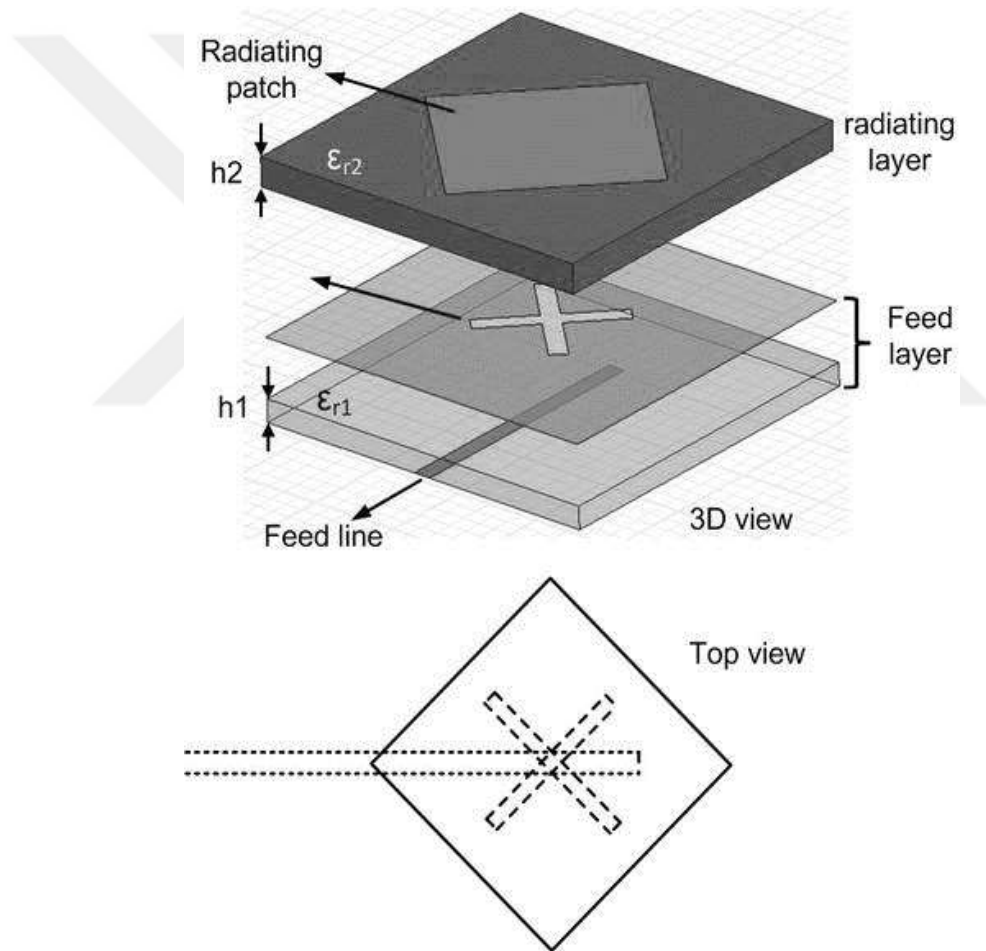


Figure 3.21: Microstrip patch antennas with aperture coupled slots. The lengths of the two crossing slots are adjusted to produce a (90°) phase difference between the two perpendicular models

Figure 3.21 shows dual crisscrossed slits and a straight spot. A similar operation, however, can be achieved by employing a slot and changing the geometry the of patches. Figure 3.22 shows hole-connected patch antennae with a track 45° rotatable slot and a square patch. This configuration is used in ref. (Huang CY et al., 1998) designed a circularly polarized antenna with an A-R spectrum frequency of about 1.1%.

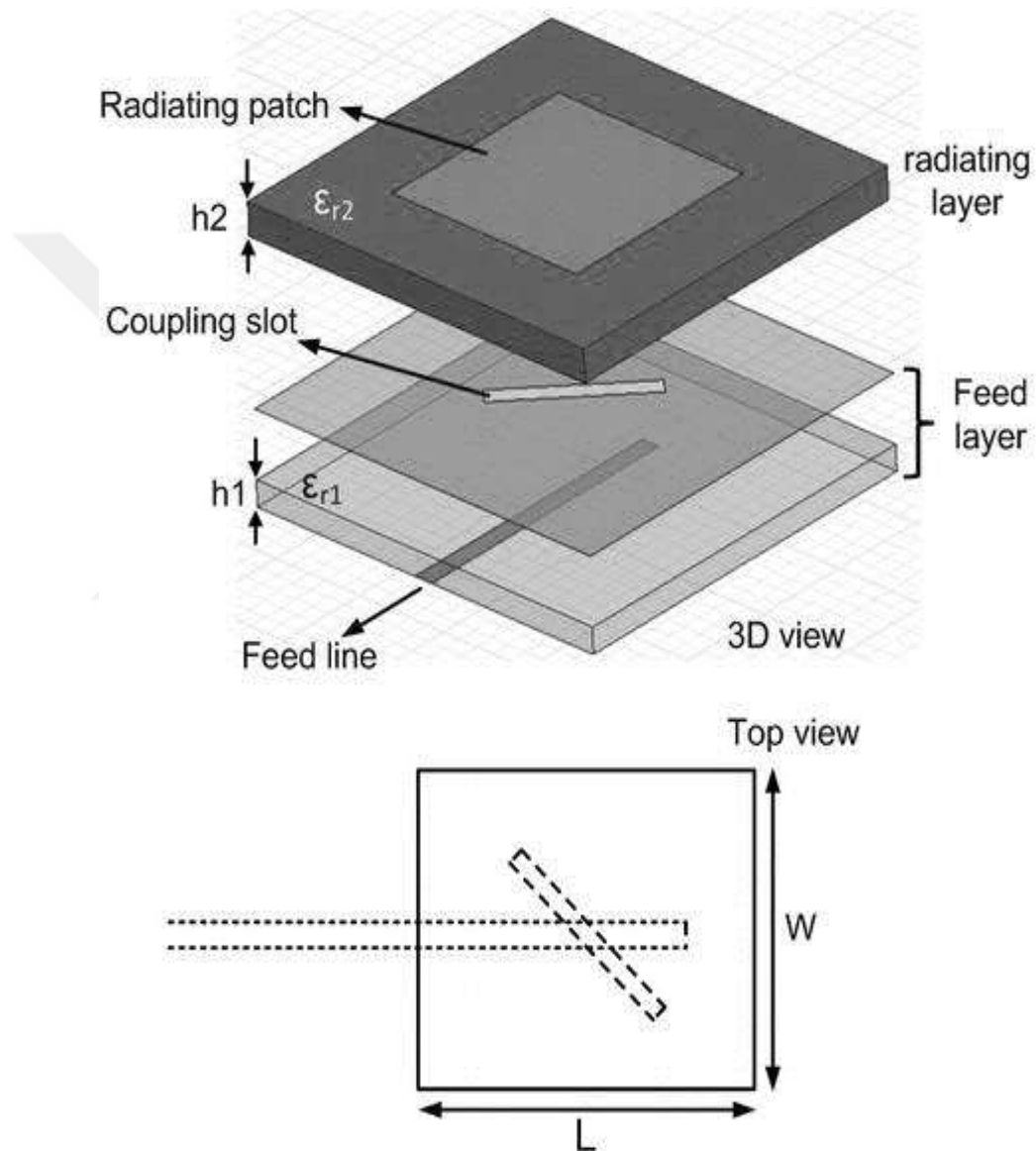


Figure 3.22: A patch-antenna with a track-(45°) rotatable hole with an almost shape-patch

3.7.4. The Array

The array approach is likely to provide the most diverse A-R answers. In this way, the array elements are rotated one at a time while having the same size but various phases. The components are each linearly or circularly polarized, but the entire display is circularly polarized. Figures 3.23 and 3.24 (James JR, 1989) to (Lo WK, 1998) show several array configurations for providing broadband circularly polarized radiation. The array elements in these figures are circularly polarized.

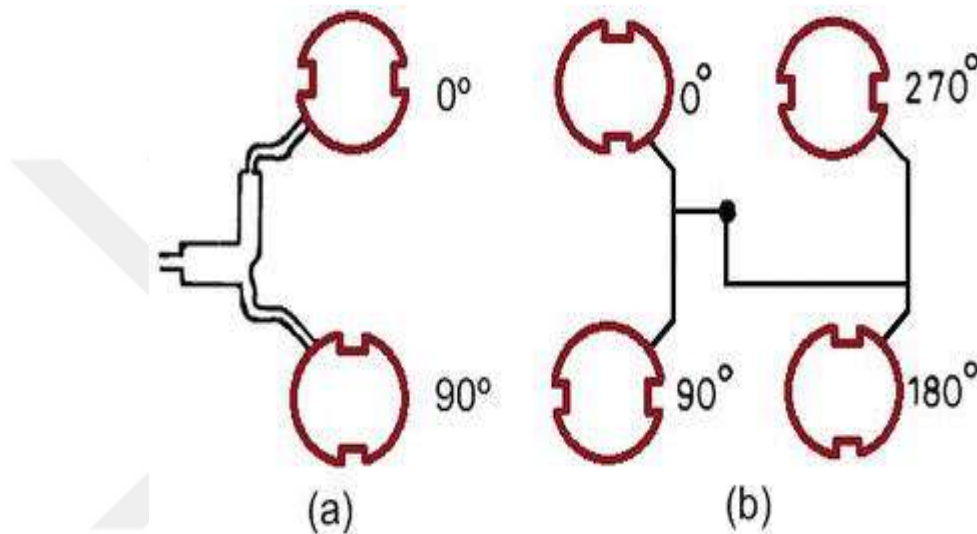


Figure 3.23: Two array configurations with sequentially rotated circular polarizers. (a). A two-dimensional array whose elements are rotated 90° and phase changed. (b). A 2-by-2 array in which each component is rotated (90°) degrees and out of stage with adjacent elements

Figure 3.23(a) (James JR, 1989) shows a one-by-two array whose components are 90° out of the stage and turned 90° relation one to one another. A 90° phase variation is achieved by lengthening the feed lines. Figure 3.23(b) (Pozar DM et al., 1995) shows his 2x2 array using the same idea. Each element in this figure has a 90° rotation and a 90° phase difference from its neighbors. Figure 3.424(a) (Teshirogi TM et al., 1985:117) depicts a 2x4 array with every element's phase equivalent to the angle of rotation relative to the element feed by the 0° phase. In reference (Teshirogi TM et al., 1985:117) a sample of this arrangement was made and the frequency response involving VSWR, and A-R is displayed in Figure 3.24. (b). The bandwidth is 13.7% for VSWR less than 1.5 and 14% for A-R less than 3.

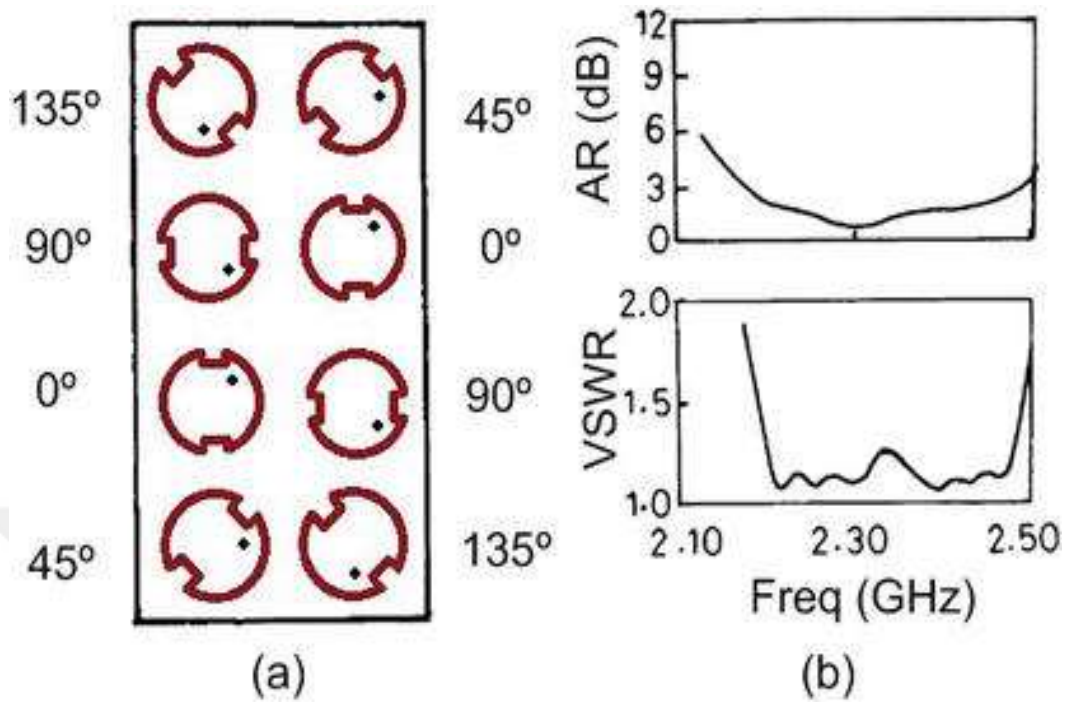
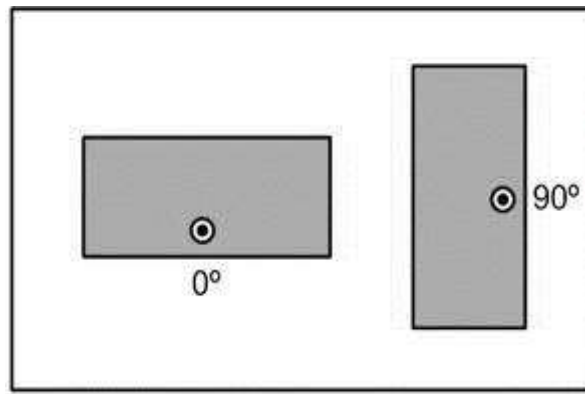


Figure 3.24: Example of gradually rotated 2 x 4 array. (a) antennae structure & (b) (VSWR), A-R of antennae are constructed as a function of frequency

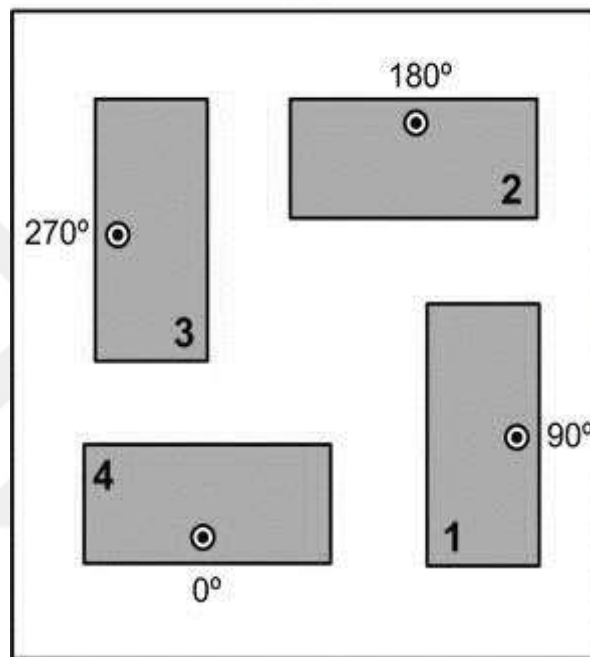
The network components are in immediate connection with the supply system in the arrangement illustrated in Figures 3.23 and 3.24. Non-contact power supply approaches, such as close-coupled and gap-coupled power supplies, can also be used in this case (Lo WK et al., 1998:2190). As stated earlier, broadband circular polarization can be achieved using an array of sequentially rotating linear polarizing elements. Figure 3.25 illustrates two sample tables (Huang J. A, 1986:1113). The elements are in the exact order as they are displayed in (Figure 3.23), (Figure 3.25(a)) shows a 1x2 lattice with two arrays of perpendicular linear polarization provided by a 90° phase variation.

It is simple to see that in this structure, the dual bimodal arrays of radiation are perpendicular with a 90° phase difference, producing circularly polarized radiation. Figure 3.25(b) shows a two-by-two progressive rotation network.

The two sets of perpendicular fixes (1, 3 - 2, 4) in this arrangement create two perpendicular modes with a 90° phase difference, increasing the antenna's gain. -10 as depicted in Figure 3.25, (a).



(a)



(b)

Figure 3.25: Two - examples of successive arrays are rotated with polarized linear members are displayed: (a) a 1x2 - array (b) a 2x2 – array

The number of elements should be raised to improve the gain even further. According to Ref. (Iwasaki H et al.,1995:604), if N elements are to be utilized for this purpose, each element must be rotated $360/N$ degrees concerning its neighbors when placed in a circle. Additionally, a $360/N$ phase shift is required between adjacent parts.

4. DESIGN OF ANTENNA AND ANALYSIS

4.1. Introduction

The goal of this study, keeping in mind the size of the antenna, is to improve the performance of the antennas in terms of increasing the bandwidth, directivity, and gain. To achieve this, it is necessary to choose an effective antenna design in accordance with one of the methods to improve the performance of the rectangular microstrip patch antennas. Using a line model transfer to analyze the antenna, calculate its dimensions, design its distances using the (MATLAB) program, select the axial feed, and then simulate this design for the rectangular antenna microstrip patch using Microwave Studio software (CST) to achieve the return loss, gain, directionality, power, and bandwidth at a resonant frequency of 2.45 GHz to make the antenna more effective, allowing it to be used in various communications applications.

4.2. Design of the Antenna

In this design, a microstrip antenna was adopted in its rectangular shape with a coaxial feed, and another radiant patch was added with a distance (D) from the basic patch. The distance to regulate how the impedance matches the antenna.

The two resonances fluctuate relative to one another because of the reciprocal interaction between patches, resulting in cross-resonance and wider bandwidth. The bandwidth is extended and suitable coupling between the two resonances is obtained by selecting the right substrate thickness and “dielectric constant.” The best coaxial designs are those with a wide spectrum of impedance, as displayed in Figure 4.1, which uses a high dielectric constant to minimize coupling to maximize radiated power and frequency bandwidth. Design parameters can be chosen to achieve it. There, feed a square microstrip antenna.

- The frequency of resonant (f_r): It is the appropriate frequency at which the antenna operates within a specified range and in this design, the resonant frequency is ($f_r = 2.45$ GHz).
- Insulation constant for substrate (ϵ_r): The antenna's size and efficiency are influenced by substrate's dielectric-constant., here the dielectric of material was (Rogers RT5870) with the dielectric-constant ($\epsilon_r = 2.33$) and the loss tangent is equal to (0.0012).

- substrate thickness (h): The height of the dielectric substrate for an antenna was chosen with coaxial feed in this design to increase the power of radiated hence, the height of the dielectric pillar used in the antenna design is $h = 1.5$ mm.

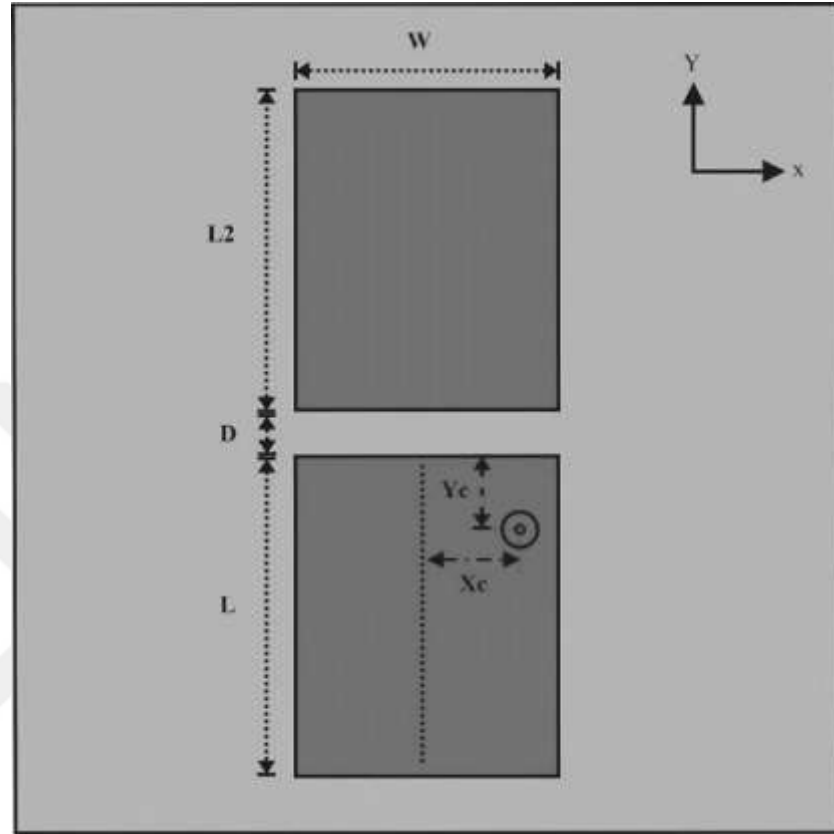


Figure 4.1: Microstrip patch antenna as a rectangular shape with the addition of another patch

4.3. Physical Parameters Calculation of Antenna

The design parameters and dimensions were calculated using MATLAB software in Appendix A to obtain the best impedance and the largest bandwidth according to the equations below by the transmission line method (Balanis, C.A, 2005). To ease our design process, the results of each parameter are displayed in Table 4.1.

- According to (James et al. 1989), the antenna's width patches the following calculation:

$$w = \frac{c \sqrt{2/\epsilon_r + 1}}{2f_r} \quad (4.1)$$

where c represents the speed of light in space.

- According to (Pozar et al. 1995), the following formula can be used to determine the length of the patches:

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + 12 \left(\frac{h}{w} \right) \right]^{-1/2} \quad (4.2)$$

where: ϵ_{reff} is effective dielectric-constant.

ϵ_r = Dielectric constant of the substrate

h = Height substrate.

w = Width patch

Due to the fringing field, the extension of patch length (ΔL) provided by (Ramesh et al., 2001):

$$\Delta L = 0.412 * h \left(\left(\epsilon_r + \frac{3}{10} \right) * \left(\frac{w}{h} \right) + 0.246 \right) / \left(\left(\epsilon_{reff} - 0.258 \right) * \left(\frac{w}{h} + \frac{8}{10} \right) \right) \quad (4.3)$$

$$L_{eff} = L + 2\Delta L, L = \frac{\lambda_0}{2} - 2\Delta L \quad (4.4)$$

- For the construction of the substrate and ground surface, antenna length and width were estimated by (Huang, 1983,) (Thomas, 2005):

$$L_g = LP + 6h \quad (4.5)$$

$$W_g = wP + 6h \quad (4.6)$$

where L_g is the ground plane's and substrate's length, W_g substrate, ground plane, and its width.

4.4. Calculations in MATLAB

The design program was written in (MATLAB). At first, the design parameters are requested, which are as follows:

- The dielectric-constant ($\epsilon_r = 2.33$)
- The substrate thickness is $h = 1.5$ mm
- The resonant frequency is $f_r = 2.45$ GHz
- The impedance at the feeding point ($z_c = 50$ ohms)

After that, the width - patch is calculated from equation (4.1), by (James et al. 1989), and through equation (4.2), the effective dielectric-constant is calculated due to the passage of the electric field from the patch to the ground through substrate passing through the air.

Then the length of the patches is calculated through equation (4.4) and considering the resulting fringing from the edges.

Using MATLAB, create a rectangular microstrip antenna using a transmission line model

=====
The dielectric-constant: 2.33

The substrate thickness (in mm): 1.5

The frequency (GHz): 2.45

The input impedance (ohm): 50

RECTANGULAR PATCH:

The width of the patch (W) is 38.25 mm

The length of the patch (L) is 29.8034 mm

The minimum length of ground plane is 38.8034 mm.

The minimum width of ground plane is 47.25 mm.

4.5. Design Parameters

Table 4.1 shows the required design parameters with an impedance ($50\ \Omega$) value, knowing that all measurements are in millimeters.

Table 4.1: Design parameters

No	Parameters	Descriptions	Value (mm)
1	w	Width - the patch	38.095
2	L	Length- the patch	29.85
3	h	Height of substrate	1.5
4	D	Distance between patch	0.193
5	L_2	Width the patches 2	38.095
6	X_c	x - center	10
7	y_c	y - center	-4

5. SIMULATION AND RESULTS

5.1. Simulation

The rectangular microstrip-patch-antenna is built using Microwave Studio (CST) software as displayed in the geometry in Figure 5.1 with a coaxial feed in Figure 5.2 and operates in compliance with “IEEE, 802.11-b, 802.11-a, 802.15.1 Bluetooth, and 802.15.4 ZigBee” applications and “802.15.3 UWB, WiMAX, and 802.11-a-b-g Wi-Fi” correspondingly, the frequency range to be watched is input in (CST) studio along with the type of antenna to be modeled, the ground plane was the first object to be modeled; in (CST) Studio, one must choose block and provide its specifications. In this instance, copper is used as the ground plane.

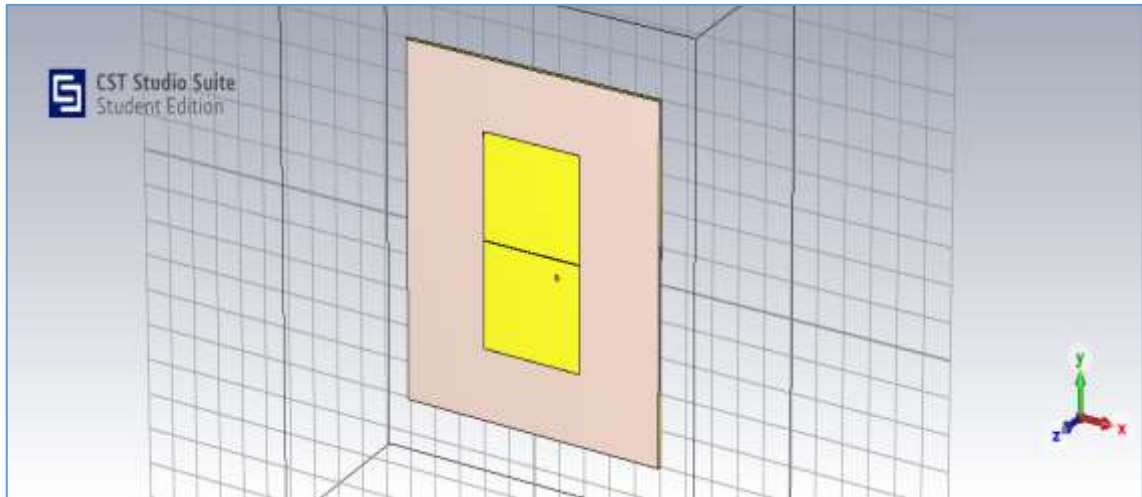


Figure 5.1: Geometrical design view

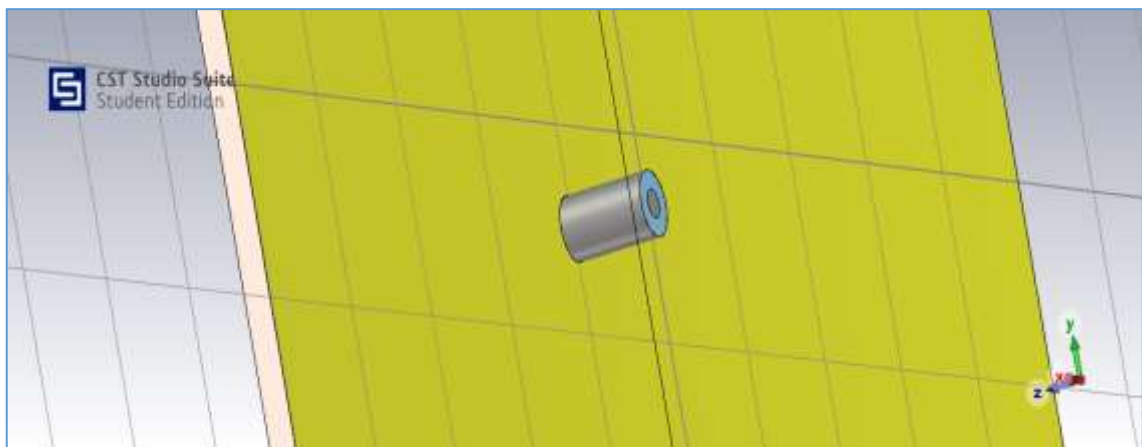


Figure 5.2: Coaxial feed

5.2. CST Studio Results

The results obtained from the simulation of the proposed design and according to the assumed parameters are displayed in Figure 5.3, where the results were better than those obtained in a previous study (Nuraddeen Ado et al., 2016), which are as follows in Table 5.1:

Table 5.1: Simulation outcome

Return Loss(S1,1)	Directivity	Gain	Bandwidth at (-10.0) dB
-55.98 dB	8.2 dBi	7.838 dBi	117.21 MHz

5.2.1. Return Loss at 2.45 GHz

The return loss value is equal to (-10.0 dB), accomplished as displayed in Figure 5.3, the antenna covers “the WLAN standard IEEE 802.11”, with a resonant frequency of 2.45 GHz.

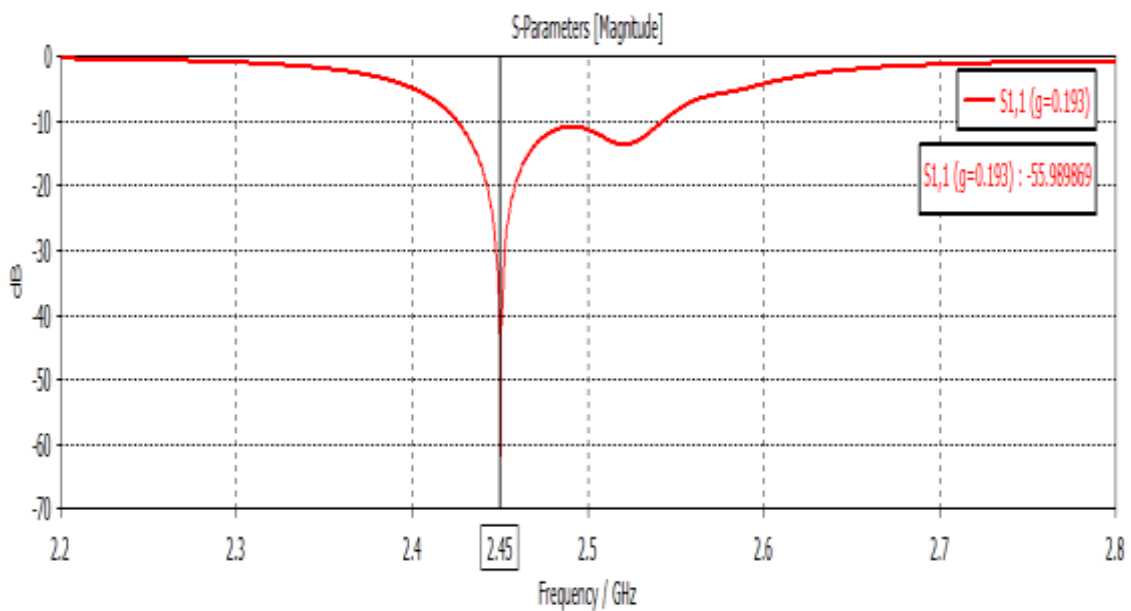


Figure 5.3: Microstrip patch reflection coefficient at 2.45 GHz

5.2.2. The Bandwidth at 2.45 GHz

The bandwidth 117.21 MHz is accomplished as displayed in Figure 5.4, the antenna covers “the WLAN standard IEEE 802.11,” with a deep frequency of 2.45 GHz, the obtained bandwidth is an improvement over the previous study (Nuraddeen Ado et al., 2016).

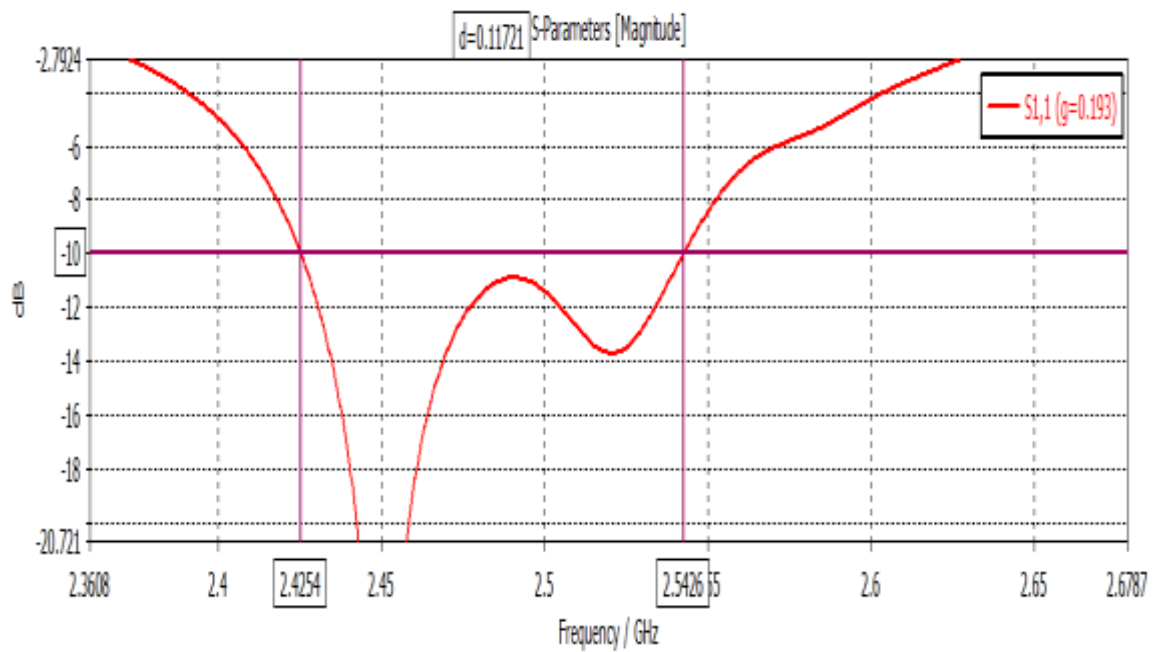


Figure 5.4: Bandwidth at 2.45 GHz

5.2.3. The Voltage Standing Wave Ratio (VSWR)

The voltage maxima to voltage minima ratio is known as the standing wave voltage ratio (VSWR), the VSWR value should range from 1 to 2. The results obtained coefficient of VSWR is small enough at a frequency of 2.45 GHz and where it corresponds to close enough to specified frequency bands for WLAN applications. Transmission line efficiency is measured using VSWR in Figure 5.5, The suggested microstrip-patch-antenna's VSWR value at the designated resonant frequency is 1.0056.

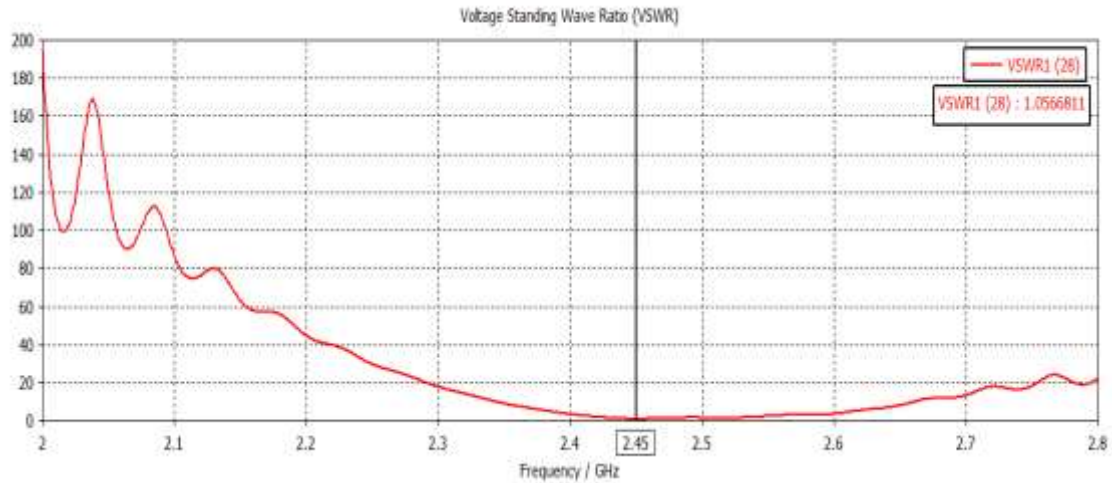


Figure 5.5: VSWR between 2 and 2.8 GHz

In Figure 5.6, we notice a change in standing wave voltage ratio (VSWR) in the case of the value of the distance between, the main patch and the parasitic patch change from zero to 0.192 mm, as the standing wave voltage ratio (VSWR), is from 1.0056 to 1.5007, and these values are considered acceptable with a resonant frequency of 2.45 GHz.

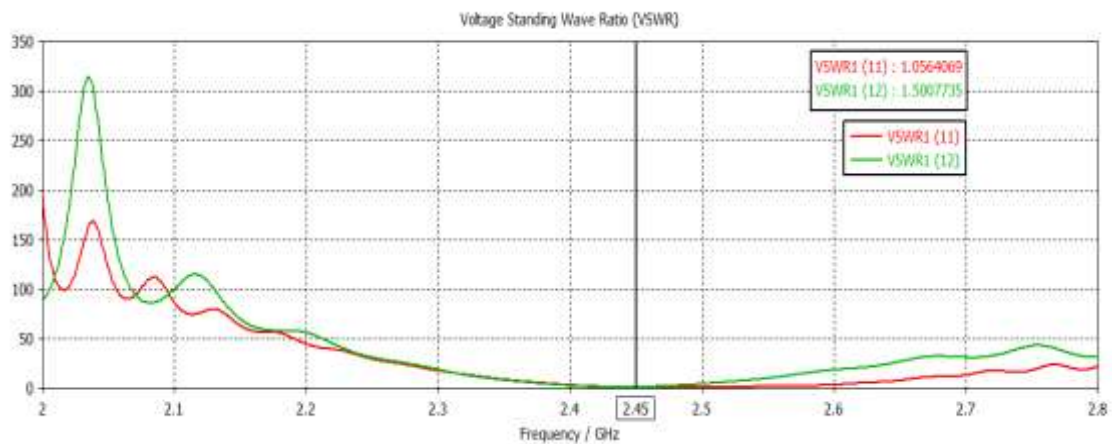


Figure 5.6: VSWR between 2 and 2.8 GHz when D=0, D=0.192 mm

5.2.4. The Directivity at 2.45 GHz

Figure 5.7 shows the 3D dimensional radiation pattern obtained from the antenna simulation at a frequency of 2.45 GHz, where the radiation pattern that the intended antenna has a consistent radiation pattern over the entire operational range with the directivity value is 8.23 dBi, for the antenna design that is suggested at 2.45 GHz is resonant frequency.

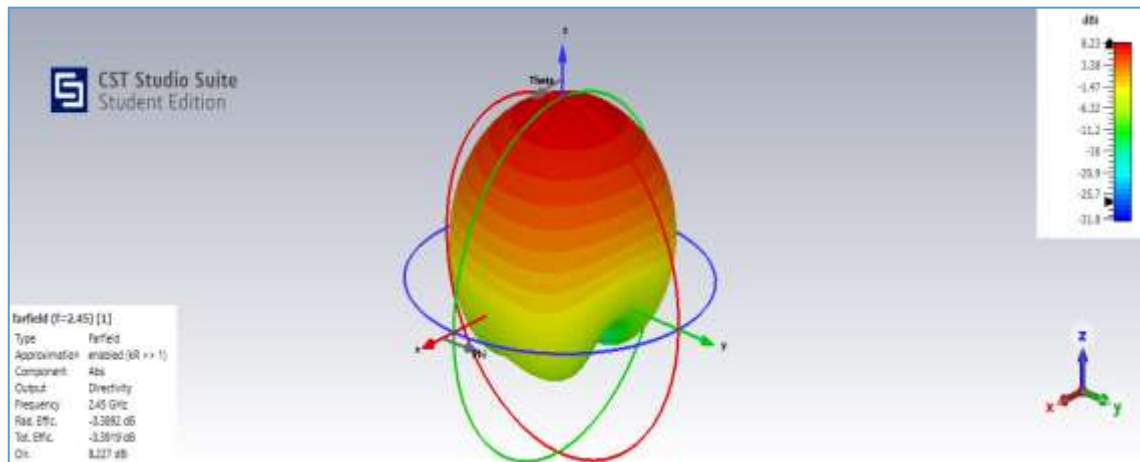


Figure 5.7: 3-D patch-antenna radiation pattern directivity with 2.45 GHz

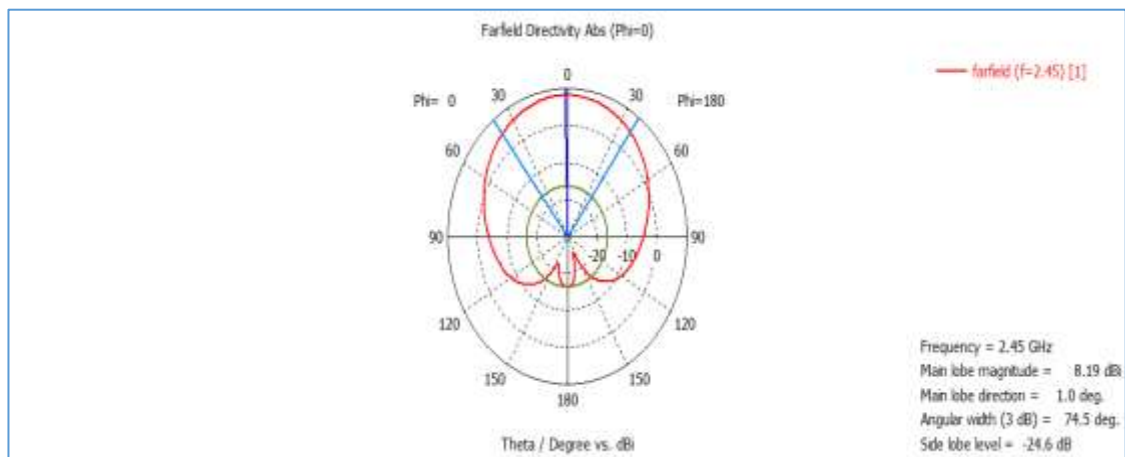


Figure 5.8: Directivity of the elevation radiation-pattern with 2.45 GHz

5.2.5. The Gain at 2.45 GHz

Figures 5.9 and 5.10 shows the 3D radiation pattern and gain obtained from the antenna simulation with a frequency of (2.45 GHz), where the radiation pattern that the intended antenna has a consistent radiation pattern over the entire operational range with a gain value is 7.83 dBi, for the antenna design that is suggested with 2.45 GHz is the resonant frequency.

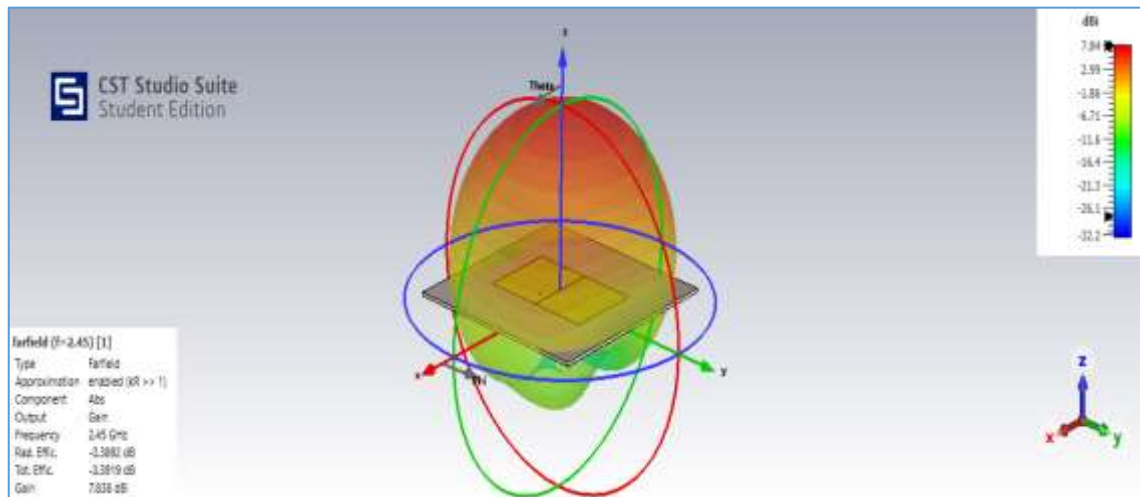


Figure 5.9: The patch antenna's 3D radiation pattern with 2.45 GHz (gain)

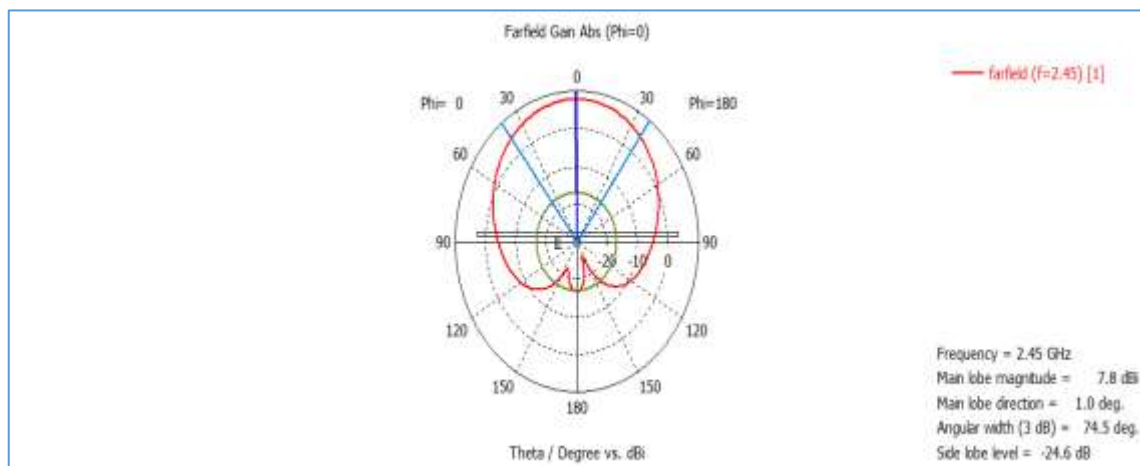


Figure 5.10: Gain at 2.45 GHz for the elevation radiation pattern

5.2.6. Surface Current at 2.45 GHz

Figures 5.11 and 5.12 at 2.45 GHz display the surface current density simulation findings for the study's antenna design. The simulation results show that the density drops off as you approach the margins, where there is a high current density along the feed line.

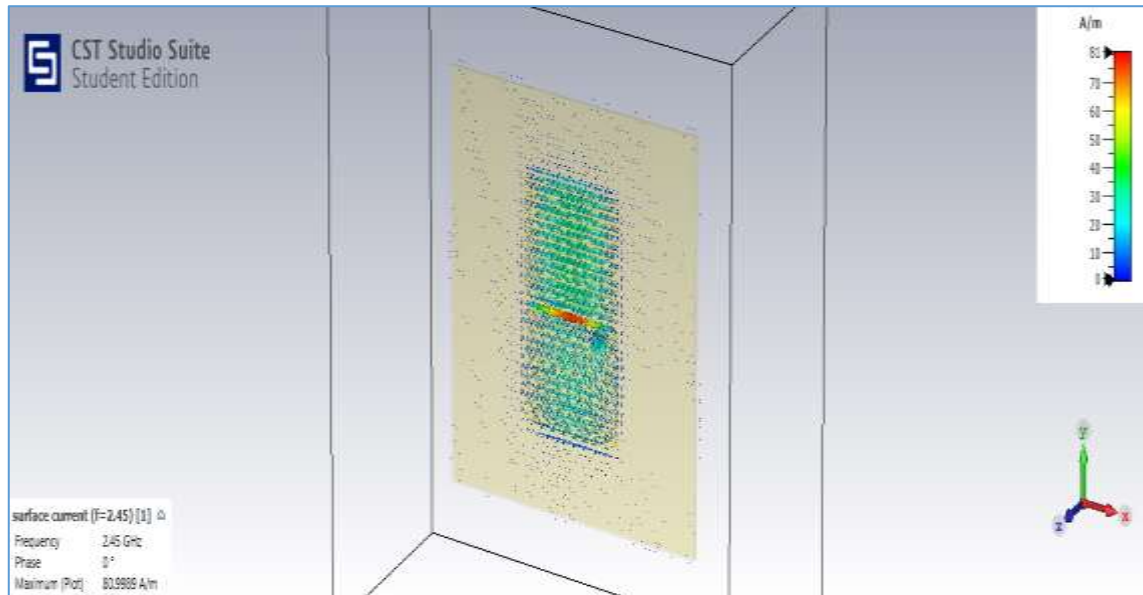


Figure 5.11: Surface current at 2.45 GHz from the front

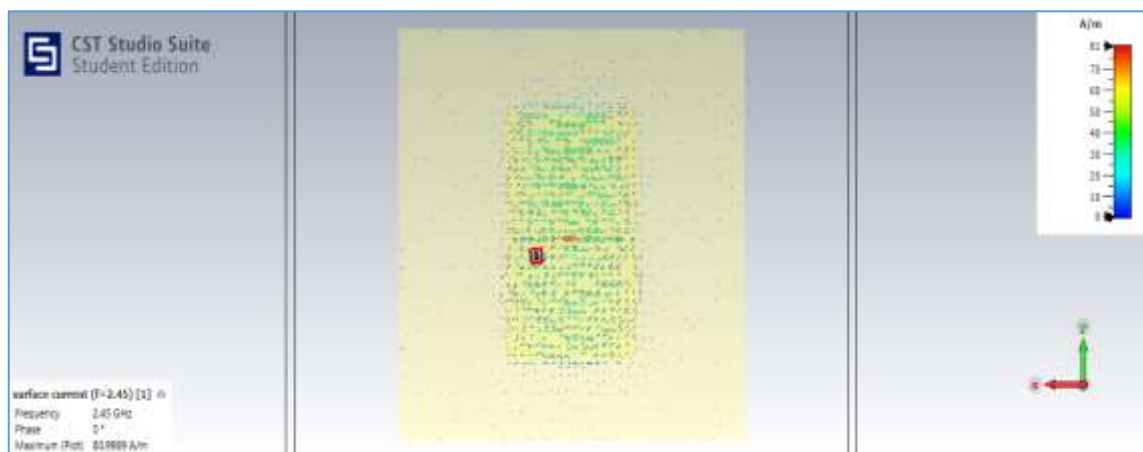


Figure 5.12: Surface current at 2.45 GHz from the back

5.2.7. Impedance at 2.45 GHz

Simulations performed on the antenna in Figure 5.11 shows that the impedance value (50.07 ohms) at 2.45 GHz is equal to the impedance value assumed in this study (Figure 5.13), where the impedance was 50 ohms. This point is used to connect the electromagnets inside and outside the board, this is known as the feed point. The electric field does not stop suddenly at the patch's perimeter, as it occurs in the hollow, where the electric field extends to the external surface, increasing radiation. The fringe fields between both the patches perimeter and the ground surface radiate to strengthen the patch fringing field, which serves to extend the antenna's frequency bandwidth.

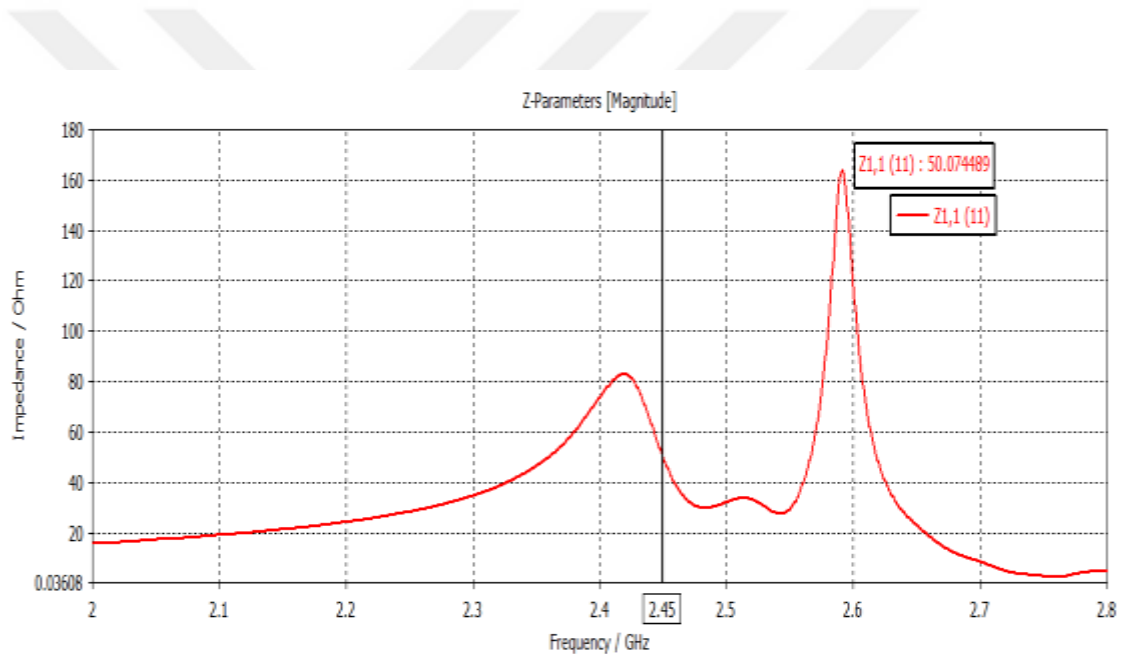


Figure 5.13: Impedance at 2.45 GHz

6. DISCUSSION

The importance of wireless communication is growing as the world becomes more connected and digitized. To lessen the difficulties of improving wireless communication, numerous studies have been carried out. Wi-Fi antenna configurations serve as the study's best examples. As the importance of the Internet increases, Wi-Fi antennae will continue to be in high demand. The devised antenna operates on the Wi-Fi band. Compared to comparable examples in the literature, it has a different structure, a smaller surface area, and uses inexpensive materials. Through tests and simulations, this has been proven. Due to its excellent return loss, it can be used in antenna designs. In this study, various techniques for increasing the bandwidth for the impedance of microstrip patch antennas that have been proposed in the literature are examined.

As indicated in Chapter 3.2, choosing a substrate can enhance bandwidth by up to 10%. This strategy, however, may have a negative impact on other antenna characteristics such as efficiency and backward radiation. It is proved in Chapter 3.3 that bandwidth can be increased by employing an in-direct feed method and linking electromagnetic areas to patch. Two techniques were presented to get up to 10% and 30% bandwidth, respectively: vicinity-connected and hole-connected patches. However, if an outside equivalent building is present and used, the achievable bandwidth for nearby-connected patches can be enhanced.

According to Chapter 3.4, a single-layer technique for improving bandwidth by using parasitic components at horizontal antenna apertures can provide 20% bandwidth at the expense of increasing antenna size, making it unsuitable for use in array configurations.

Chapter 3.5 discusses the multilayered stack of patches method that uses parasitic on the vertical parts to achieve an extremely broad bandwidth (particularly 50 to 70%). Using this technology, the planar antenna size is kept to a minimum, making it appealing for use in arrays.

7. CONCLUSIONS

According to the design and analysis results, a rectangular microstrip patch antenna was designed in this study. The findings were gathered and reviewed, and they are congruent with hypotheses and studies published in the scientific literature, as mentioned in Chapter 5.

The reciprocal interaction between patches causes the two resonances to fluctuate in relation to one another, resulting in cross-resonance and a broader bandwidth. By choosing the proper substrate thickness and dielectric constant, the bandwidth is increased and the coupling between the two resonances is suitable, resulting in optimized bandwidth. The performance and efficiency of the antenna are increased by using a high permittivity to reduce coupling and achieve a broader bandwidth for impedance. This technique also produces high surface wave efficiency.

The frequency spectrum has a bandwidth of 2.45 GHz and covers 117.21 MHz with a gain of 7.83 dB and a fixed radiation pattern free of side or back lobes. In terms of the radiation pattern, return loss, and VSWR corresponding to an ideal impedance at the center frequency of 50 ohms, it demonstrates the benefits of good antenna design. This antenna is simple to assemble on a substrate due to its thinness and small size. For WLAN applications using “IEEE 802.11 Wi-Fi, IEEE 802.15.1 Bluetooth, and IEEE 802.15.4 ZigBee standards,” the feed-in mechanism utilized in this design is a solid option.

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APPENDIX

Appx. 1. MATLAB PROGRAM

MATLAB Program for Design and Analysis Rectangular-Microstrip-Patch-Antenna dimensions, depending on the equations mentioned.

```
clear, clc , close all

format long

disp('Using MATLAB, create a Rectangular-Microstrip-Patch-Antenna using a
transmission-line-model');

disp('=====
=====');

Er0=input('Introducing the Dielectric-constant:');
h1=input('Introducing Substrate-thickness (in mm):');
fo=input('Introducing the Frequency (GHz):');
zo=input('Introducing the input-impedance (ohm):');

disp('Calculating-Please-wait. ');

fo=fo*1e9;

q=1.77;

Er0=q*Er0;

%"Determine - the width"

wth=(3e8/(sqrt((Er0+1)/2)*2*fo))*1000;    %"in mm"

%"Determine the effective Dielectric-constant"

Er_eff=((Er0+1)/2)+ (((Er0-1)/2)* (1+((12*h1)/wth))^-0.5);

%"Determine the extension of length L"
```

```

delt_l=((Er_eff+0.3)*((wth/h1)+0.264))/((Er_eff-0.258)*((wth/h1)+0.8))*(0.412*h1);

%"in mm"

%"Determine the effective length"

l_effc=(3e8/(2*fo*sqrt(Er_eff)))*1000;

%"Determine the actual length"

Lo=l_effc-(2*delt_l);

la0=(3e8/fo)*1000;

k=(2*pi)/la0;

Xo=k*(wth);

i11=-2+cos(Xo)+(Xo*sinint(Xo))+(sin(Xo)/Xo);

G0=i11/(120*pi*pi);      %"Conductance"

A0=@(th)(((sin((Xo./2).*cos(th))./cos(th)).^2).*(besselj(0,(k.*LO.*sin(th))))).*(sin(th)).

^3);

A1_1=integral(A0,0,pi);

g_12=A1_1/(120*pi*pi);

r-in=1/(2*(G0+g_12));  %"in ohms"

Lg-min=6*h1+LO;  %"according to the 2004 book by Punit S. Nakar"

Wg-min=6*h1+wth;

disp('RECTANGULAR- PATCH:')

disp(['The width the Patches (Wp) is:',num2str(wth),' mm'])

disp(['The length - the patch (Lp) is:',num2str(LO),' mm'])

disp(['The minimum length - Ground plane is:',num2str(Lg-min),' mm'])

disp(['The minimum width - Ground plane is:',num2str(Wg-min),' mm'])

```

Using MATLAB, create a Rectangular-Microstrip-Antenna using a transmission -line- model.

=====

Introducing the Dielectric-constant:2.33

Introducing Substrate thickness (in mm):1.5

Introducing the Frequency (GHz):2.45

Introducing the input- impedance (ohm):50

RECTANGULAR-PATCH:

The width – of the patch (W_p) is 38.25 mm.

The length – of the patch (L_p) is:29.8034 mm

The minimum length of - Ground plane is:38.8034 mm

The minimum width of - Ground plane is:47.25 mm