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DESIGN OF MICROSTRIP PATCH ANTENNA WITH IMPLEMENTATION OF ARRAY

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A dissertation submitted in partial fulfilment
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ABSTRACT

This project focuses on the designs of a microstrip patch antenna with implementation of 2x1 array using CST Studio Suite 2022. The primary objective is to enhance the performance of the antenna by utilizing an array configuration with different inset-feedline dimension, where 2x1 array is the subsequent design from single microstrip patch antenna. The operating frequency chosen for this study is 2.45 GHz and the antenna substrate material employed is FR-4, with a dielectric constant of εr = 4.3. The dimensions of the microstrip patch array antenna are (63.4 x 113.7 x 1.6) mm^2. The simulation results serve as a benchmark for assessing the effectiveness of the array implementation. Furthermore, the fabricated antenna undergoes a rigorous validation process by comparing the results obtained from the fabrication with the simulation outcomes. This comparison allows for an assessment of the practicality and reliability of the design. It was found that implementation of 2x1 array configuration has successfully improved the performance compared to single microstrip patch antenna. In terms of return loss, S_{11} (-11.64 dB to -17.95 dB) improved by 54.18% at 2.45 GHz, gain improvement (2.58 dBi to 5.06 dBi) by 96.12%, and bandwidth frequency, (63 MHz to 108 MHz) improved by 71.43%.

ABSTRAK

Projek ini memberi tumpuan kepada reka bentuk antena tampalan jalur mikro dengan pelaksanaan tatasusunan 2x1 menggunakan CST Studio Suite 2022. Objektif utama adalah untuk meningkatkan prestasi antena dengan menggunakan konfigurasi tatasusunan dengan dimensi 'inset-feedline' yang berbeza, di mana tatasusunan 2x1 ialah reka bentuk seterusnya daripada antena tampalan jalur mikro tunggal. Kekerapan operasi yang dipilih untuk kajian ini ialah 2.45 GHz dan bahan substrat antena yang digunakan ialah FR-4, dengan pemalar dielektrik εr = 4.3. Dimensi antena tatasusunan tampalan jalur mikro ialah (63.4 x 113.7 x 1.6) mm2. Hasil simulasi berfungsi sebagai penanda aras untuk menilai keberkesanan pelaksanaan tatasusunan. Tambahan pula, antena fabrikasi menjalani proses pengesahan yang ketat dengan membandingkan keputusan yang diperoleh daripada fabrikasi dengan hasil simulasi. Perbandingan ini membolehkan penilaian kepraktisan dan kebolehpercayaan reka bentuk. Didapati bahawa pelaksanaan konfigurasi tatasusunan 2x1 telah berjaya meningkatkan prestasi berbanding antena tampalan jalur mikro tunggal. Dari segi kerugian pulangan, S11 (-11.64 dB kepada -17.95 dB) bertambah baik sebanyak 54.18% pada 2.45 GHz, memperoleh peningkatan (2.58 dBi kepada 5.06 dBi) sebanyak 96.12%, dan frekuensi jalur lebar, (63 MHz hingga 108 MHz) bertambah baik sebanyak 71.43%.

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LIST OF ABBREVIATIONS

RF	-	Radio Frequency
CST	-	Computer Telecommunication Union
FR-4	-	Flame Retardant Four
VSWR	-	Voltage Stand Wave Ratio
Wi-Fi	-	Wireless Fidelity
PCB	-	Printed Circuit Board
BW	-	Bandwidth
RCS	-	Radar Cross Sections
WLAN	-	Wireless Local Area Network
LAN	-	Local Area Network
MAN	-	Metropolitan Area Network
MMIC	-	Microwave Monolithic Integrate Circuits
PCB	-	Printed Circuit Board
RCS	-	Radar Cross Section
FYP	-	Final Year Project
VNA	-	Vector Network Analyzer
PTFE	-	Polytetrafluoroethylene
FR-4	-	Flame Retardant 4
MPA	-	Microstrip Patch Antenna
HPBW	-	Half-power Beamwidth
MP	-	Microstrip Patch

CHAPTER 1

INTRODUCTION

1.1 Research Background

In the current era of globalization, antennas are an essential component of any communication system used to advance human life. Webster's Dictionary stated that antenna is "a usually metallic device (as a rod or wire) for radiating or receiving radio waves" [1]. Figure 1.1 shows a traditional antenna which was a relic from 1970's [2]. The revolutionary technology following traditional antenna is called as microstrip antenna and it was created to enable for the better integration of an antenna and other communication system driving electronics on a single printed circuit-board or semiconductor chip.

Figure 1.1: Traditional Antenna [2]

The history of microstrip antenna begins in 1950's [3]. Consequently, it took almost 20 years for this concept to become a reality, gradually after the invention of printed circuit board (PCB) technology in 1970's [3]. Ever since, the popularity of microstrip antennas has gradually increased with a wide range of applications due to their positive features of compact size and design, light weight, planar configuration, cheap, conformal to non-planar geometries, array suited, with simplicity of construction and pairing with monolithic microwave integrated circuits (MMICs) and electromagnetic elements of versatility (polarization, input impedance, radiation pattern) [3][4].

Microstrip antennas consist of various kind such as microstrip patch antenna, printed dipole antenna and microstrip slot antenna. The most universally used type of antenna are the patch antennas, as shown in Figure 1.2. It is due to their benefits of being low profile, small and lightweight, high efficiency, less expensive, excellent mechanical strength, high adjustability to surrounding, broad frequency band, wide range of frequency coverage, and minimum radiation damage to human body [5].

Antennas are crucial components of any wireless system. It is a device capable of transmitting and/or receiving electromagnetic signal transmission. Most antennas are resonant devices that are most efficient at working within a specific range of frequencies. Any radio system's antenna must be tuned to the same frequency range as the radio it is communicating with otherwise it will be degraded [6]. Due to this recently, microstrip antenna design has shifted its focus to the creation of innovative methods for fabricating antennas independently.

Over the period of time, antennas with compact design, microstrip antennas and radar cross sections (RCS) have all been substantially used in various modern communication systems [7-10]. With an excellent design of antenna, it might significantly decrease the load on the system and boost its overall performance. Thus, the revolutionary development of antennas plays a significant role in improving the features of antennas so that it can cope with various technologies nowadays.

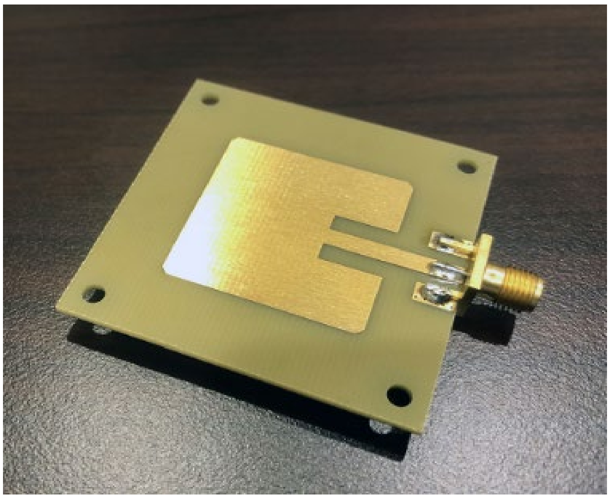

Figure 1.2: Microstrip Patch Antenna [11]

1.2 Problem Statement

Firstly, a single patch microstrip antenna exhibits limitations in terms of signal strength, directionality, and bandwidth frequency in its overall performance. It may struggle to provide good value of return loss, directivity, and narrow bandwidth which limiting its coverage. Its ability to focus signals on a specific direction may be less precise, leading to potential transmission errors. Next, the antenna's shape and frequency range should be selected based on the desired use as well as size for an easy fabrication [12]. Therefore, dimension of inset-feedline of antenna and other method to improve design of microstrip antenna by implementing array configuration should be investigated. This is to proof how it can affect the overall performance of microstrip patch antenna compared to microstrip patch array antenna [13].

1.3 Objectives

The objective of this research includes:

i. To design microstrip patch antenna with implementation of array operating at 2.45 GHz.

ii. To analyse the performance of microstrip patch array antenna in terms of return loss, gain, radiation pattern and Voltage Standing Wave Ratio (VSWR).

iii. To validate the simulation measurement performance of microstrip patch array antenna by using Vector Network Analyzer (VNA).

1.4 Scope of Research

This project will focus on designing a microstrip patch array antenna working at 2.45 GHz operating frequency. The designed antenna is being implemented with array configuration to observe its effect towards the performances of the designed initial design of single microstrip patch antenna. CST Microwave Studio Suite will be used in this project. Microstrip patch array antenna is used as they are relatively small in size, cheaper, and easier to fabricate. The microstrip feedline technique will be used in this antenna design. Next, the performance of microstrip patch antenna will also be analysed which covering on radiation pattern, return loss, gain and also VSWR. Lastly, in order to validate the simulation performance, the microstrip patch array antenna is fabricated, and the measured result will be compared with simulated results.

1.5 Thesis Outline

This paper is comprised of three sections: the introduction, the literature review, and the methodology. Chapter 1 discuss on the background research, problem statement, objectives, and scope of the research.

Besides, Chapter 2 describe the research's literature review. The chapter starts with antenna fundamentals, applications, and antenna types. Antenna types such as dipole antennas, waveguide antennas, array antennas, and microstrip antennas are discussed, along with their applications. Since the microstrip antenna is used to design a rectangular patch array antenna in this thesis, the advantages, disadvantages, and applications of microstrip are discussed. Following that, antenna parameters such as gain, return loss, and voltage stand wave ratio, are discussed. Finally, previous researchers' techniques are compared in a table, and their limitations are discussed.

Methodology is discussed in depth in Chapter 3. The chapter includes a flowchart, and proposed design specification. Next, methods on designing proposed antenna by using CST Studio Suite Software is also explained in this chapter. Last section in Chapter 3 explain in detail on microstrip patch array antenna fabrication methods and how to validate the fabricated antenna’s performance.

Chapter 4 discussed on the simulation and fabrication results of the antennas. It consists of results obtained from single microstrip patch antenna, initial design of microstrip patch array antenna, improved design of microstrip patch array antenna and fabricated microstrip patch array antenna. The analysis of comparisons between each of the antenna’s simulation and fabrication results are specifically explain in this chapter by referring to tabulated data of antenna’s results.

Lastly, Chapter 5 is focusing more to the summary of research. The suggestion and recommendation for future research also stated.

Chapter 2

LITERATURE REVIEW

2.1 Overview

This chapter outlined on the concept design, types, and parameters of antenna. The basic antenna principle is also discussed. Due to a microstrip patch array antenna is chosen for this antenna design, the features of the microstrip array antenna, as well as its benefits and drawbacks are discussed in this chapter. Furthermore, the explanation of antenna parameters based on their return loss, gain, bandwidth, radiation pattern, and efficiency that are used to evaluate antenna performance are also being examined in this chapter. Finally, prior research approaches will be compared and discussed.

2.2 History and Basic Principle of Antenna

In 1886, Hertz created the world's first wireless electromagnetic system [14]. Later, Marconi was able to successfully transmit signals from England to Newfoundland across an extremely great distance. Ever since Marconi's discovery, antenna technology has mostly focussed on wire-based radiation elements with operating frequencies ranging from low to ultra-high (UHF). Before World War 2 happen, the modern antenna technology never arises, until then researchers began designing unique components such as waveguide apertures, horns, reflectors, and lenses. In 1937, phased arrays were first implemented. However, the hugest advancements in phased array antenna theory and execution arose during the 1960s [14].

By referring to [15], antenna is "a generally known as metallic device (as a rod or wire) used for transmitting or receiving radio waves". It does consist of combination of sending and receiving signals. Besides, antennas are classified as passive devices depending on their frequency spectrum and how they radiate electromagnetic waves in various sizes and shapes. Moreover, if the antenna exceeds its limit, the incoming signal will be rejected. Furthermore, the antenna is widely utilised as a component in wireless communication systems such as RF and microwaves. Figure 2.1 shows how does the electromagnetic source being transmitted and radiated to free-space wave. In general, antenna size is inversely proportional to frequency. The following equation shown defines the size of antenna.

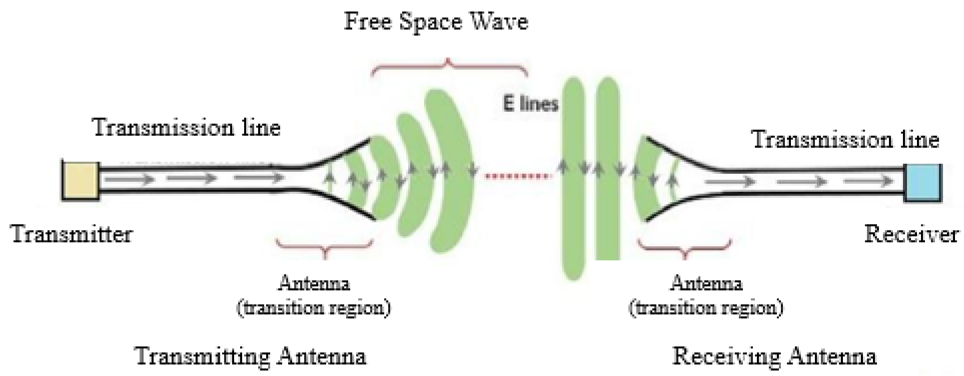

Figure 2.1: Microstrip Patch Antenna Signal Transmission [15]

The wavelength is referred to in relation to antenna size. The wavelength of an electromagnetic signal is the distance it travels in one complete cycle. The wavelength is proportional to the frequency [16]. The size of an antenna can be calculated using the following equation, (eqn) 2.1:

$$\lambda = \frac{c}{f} \qquad \text{eqn (2.1)}$$

Where:

λ : Wavelength (m)

f : Frequency (Hz)

c : Speed of light (3×10^8 m/s)

2.3 Types of Antennas

There are various sorts of antennas, and each one may perform differently. There are two types of antennas that are omni-directional and directional. These antennas have different methods in term of their specific radiation patterns. An omni-directional antenna receives signals from all paths equally, whereas directional antennas receive signals from only one direction [17]. The example of omnidirectional antenna is dipole type which is adapted in radio wave transmission meanwhile the dish antenna is a type of directional and commonly utilized in radars and satellite communications. Several examples of antenna such as microstrip patch, dipole, waveguide, and array will be explained.

2.3.1 Microstrip Patch Antenna

One of the most regularly used types of antennas by the engineers and researchers around the world are the microstrip patch antenna and it was discovered relatively recently. Due to the engineers may directly print microstrip or patch antennas on a semiconductor chip or circuit board, these antennas are becoming more valuable. Microstrip antennas are widely exploited in a range of wireless communication applications. Microstrip antennas are low profile, inexpensive and simple to manufacture. Figure 2.2 depicts the fundamental layout of a microstrip patch antenna.

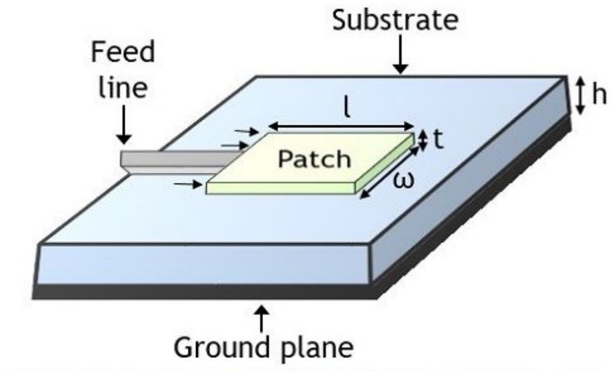

Figure 2.2: Basic Design of Microstrip Patch Antenna [18]

By referring to Figure 2.2, the basic design of microstrip patch antenna shows the labelling for each of the side or edge structure of the antenna. *W* represents for patch width, *L* represents for patch length, meanwhile h represents for substrate thickness. To attain top performance, the low dielectric constant substrate enables increased bandwidth and efficiency. As a result, the type of substrate is critical in determining antenna dimension.

2.3.2 Dipole Antenna

When energy is radiated from a bent wire, the antenna at the end of a transmission line is called a dipole. The input impedance reactance is a consequence of the dipole's radius and length. As the radius becomes smaller, the amplitude reactance will become greater [19]. Due to this, the radius and length of dipole must be interpreted. For bilateral symmetry, the dipole antenna is separated into two comparable conducting elements, such as rods or metal wires. The operating current of the transmitter is applied, or the output signal to the receiver is delivered between the two sections of the antenna. Figure 2.3 explain two poles of antenna are equally approximate to quarter the radiator's operating wavelength.

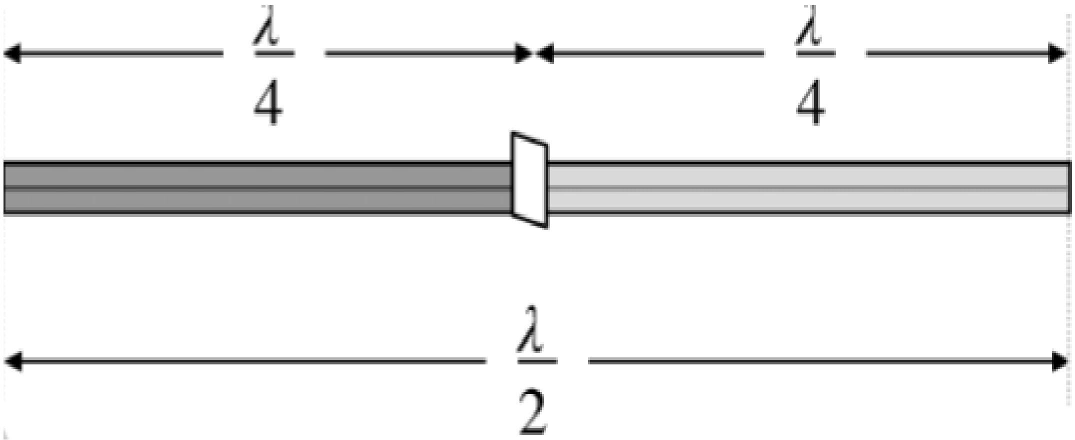

Figure 2.3: A Half-wave Dipole Antenna [19]

2.3.3 Waveguide Antenna

In order to transmit electromagnetic waves across large distances, wideband devices called as waveguide antennas are used. Figure 2.4 illustrates an example of waveguide antenna. This antenna is made of hollow metal tubes, and it is available in rectangular and circular cross sections. Waveguide antennas can precisely direct electricity where it is needed, handle vast amounts of energy, and function as a high-pass filter [20]. Hence, waveguide antenna is frequently used at microwave frequencies.

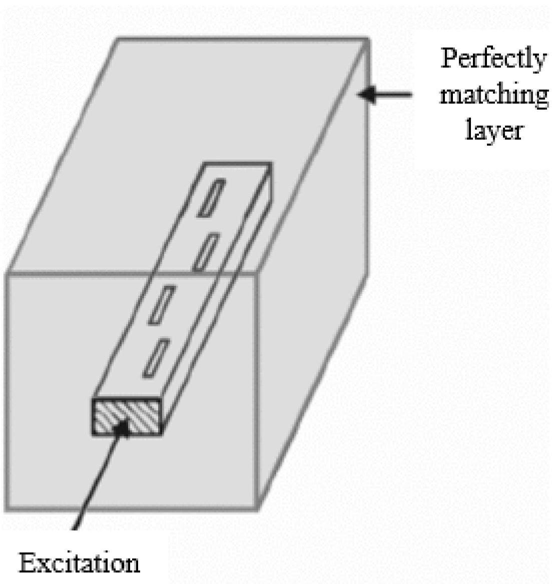

Figure 2.4: Rectangular Waveguide Slot Antenna [21]

2.3.4 Array Antenna

An array antenna, often called a phased antenna, consists of two or more antennas working together as one to boost transmission and reception capabilities. The radiating structure of the antenna is composed of individual elements and radiators. Each of these radiators has an induction field. Due to their near proximity, the elements are affected by the induction field of their adjacent [22]. The radiation pattern is the single vector sum. The array antenna improves overall gain by providing diversity reception [23]. However, there are some disadvantages of array antenna because of its volume, raised expense, and complexity in antenna architecture. In terms of antenna array benefits, it has a compact design, a high scanning gain, and a broad coverage area [24]. The example of array antenna that is used in cellular telecommunication system is shown in Figure 2.5, where two of the sender and receiver of antennas are attached at every side of cell tower.

Figure 2.5: Cell-tower Array Antenna [25]

2.4 Features and Types of Microstrip Patch Array Antenna

The antenna consists of a metallic radiating patch attached to a dielectric substrate and a ground plane. Specifically, a microstrip transmission line supplies power to the microstrip patch. The microstrip patch has dimensions of length, L and width, W which is placed on top of a substrate with dimensions of thickness, h and permittivity. By