Faculty of Engineering

# INVESTIGATION ON THE RELIABILITY OF JEANS AS A TEXTILE ANTENNA FOR SMART WEARABLE ANTENNA APPLICATION

Mohamad Muzaini Bin Mohd Sahidi

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# INVESTIGATION ON THE RELIABILITY OF JEANS AS A TEXTILE ANTENNA FOR SMART WEARABLE ANTENNA APPLICATION

MOHAMAD MUZAINI BIN MOHD SAHIDI

64861

A dissertation submitted in partial fulfilment
of the requirement for the degree of

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# ABSTRACT

This report demonstrates the development of a sectorial slot Pac-Man textile patch antenna for a single frequency ISM band at 2.45GHz (WLAN) for smart wearable devices. Design of the Pac-Man patch antenna that utilized the jeans as substrates material (εr = 1.7, Loss δ = 0.025, h = 1mm) was being developed using electromagnetic tools that is Computer Simulation Technology (CST). The Pac-Man patch antenna mounted on a jeans substrate needs to demonstrate that it is possible to employ textile materials in the construction of antennas that are able to operate in the specified frequency band. Jeans is prove to be well qualified selection whenever to be used as textile antenna. This was due to the enhancement of the bandwidth with normal circular patch of 1.81%. The gain was maintained at about 2.14dBi at normal flat condition. Then, the proposed antenna was analysed in term of resonance frequency, return loss, voltage standing wave ratio (VSWR), radiation pattern, directivity and gain under bending condition of four different cylinder radius.

# ABSTRAK

Laporan ini menunjukkan pembangunan antena tampalan tekstil Pac-Man slot sektorial untuk jalur ISM frekuensi tunggal pada 2.45 GHz (WLAN) untuk peranti pintar boleh pakai. Reka bentuk antena tampalan Pac-Man yang menggunakan jeans sebagai bahan substrat ($\varepsilon r$ = 1.7, Loss $\delta$=0.025, h = 1mm) telah dibangunkan menggunakan perisian elektronik iaitu Computer Simulation Technology (CST). Antena tampalan Pac-Man yang dipasang pada substrat jeans perlu menunjukkan kebolehpakaian bahan tekstil tersebut dalam pembinaan antena yang boleh beroperasi dalam jalur frekuensi yang ditentukan. Jeans terbukti sebagai pilihan yang layak apabila untuk digunakan sebagai antena tekstil. Ini disebabkan oleh peningkatan lebar jalur dengan tampalan bulat yang biasa sebanyak 1.81%. Gandaan antena dikekalkan antara nilai 2.14dBi pada keadaan permukaan rata. Kemudian, antena yang dicadangkan dianalisis dari segi kekerapan resonans, kehilangan kembali, gelombang berdiri voltan (VSWR), corak sinaran, pengarahan dan gandaan di bawah keadaan lenturan empat jejari silinder yang berbeza.

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| | | |
|---|---|---|
| CST | - | Computer Simulation Toolkit |
| EPIRB | - | Emergency Position Indicating Radio Beacon |
| E-Plane | - | Electrical Plane |
| HPBW | - | Half Power Beam Width |
| MPA | - | Microstrip Patch Antenna |
| RF | - | Radio Frequency |
| S-parameter | - | Scattering parameter |
| VSWR | - | Voltage Standing Wave Ratio |
| WCS | - | Working Coordinate Systems |
| Wi-Fi | - | Wireless Fidelity |
| WLAN | - | Wireless Local Area Network |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Our daily lives have become ever more entwined during the past few years. Wearable communication systems are an area of significant research that is rapidly expanding thanks to recent advances in wireless device technology. Researchers have carried out many investigations on wearable button antennas, electro-textiles, and magnetic composite material RF antennas [1]. Wearable antennas and their conductive elements may soon be made from textiles, thanks to the recent development of textiles as substrate materials.

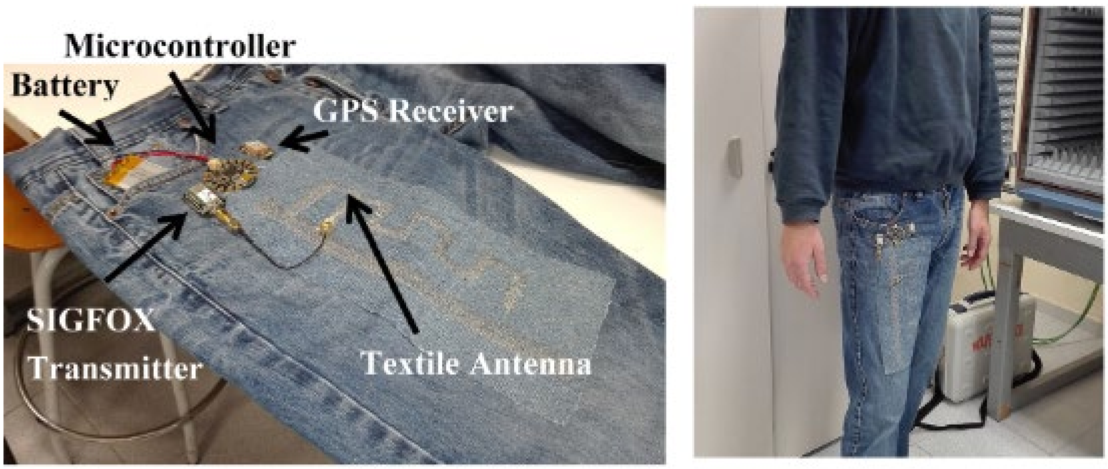


**Figure 1.1**: Body worn antenna for smart wearable clothing application [2]

This provides complete freedom in the future to create body-worn antenna systems embedded in smart clothing, for instance. Figure 1.1 shows a textile antenna being patch onto jeans as substrate for smart wearable clothing. These systems help detect movement on the body during exercise, monitor physiological processes such as heart rate and blood pressure, assist emergency services, and connect to a public network [2]. Current and future generations will benefit greatly from work being done on portable, wearable antennas. As a result, the wearable antenna must be body-conforming and not obstruct the user's movement. Additionally, the textile-based structure of the wearable antenna must meet specific characteristics, including low electrical resistance, flexibility, and deformability [3].

This report describes the design process for a single band textile antenna for smart wearable applications that adheres to IEEE 802.11 standards and operates at 2.45 GHz. Denim was chosen as the substrate since it enhances people's comfort and easily integrates into clothing. Additionally, lighter and thinner materials can aid in the shrinking process for wearable antennas.

## 1.2 Problem Statement

One of the concerns on the antenna designing was on the substrate material selection. To determine an appropriate substrate, understanding the electrical performance of the material is crucial. Because this material data is unavailable, electrical characterisation of various textile materials is required. It is not considered as direct operation, and various measuring techniques must be utilised to analyse the component such as dielectric permittivity.

Second issue concerning on the antenna's performance under bending conditions. Whenever the antenna is patched to clothing, it is subjected to a various of bending occurrences. The critical challenge is keeping the antenna's characteristics at an allowable level in all settings considered normal operation conditions. These parameters are a bend resistance, operating frequency (bend stability), and efficiency (prevent human tissue from degrading efficiency) [4].

The third issue is the fabrication itself. The fundamental problem is making the antenna resistant to manufacturing tolerances. Fabric and yarn are fibres assemblages fabricated from linear long-chain polymers, and the fibres are long and thin [3]. Most of these fibres have low electrical conductivity, making them suitable dielectrics for textile antennas. The dielectric constant ($\varepsilon_r$) is the relative permittivity of the substance to that of free space. The dielectric constants of the antenna substrate are important in antenna design. Dissimilarities of substrates with varying dielectric constants would impact the antenna's functioning. Organic and artificial fibres are the two main categories of textile substrates used in antennas. On the other hand, jeans textiles have a low dielectric permittivity, reducing surface wave losses and increasing antenna impedance bandwidth [5].

### 1.3 Objectives

i. To investigate the reliability of jeans as a textile antenna for smart wearable antenna application.
ii. To design a single-band textile patch antenna operable at 2.45 GHz on selected jeans substrate material by using CST Microwave studio.
iii. To verify the simulation analysis on return loss, resonance frequency and gain of the textile antenna to analyse its performance and reliability under bending condition

### 1.4 Scope of work

The purpose of this study is to investigate the reliability of jeans as a textile antenna for smart wearable antenna applications, which will be accomplished through the use of a microstrip patch antenna. To do so, a single band 2.45GHz Pac-Man microstrip patch antenna will be designed using Computer Simulation Tool (CST) software. This investigation will focus on the antenna's performance under various bending conditions. A single-resonance patch antenna is demonstrated based on the conventional sectorial slot Pac-Man patch antenna. In order to evaluate the textile antenna's performance and dependability, the graph of return loss, resonance frequency, and gain will be provided after the simulation has been completed perfectly with the appropriate parameters.

### 1.5 Thesis Outline

Each thesis section is broken down into a separate chapter: introduction, literature review, and methodology. Chapter 1 provides an overview of the study's background, objectives, and scope.

The literature review for the research is explained in detail in Chapter 2 of the report. It all starts with the foreground, which is fashionable yet functional clothing. Antenna basics, antenna applications, and the role of substrate in wearable antennae are all included. There is also information about the shape of the microstrip patch antenna, the feeding technique, and the antenna’s properties. The antenna’s return loss, gain, radiation pattern, impedance, efficiency, bandwidth, and beamwidth are all specified. Feeding techniques were also explained in a straightforward manner. Additionally, the investigation of prior research on sectorial slot Pac-Man antennas is included.

Flowcharts, Gantt charts, and design specifications will be used to illustrate the research methodology in Chapter 3. A brief overview of computer simulation technology (CST) was provided. This chapter also discusses the substrates that were used. Furthermore, antenna segment and substrate properties will be described in this chapter as well.

In Chapter 4, the simulation results are presented for a defined sectorial slot Pac-Man textile patch antenna constructed with jeans as the substrate material. The results will be provided based on the return loss, VSWR, gain, directivity, and radiation pattern in the antenna's polar plot, which were estimated using Computer Simulation Technology (CST). There will also be a detailed explanation of the comparison between the initial design and the optimised value. In addition to this, an investigation into the parameter analysis of the Pac-Man patch antenna will be carried out under bending conditions.

The purpose of Chapter 5 is to provide a conclusion of the results that were gathered to determine the successability of this study's objectives. Additionally, it's for the project's final determination and recommendation for future work to be drawn from the findings of this study.

# Chapter 2

# LITERATURE REVIEW

## 2.1 Overview

The purpose of this chapter is to provide a basic introduction to the concept of smart clothes. In microstrip patch antennas, substrate material plays a vital role in influencing efficiency. Hence the role of substrate material will be discussed. Following that, the microstrip patch antenna and its associated application will be introduced. The properties of a microstrip patch antenna, such as its return loss, bandwidth, radiation pattern, gain, resonance frequency, and efficiency, are discussed in detail in the following sections. After that, this chapter will offer information on various other forms of microstrip patch antennas. Afterward, a quick rundown of feeding techniques such as transmission line feed, coaxial feed, proximity coupled feed, and aperture coupled feed is provided. The previous research on antenna design will be supplied as a further aid for readers.

## 2.2 Smart Wearable Clothing

To put it another way, "smart clothing" refers to apparel equipped with various sensors that may collect data about its wearer or the environment around them and transmit it wirelessly. This type of technology operates wirelessly with the assistance of an antenna that has been patched into it. Clothing items that have been added with technology to make them more useful than they were meant to be are called smart clothes. They can also be called high-tech clothing, smart garments, smart textiles, or e-textiles.

Some smart clothing use new materials with embedded electronics, while others use sensors and other hardware to achieve smartness. Using Bluetooth or Wi-Fi, many smart garments can connect with an app or programme running on a second device. However, the success of this intelligent clothing is entirely dependent on the antenna's ability to receive, share data and interact with one another as if they were live organisms.

In terms of visibility, health advantages, comfort, and aesthetics, smart clothing is expected to be a huge industry in the near future [6]. Consequently, the widespread use of microstrip antennas is well-known across several industries due to its low-cost substrate material and simple manufacturing.

According to Park 2014 [7] smart clothing is a novel approach in apparel that provides significant added value. High-performance, multi-functional clothing with an emotional and functional nature differing from fashion products. It is defined as a fusion of clothes, information, and communication technologies. As a textile product, Hee-Young 2017 [8] quotes, wearable technology that can sense and respond to the environment or a human body stimulation is known as smart clothing.

Aiming to give both fun and information, Kim 2013 [9] classified wearable electronics into three categories: fitness, healthcare and infotainment. Also, family-friendly wearables can send children's locations to their parents' phones and track their health and sleeping patterns in real time. There are now a lot of smart products on the market in France that allow people to keep an eye on the health of their older relatives at any time Kim 2014 [10].

## 2.3 Roles of Substrate in Wearable Antenna

In the fabrication of microstrip patch (metallic sheet) antennas, the substrate serves as a base or container on which the antennas are mounted. The substrate is critical to the operation of the antennas. Along with its conventional function of insulating the human body from heat and cold, it also performs additional functions such as sensing, stimulating, and communicating. In microstrip antennas, the substrate is primarily used to reinforce the antenna mechanically.

The substrate should be made of a dielectric material to support the antenna, circuitry, and transmission lines. Because of this, a substrate has to meet both electrical and mechanical requirements, which can be challenging. Textile substrate material parameters such as dielectric constant and loss tangent significantly impact electromagnetic energy propagation and antenna performance.

Several microstrip patch antenna designs are most typically utilised in wearable applications because of their ability to protect the body tissues and radiate in a vertical direction to the planar structure. Choosing a suitable substrate is essential for cost, efficiency, and size considerations. Patch antennas are created by carving the pattern of the antenna elements into a metal trail attached to an insulating dielectric substrate. On one side of the substrate, a ground plane is created by applying a flat metal sheet [11].

The usage of substrates (dielectrics) improves a textile antenna's mechanical and electrical stability. As a result of their increased permittivity, they can help minimise the antenna's size and provide displacement current, which produces a time-varying magnetic field (as described by Ampere's Law). Time-varying electric fields are then generated, and this creates a propagating electromagnetic field, according to Faraday's laws. Due to this, the antenna's radiation capability can be improved by using a substrate.

To begin designing a microstrip patch antenna, it is necessary first to establish the substrate material and thickness. Designing an antenna becomes much simpler once a comprehensive understanding of the effects of substrate material and thickness on antenna performance is gained. Therefore, an essential task in constructing a microstrip patch antenna is selecting the appropriate dielectric material and its thickness.

## 2.4 Microstrip Patch Antenna

When it comes to wireless communication systems, the antenna is one of the most critical components. An antenna is a part of a transmission or reception system used to transmit or receive electromagnetic waves [12]. Antennas manufactured in the form of microstrips are relatively common. Traditional microstrip fabrication techniques make microstrip antennas incredibly simple to build.

On one side of microstrip antenna, there is a ground plane, while the other side being placed with a radiation patch [13]. Printed circuit technology came up with the idea of microstrip patch antennas, which are antennas that can be used to make waves in an electronic system, not just for circuit parts and transmission lines. According to Kai Fong et al. 2017 [14], at the proper location, the ground plane is supported above the metallic area by a thin dielectric substrate as in Figure 2.1. Figure 2.1 shows an example of rectangular microstrip patch antenna mounted on a substrate material. As seen in Figure 2.1, the structure of rectangular microstrip patch antenna being embedded on a substrate material and a ground plane as the layer.

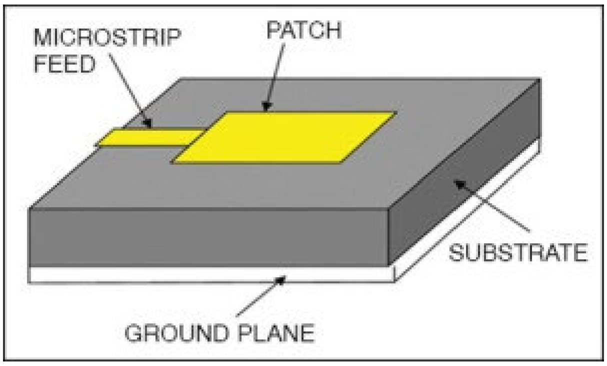


**Figure 2.1**: Example rectangular microstrip patch antenna [15]

In some applications today, antenna is being used to continuously monitor biometric data from the human body, which is a promising development. To accomplish this, they must always be in close proximity to the human body, monitoring and transmitting biometric data. It is impossible to keep an antenna permanently affixed to the human body if it is made of hard material. In addition to being comfortable to wear for lengthy periods of time, an antenna constructed of textile material will not hurt the human body. Wearable antennas will find applications in various fields such as healthcare, recreation, and firefighting, among others.

The pros and cons of microstrip patch antenna are described as in Table 2.1:

**Table 2.1**: Pros and cons of microstrip patch antenna [16]

<table>
<tr><th>Advantage</th><th>Disadvantage</th></tr>
<tr><td>Lightweight</td><td>Has a narrow impedance bandwidth, typically less than 5%.</td></tr>
<tr><td>Low cost</td><td>Low RF power handling capability due to close proximity of emitting patch to ground plane.</td></tr>
<tr><td>Ease of installation</td><td rowspan="4">Microstrip arrays generally have larger ohmic loss than arrays of other types of antennas of equivalent aperture size.</td></tr>
<tr><td>Rugged</td></tr>
<tr><td>Can be produced by printed circuit technology</td></tr>
<tr><td>Can be integrated with circuit elements</td></tr>
</table>

Table 2.1 shows that the advantages of microstrip patch antennas include their small size, low cost, ease of installation, and numerous other advantages. However, the impedance bandwidth is extremely limited, the RF power is relatively low, and the ohmic loss is extremely high.

### 2.4.1 Shape of Microstrip Patch Antenna

Microstrip Patch Antennas come in a variety of shapes, including square, rectangle, dipole, circular, elliptical, triangular, disc sector, circular ring, and ring sector as in Figure 2.2. The patch can be made in a variety of shapes. However, rectangular and circular are the most prevalent due to their ease of analysis and fabrication and their appealing radiation properties, particularly their low cross-polarisation. Table 2.2 shows a comparison in performance between circular and rectangular shape microstrip patch antenna.

Based on the Table 2.2, it can be observed that, circular microstrip patch has a better performance compared to rectangular patch in terms of return loss, bandwidth, VSWR, and HPBW. Furthermore, the circular patch is the second most popular form following the rectangular patch due to its linear and circular polarisation, array compatibility, feed line flexibility, and multi-frequency functioning.

Circular patches offer numerous benefits, including design flexibility, the maximum bandwidth in GHz, acceptable lossy characteristics, increased gain, and ideal electric and magnetic field strength patterns [17]. Unlike the other shape, the circular patch has only one degree of freedom to control, namely the patch's radius, making the design process much easier. Therefore, whenever designing a microstrip patch antenna, the patch's shape is critical for analysing the antenna's performance and other characteristics as well as for ease of analysis.