DESIGN AND SIMULATION STUDY OF ANTENNA FOR WIRELESS BODY AREA NETWORK (WBAN)

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Thesis submitted in fulfillment of the requirements
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Thank you.

ABSTRAK

Kemajuan teknologi yang pesat menyebabkan berlakunya peningkatan dalam sector perubatan dan melahirkan teknologi baharu iaitu Rangkaian Badan Tanpa Wayar (WBAN). Rangkain badan tanpa wayar (WBAN) adalah rangkaian sensor yang dilekatkan pada tubuh badan manusia. Istilah WBAN diperkenalkan oleh Van Dam pada tahun 2001. Untuk reka bentuk, antena tampalan jalur mikro digunakan kerana ianya adalah calon terbaik untuk diaplikasikan pada tubuh badan. Antena jenis ini mempunyai pancaran radiasi yang berserenjang dengan satah tanah membuatkannya dapat melindungi tisu badan dari sinaran radiasi [1]. Thesis ini menerangkan tentang reka bentuk dan simulasi antena untuk rangkaian kawasan badan tanpa wayar (WBAN). Antenna ini direka untuk beroperasi pada 2.45GHz (ISM). Prestasi antena akan diuji dalam keadaan lentur, model lapisan badan manusia untuk menguji nilai SAR dan model lengan badan manusia untuk menguji prestasi antena apabila dipasang pada badan. Reka bentuk dan analisis dibuat menggunakan CST Studio Suite 2019. Semua parameter penting untuk reka bentuk antena seperti lebar jalur, gain, VSWR, S-Parameter, Return loss, directivity dapat ditujukkan di dalam projek ini.

ABSTRACT

The rapid advancement of technology has led to an increase in the medical sector and the introduction of a new technology, namely the Wireless Body Network (WBAN). A wireless body network (WBAN) is a network of sensors installed on the human body. The term "WBAN" was introduced by Van Dam in 2001. For the design, a micro-band patch antenna is used because it is the best candidate for application to the body. This type of antenna has a radiation beam that is perpendicular to the ground plane (ground), making it able to protect body tissues from radiation [1]. This thesis describes antenna design and simulation for wireless body area networks (WBAN). This antenna is designed to operate at 2.45GHz (ISM band). The antenna performance will be tested in bending conditions, with a human body layer model to test the SAR value and a human body arm model to test the antenna performance when attached to the body. Design and analysis were done using CST Studio Suite 2019. All-important parameters for antenna design such as bandwidth, gain, VSWR, S-Parameter, return loss, and directivity can be shown in this project.

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LIST OF SYMBOLS

Hz	Hertz
K	Kilo
M	Mega
G	Giga
L	Length
W	Width
Mm	Millimetre
Cm	Centimetre
dB	Decibel
Ω	Ohm
π	Phi
εr	Dielectric Constant
Fr	Operating frequency
θ	Loss tangent
H	Substrate thickness
T	Patch thickness

LIST OF ABBREVIATIONS

WBAN	Wireless body area network
LF	Low Frequency
HF	High Frequency
VSWR	Voltage Standing Wave Ratio
S11	Return Loss
ISM	Industrial, Scientific and Medical
SAR	Specific Absorption Rate
CST	Computer Simulation Technology
PCB	Printed Circuit Board
PDMS	Polydimethylsiloxane

CHAPTER 1

INTRODUCTION

1.1. Research Background

With the increase of population and chronic disease in the word also the rising of modern technology, the healthcare paradigm is shifted from managing illness to proactively managing wellness. We call it u-healthcare era. The expansion of u-healthcare will allow remote healthcare services by focusing on prevention and early detection/treatment of disease with the help of recent advance in wireless technologies. Most illnesses might be avoided if they were diagnosed early on [2].

Wireless body area network (WBAN) is a wireless communication system that connects multiple miniature body sensors to a single wearable hub on, near, and around the human body as shown in figure 1. It enables low-cost, continuous health monitoring through the Internet, as well as real-time updating of medical information [3]. As a result, traditional antennas are no longer viable for this new technology due to their inflexible nature. There are several types of antennas which is different in-body, on-body and off-body channel model. WBAN also can be classify either as an implant or as a wearable device. In this report, the device that will be discuss is wearable antenna. This wearable antenna can be attached with clothing or wearable such as wrist watch, shoes, health monitoring devices and etc [4].

The ability to apply a limited set of wireless sensor nodes on the human body opens the door to a wide range of applications in a variety of fields. Usually, it can be divided to three field which is healthcare, sport, entertainment also military and defence. For healthcare, several sensors are deployed inside or on human body allowed the patient and doctor to easily monitor the body. WBAN application in healthcare can monitor the temperature, toxins, blood pressure, electrocardiogram (ECG), electroencephalogram (EEG), electromyogram (EMG), pulse oximetry, drugs delivery, post-operative, glucose level and etc. In sport and entertainment, user can get details about their sport activity and used them to avoid injuries and plan for future training to improve their performance.

A real-time log of vital indicators such as blood pressure, heart rate, blood oximetry, and posture can help you enhance your fitness and athletic performance. Besides that, WBAN application also very helpful in military and defence. In order to prevent threats, a set of sensors could monitor important parameters and give information about the surrounding environment, while data obtained at the squad level will allow the commander to organise squad activities and tasks [5].

The antenna is important to the effective operation of a WBAN system because it can influence the complexity of the receiver and transmitter design. The impact of the wearer on the transient characteristics should be addressed in the antenna design since the antenna of a WBAN might be put on a human body. They also should be comfortable and conformal to the body shape, but they should be highly reliable and efficient. The requirement for WBAN antenna is low backward radiation, low height with compact form, low coupling to the human body, low-power, miniaturised, lightweight devices and suitable transient characteristics (high system-fidelity factor) [6].

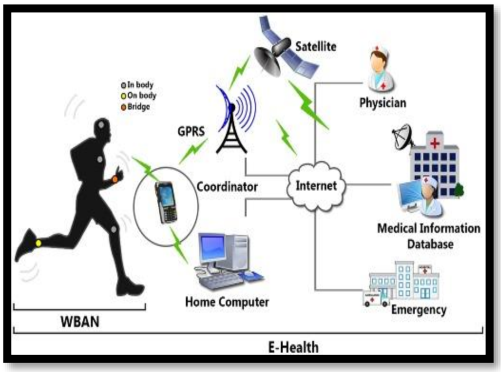


Figure 1: WBAN Application

1.2. Problem statement

WBAN antenna don't have a specific design shape. It can be various of design depending to the design requirement. So, it is important to know the design parameter before proceed with the actual design. The most important thing to consider during design the antenna is the resonance frequency. There are various frequency ranges used for the WBAN antenna. So, the suitable range of antenna needs to be defined so that it can be used for various applications. Next is, WBAN antenna size must be as small as possible, but it is hard to keep the best performance of the design if the size is small. The conventional antenna is not flexible and difficult for user movement. WBAN antenna must be design with the suitable material so it can be flexible and can bending when the body move so it will not interfere with the body comfort and the performance of antenna can still acceptable. The selected design for wearable antenna in WBAN is quite important because it can harm the body. The parameter that shows the effect of radiation to the body is using Specific Absorption Rate (SAR). It must not exceed the limit IEEE 1.6W/Kg average for 1 g of tissue and International Electronical Commission (IEC) 2W/Kg average over 10g of tissue [7].

1.3. Objective of project

The goal of this project is to design and simulation analysis study of three type of substrate antenna to achieve better transmission performance. The design and analysis are done using CST Studio Suite Software because this is one of the best software to analysis antenna pattern and also often used by the users. Before make the analysis, the most importance thing to consider is what parameter need to change to increase the antenna performance. At the end of this project, the objective that need to be achieve is:

- Able to design and analysis the WBAN antenna using CST Studio Suite.
- Able to design a small size and comfortable antenna for wearable application.
- Able to design an antenna that can be operated in ISM band (2.4-2.5 GHz).

- Able to make comparison analysis for the design of the WBAN antenna to give a better performance.

1.4. Scope of project

To achieve the objective of the project, the project has been divided into a few scopes. This is to make the progress run smoothly and reduce the complexity of the project and also give the better output at the end of the project. The scope of the project is:

- The antenna design is based on wearable antenna for WBAN only.
- Design and simulation analysis for antenna using CST SS software.
- Resonance frequency for the design analysis is in ISM band (2.4-2.5GHz).
- The validation for the design is based on literature review.
- The material used for antenna will be any material that is soft and can be bending that suitable to be attach on human body.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction to WBAN antenna

Literature review is an overview about the previous work that has been done with a specific topic. Producing a literature review usually needed for graduate and post-graduate students for example in the preparation of a thesis and journal article.

WBAN is a wireless communication system that links several small body sensors to a single wearable hub on, near, and around the human body. It provides for low-cost, continuous health monitoring through the Internet, as well as real-time medical information updating [8]. This chapter will discuss more detail about WBAN antenna. Here we will discuss about antenna requirement and design for WBAN application. The explanation will be covered such as the type of feeding methods, antenna parameter, WBAN application and proposed design based on the past literature review.

2.2. Microstrip Patch Antenna

Microstrip patch antenna is the most popular in wireless communication application because of it has many advantages [9]. A microstrip patch antenna's significant characteristics are its ease of fabrication, light weight, and low cost. The patch antenna is design based on the requirement of the application such as bandwidth, impedance matching, resonance frequency, radiation pattern and etc. The patch antenna made up from micro-tapes as shown in figure 2. The main component of microstrip patch antenna is ground plane, substrate, microstrip patch and feed. The material for patch and ground may be a copper or gold and for substrate it can be any material with difference dielectric constant. The patch shape can be circular, rectangular, square, elliptical, ring and triangular depend on the application [10].

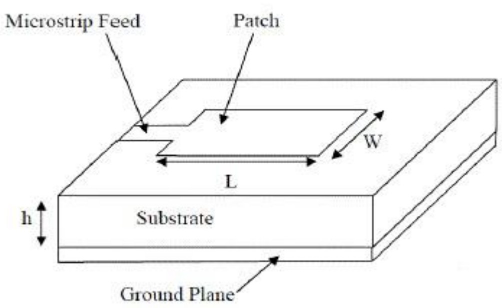


Figure 2: Microstrip patch antenna design

2.2.1. Advantage and Disadvantage of Microstrip Patch Antenna

Advantage:

- Low fabrication cost.
- Able to fabricate the feed line.
- Light weight and low volume.
- Suitable for linear and circular polarizations.
- Compact and slim
- Reconfiguration appearances can be easily be obtained.
- Support single, dual, and triple operating frequency.
- Conformable to planar and nonplanar surfaces.
- Adopted in different types of frequency bands that may have varied specifications

Disadvantage:

- Low gain.
- Low efficiency due to dielectric losses and conductor losses.

- lower impedance bandwidth.
- It has higher level of cross polarization radiation.
- The microstrip antenna structure radiates from feeds and other junction points.

2.3. Feeding method

A variety of methods can be used to feed microstrip patch antennas. These methods can be divided into two categories which is contacting and non-contacting. For contacting methods, it consists of microstrip line feed and co-axial plane feed. For non-contacting techniques are aperture coupled feed and proximity coupled feed. The RF power is provided directly to the radiating patch via a connecting device such as a microstrip wire in the contacting method. Electromagnetic field coupling is used in the non-contacting system to transmit power between the microstrip line and the radiating patch [11].

2.3.1. Microstrip Line Feed

As illustrated in Figure 3, a conducting strip is attached directly to the edge of the microstrip patch. The conducting strip is narrower than the patch, and this type of feed arrangement has the benefit of allowing the feed to be etched on the same substrate as the patch, resulting in a planar structure [11]. This feeding method is the simplest to manufacture compare to all the microstrip antenna feeding approaches. This approach, however, has flaws such as unwanted radiation production and limiting data transmission.

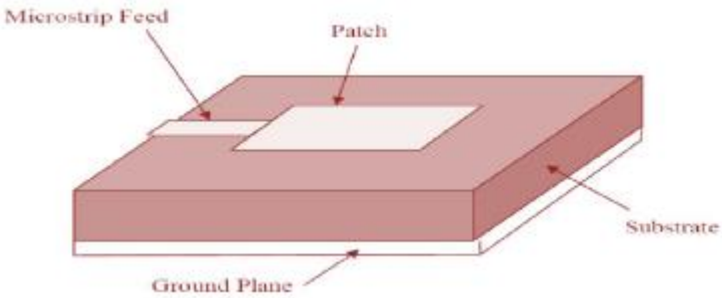


Figure 3: Microstrip line feeder

2.3.2. Coaxial feed

Coaxial feed, often known as probe feed, is a common method for feeding Microstrip patch antennas. As we can see in figure 4, the coaxial connector's inner conductor extends through the dielectric and is attached to the radiating patch, while the outer conductor is linked to the ground plane. The benefit of this feeding system is that the feed may be positioned anywhere inside the patch in order to match with input impedance [11]. This feed technique is simple to fabricate and produces less spurious radiation. However, there are several weaknesses in this feed method, which is narrow bandwidth and connected with ground plane connector that make these feeding methods not suitable to be used for WBAN application.

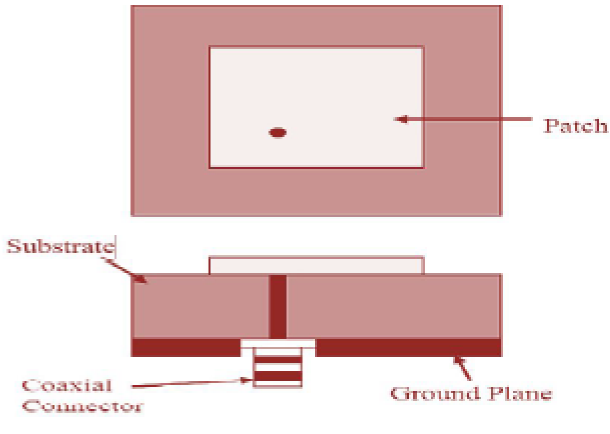


Figure 4: Coaxial feed

2.3.3. Proximity Coupled Feed

The electromagnetic coupling scheme is another name for this sort of feed technique. This feed techniques used two substrates for the design and the feed line is placed between these two dielectric substrates, while the radiating patch is placed on top of the upper substrate. The fundamental benefit of this feed method is that it removes spurious feed radiation while also providing extremely high bandwidth (as high as 13 percent) due to the increasing in the thickness of microstrip patch antenna [11].

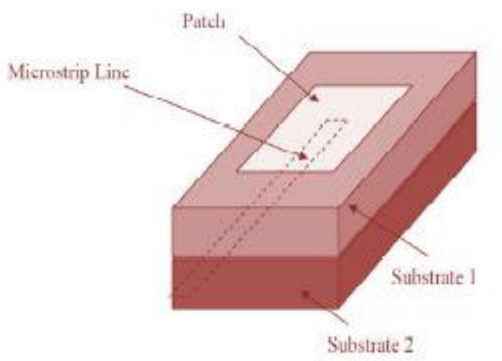


Figure 5: Proximity Coupled feed

2.3.4. Aperture Couple Feed

Aperture Couple Feed is one of the non-contacting techniques in feeding methods. In this type of feed technique, the microstrip feed line and radiating patch are separated by the ground plane as shown in Figure 6. Through a slot or an aperture in the ground plane, the patch and the feed line are connected. Also, the return loss value (S11) can be increased and the bandwidth size can be larger due to the length and width of the slot. Generally, the position of the slot is in the middle of the radiation patch. Apart from that, this feeding technique can minimize spurious radiation.

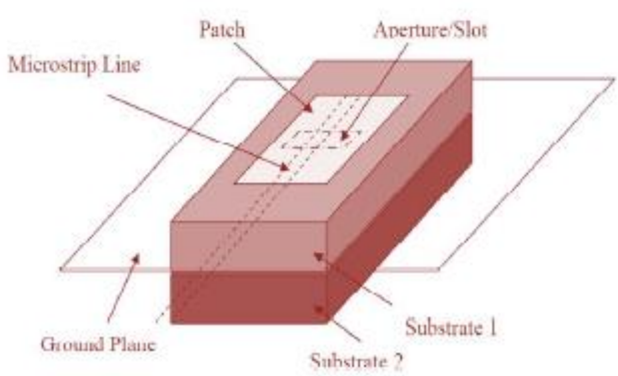


Figure 6: Aperture Coupled feed

2.4. Antenna parameter for WBAN

2.4.1. Directivity

The concentration of an antenna's radiation pattern in a certain direction is measured by directivity. Directivity is measured in decibels (dB). The higher the directivity, the more focused or concentrated the antenna's beam is. The beam will also go further with a higher directivity.

$$Antenna\ Gain = Directivity\ X\ Antenna\ Efficiency \qquad 2.1$$

Gain is the product of directivity and efficiency. Where efficiency takes into consideration for the losses of antenna such as manufacturing flaws, surface coating losses, resistance, VSWR, dielectric, and any other factor on the antenna.

2.4.2. Gain

Gain is another useful measure to describing the performance antenna. It’s closely related to the directivity. The directivity is a measure that describe only the directional properties and controlled only by the pattern when gain is defined as the ratio of the intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically [12]. It shows the ability of the antenna to be able to radiate the assumed power into space in a specific direction. Besides, it demonstrates the ability of the antenna to convert the electromagnetic waves obtained into electrical power.

2.4.3. Efficiency

"Antenna Efficiency is the ratio of the antenna's radiated power to the input power absorbed by the antenna," according to the standard definition. Simply explained, an antenna's job is to emit the power it receives with the least amount of loss. The efficiency of an antenna describes how well it can transmit its output with the least amount of transmission line losses. The mathematical expression for antenna efficiency is given below:

$$\eta e = \frac{Prad}{Pinput} \tag{2.2}$$

Where:

ηe is the antenna efficiency.

$Prad$ is the power radiated.

$Pinput$ is the input power for the antenna.

2.4.4. Bandwidth

The bandwidth is defined as the range of frequency within which the performance of antenna. It can be considered to be the range of frequencies when the antenna characteristic (such as pattern, beam width, input impedance, polarization, gain, radiation efficiency) are within an acceptable value at the centre frequency (usually the resonance frequency for a dipole) [12].

2.4.5. Radiation pattern

Radiation pattern or also called antenna pattern is defined as "a mathematical function or a graphical representation of the properties of antenna radiation as a function of space coordinates". In most cases, the radiation pattern will be represented as a function of directional coordinates and was determined in the far-field region. The properties include power flux density, field strength, directivity, phase, polarization, and radiation intensity [12]. By using CST SS 2019, the radiation pattern determines the energy generated and radiated by the antenna.

2.4.6. Voltage standing wave ratio (VSWR)

In a radio frequency (RF) electrical transmission system, the voltage standing wave ratio (VSWR) is defined as the ratio between transmitted and reflected voltage standing waves. It is a measurement of how well RF power is carried from the power source to the load through a transmission line. A power amplifier linked to an antenna through a transmission line is a frequent example. It determines the efficiency of power transmission over a transmission line from a source to a load. The VSWR can be 1:1 (or simply 1), which is an ideal condition in which the load absorbs 100% of the power from the source [13] VSWR is rarely found to be 1:1 in real-world applications, and systems are intended to keep the VSWR as near to unity as feasible. An acceptable value for most antenna application is between 1 and 2. A minimum value of 1 represent that there is no power is reflected from antenna or we call it ideal design [14] .

2.4.7. Return loss

Due to transmission line discontinuities, some signal power is always reflected or returned to the source when a signal is transferred across a transmission line. A connection to a system, another transmission line, or a connector might be the source of the break. The measure of this reflected power is called as returns loss.

Return loss is the ratio of the reflected power to the incident power, in decibels (dB).

$$Return\ Loss(dB) = 10\ log_{10}\frac{Pout}{Pin} \qquad 2.3$$

2.4.8. Specific Absorption Rate (SAR)

One of the crucial parameters for human well-being when deal with wearable antenna is SAR value. Specific Absorption Rate (SAR) is the parameter that is used to measure the rate at which energy is absorbed by human tissues [15]. It will be harming the body tissue when the SAR level exceed 1.6W/kg for 1g tissue for U.S standard and 2W/kg for 10g tissue for EUR standard [16] . The most typical problem is human body absorption of radiation due to proximity to the antenna. So, the SAR value should be as low as possible [17]. SAR can be calculated as below:

$$SAR = \frac{\sigma E^2}{\rho} \qquad 2.4$$

Where: E is the electric field intensity, σ is the human tissue conductivity and ρ is the human tissue mass density. The standard unit for SAR is watt per kilogram (W/kg).

2.4.9. Bending effect

Bending effect is one of critical requirement of WBAN application that need to consider when deal with this antenna type. The impact of the wearer on the transient characteristics should be addressed in the antenna design [18]. It's because the human body surface not always flat and the radiation will be change when the antenna in the bending states. So, it's also important to consider the bending effect when the antenna need to be attached to the body surface [19]. Because of the irregular shape of the human body and the fact that there are different human sizes on this planet, the antenna must be tested at a variety of bending radii. Article [20] test the antenna bending at five different angle which is 20,30,45,60 and 70 degrees. Using polystyrene cylinder with diameters of 70mm,80mm,100mm and 140mm to test the frequency under bending condition[21].

2.5. WBAN application

WBAN can be classified in three categories which is healthcare, Sport and entertainment, and also military and defence. The details and function for this application will be discuss based on the categories.

2.5.1. Healthcare

At first impression, this looks to be the most promising use for a WBAN. Several sensors that is comfortable will be attach on or in the human body allows the patient and doctor to monitoring the human body's functions and characteristic through a wireless communication channel. WBANs can help hearing and visually impaired persons enhance their quality of life by using hearing aids, cochlear implants, and artificial retinas, respectively. The list of application that can benefit from WBAN usage is such as temperature monitoring, glucose level, pulse oximetry, drugs delivery, post-operative, toxins, blood pressure, electrocardiogram (ECG), electroencephalogram (EEG), electromyogram (EMG) and etc [5].

2.5.2. Sport and entertainment

A real-time log of vital parameters such as blood pressure, heart rate, blood oximetry, and posture can help you enhance your fitness and athletic performance. Users may gather information about their athletic activity in this way and utilise it to prevent injuries and organise future training sessions to improve their performance. WBANs improve the realism of the user experience in the entertainment industry. The position of different part of the human body can be track using motion capturing techniques. Thanks to this technology because it allows user to use his body as a controller in videogames [5].

2.5.3. Military and defence

The long-term programme known as Network-Enabled Capability (NEC) aims to produce greater military effect through the use of information systems. New technology added by a WBAN has increasing the performance for military at both individual and squad level that engaged in military operations. at the individual level a set of sensors may monitor important indicators and offer information about the surrounding environment in order to prevent threats, while data collected at the squad level will allow the commander to better coordinate squad duties and tasks [5].

2.6. WBAN frequency range

Before design any antenna, one of the important parameters that need to be defined first is the resonance frequency. It’s to make sure that our antenna is suitable with the required application. There are various frequency range used for WBAN antenna. Every frequency range have the advantage with different function. From previous study, majority of frequency range that has been used is in ISM Band which is from (2.4-2.5GHz) as shown in figure 7. ISM band is (industrial, scientific and medical) or also called unlicensed band. It has gained a lot of attention among the researcher because its word wild application such as Wi-Fi, Bluetooth, Zigbee and RFID system [4].

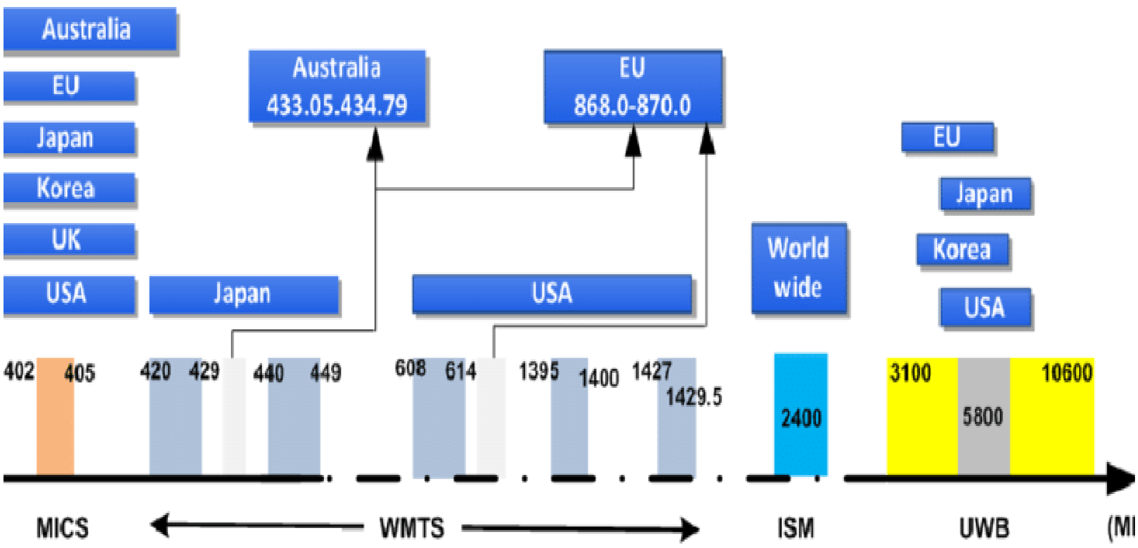


Figure 7: Frequency range for WBAN

2.7. **Proposed design comparison**

Table 1: Proposed design from literature review

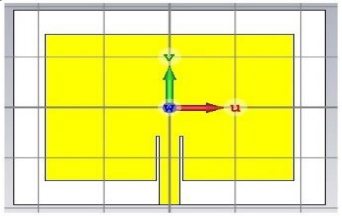
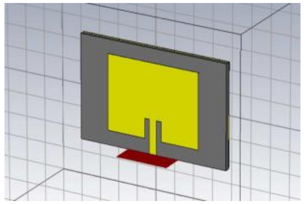
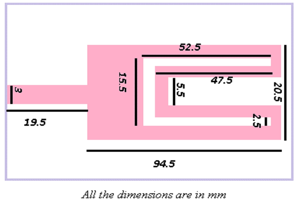
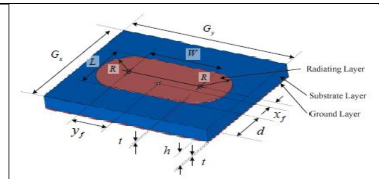
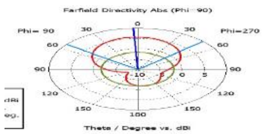
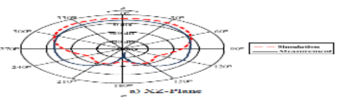
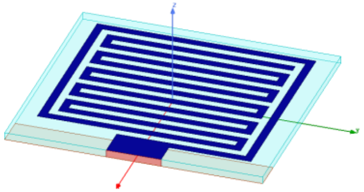
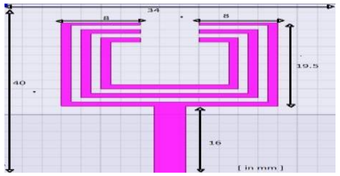
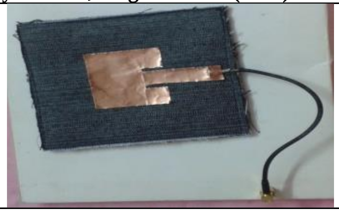
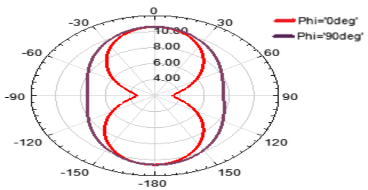
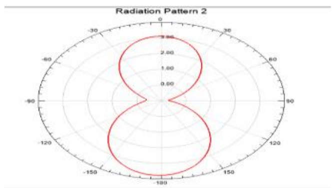
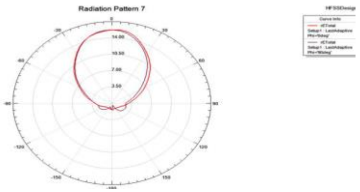
Parameter	**Design of Rectangular Microstrip Patch Antenna for 2.4 GHz applied a WBAN** [10]	**Development of Rubber Substrate for More Robust Flexible Wearable Antenna at 2.4 GHz Application** [14]	**U Slotted Wide Band Wearable Patch Antenna for WBAN Applications** [7]	**Design of Textile Capsule-Shaped Patch Antenna for WBAN Applications** [22]
Author/Year	**Hector Kaschel, Cristian Ahumada (2018)**	**Farisha Eriena Rahmad, Sarah Yasmin Mohamad (2021)**	**Shivani Sharma, M R Tipathy (2020)**	**Charinsak Saetiaw (2017)**
Design				
Material	**Ground: Copper Substrate: FR-4 Patch: Copper**	**Ground: Copper Substrate: Rubber Patch: Copper**	**Ground: Copper Substrate: Polyflon PTFE Patch: Copper**	**Ground: Copper Substrate: Denim Patch: Copper**
Dielectric constant Loss tangent Substrate Height	**4.3 - 1.6mm**	**3.0 0.02 2.7mm**	**2.1 0.0004 6mm**	**1.95 - 0.91mm**
Resonance Frequency	**2.4GHz**	**2.4GHz**	**5.4GHz**	**2.45GHz**
S-Parameter/Return loss	**-54.99dB**	**-49.659dB**	**-39dB**	**-40dB**
Bandwidth	**(2.3616-2.4426) GHz**	**-**	**250MHz**	**2.3994GHz - 2.5801GHz**
Radiation pattern				
Peak gain	**5.63dB**	**8.16dBi**	**8.4dB**	**3.5dB**
VSWR	**1.0045**	**1.007**	**1.06**	**-**

Table 2: Proposed design from literature review

Parameter	A Compact Wearable 2.45 GHz Antenna for WBAN Applications [4]	A Miniascape-Like Triple-Band Monopole Antenna for WBAN Applications [3]	Design and Analysis of Wearable Antenna for Wireless Body Area Network [15]	Wearable -Textile Patch Antenna using Jeans as Substrate at 2.45 GHz (1)
Author / Year	**Nesasudha M, Abi T Zerith M (2020)**	**Chun-Ping Deng, Xiong-Ying Liu (2012)**	**S. Karthikeyan (2019)**	**Sweety Purohit, Falguni Raval (2014)**
Design				
Material	**Ground: Copper Substrate: PDMS Patch: Copper**	**Ground: Copper Substrate: Flexible Panasonic R-F770 Patch: Copper**	**Ground: Copper Substrate: Bed sheet cotton Patch: Copper**	**Ground: Copper tape Substrate: Jeans Patch: Copper tape**
Dielectric constant Loss Tangent: Substrate Height	**2.71 0.0134 1mm**	**3.2 0.002 0.05mm**	**3.27 0.00786 1.26 mm (overall)**	**1.6 - 3.5mm**
Resonance Frequency	**2.45GHZ**	**3.2, 4.5,8.1 (UWB 3.1-10.6)**	**2.45GHz**	**2.45GHz**
S-Parameter/ Return loss	**-26.82**	**< -10dB**	**< -10dB**	**-32.5722dB**
Bandwidth	**2.4 GHz – 2.5 GHz**	**3.1–3.3, 4.2–4.9, and 6–10.6 GHz**	**2.1-2.7GHz, 3.6-4.3GHz**	**2.4-2.5GHz**
Radiation pattern				
Peak Gain	**1.9dB**	**4.4,5.3,7.5**	**3.84**	**7.26dB**
VSWR	**1.1119**	**<2**	**1.2391**	**-**

2.8. Material for substrate

Polymer based antenna become a popular topic in the field of wearable antenna. It’s because of the advantage of antenna substrate that they are low cost and able to withstand mechanical strains. The flexibility of an antenna is depending on the type of material for substrate used. The flexible antenna is sturdy, light and can be withstand mechanical stretching to a certain extent [13]. The qualities of the materials utilised can have an impact on the antenna's performance. The permittivity and thickness of the substrate, for example, determine the bandwidth and efficiency of a planar microstrip antenna [23]. The proposed antenna [1], [24], [25] used denim material to increase comfortable level and easy to integrated into clothes. The substrate material used in [15] is bed sheet cotton with a relative permittivity of 3.27 and the loss tangent is 0.00786. The substrate also has an impact on antenna performance. Textile material has a low dielectric constant, which improves the antenna's impedance bandwidth and lowers surface wave losses [25]. Many materials have been used as a substrate for WBAN antenna. For example, plastic, rubber, textile, paper, PDMS and various natural materials [26]. But for this case, the material that will be discuss is between jeans, PDMS and rubber because these three materials is consider as a famous material for WBAN.

2.8.1. Jeans

Jeans is one of the textile materials that has been used for wearable material. The textile material usually has a low dielectric constant which can increase the bandwidth of the antenna and also reduce the surface losses [25]. The denim material can increase user comfortable level and also easy to integrated into the clothes. This textiles material is commonly used as interesting substrates for wearable antennas.

2.8.2. PDMS

Polydimethylsiloxane (PDMS) is a silicone-based elastomer. The advantage of using PDMS as substrate is flexibility, softness, thermally stable, transparency and also water resistance. Furthermore, the dielectric characteristics of the PDMS substrate may be changed to suit various RF/microwave applications by loading it with additional materials [27].

2.8.3. Rubber

Rubber is the first substance that comes to mind when we talk about flexible materials. Rubber's mechanical features make it a viable choice for this application. After deformation, rubber may also spontaneously and forcibly return to its original shapes [13]. Rubber is a natural polymer that is suitable material for antenna substrate due to its high resilience, wide stretch ratio, good chemical stability, good weather ability, waterproof, heat resistance, and can easily bending. The most interesting fact about rubber is its extracted naturally make it environment-friendly [26]. Rubber can be processed into variety of shapes and also can be attached to metal inserts or mounting plates [28].

CHAPTER 3

METHODOLOGY

3.1. Introduction

This chapter will cover the steps requirement to design and analysis the antenna for WBAN applications. This project has been divided into several steps which is antenna research, antenna design, antenna simulation and analysis of antenna. The overall step for this project is as shows in the figure 8 below.

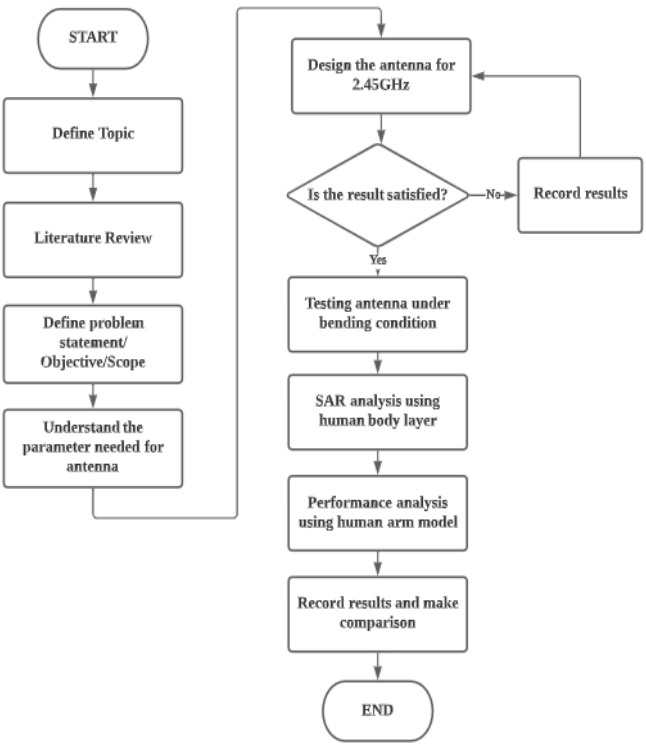


Figure 8: Flow Chart for overall project

3.2. Antenna research

This project starts with the antenna research. It's important to get a better research based on the topic given to make sure the project is in a correct way. WBAN is a new technology for this era, however there are a lot of research paper that can be found in internet because this title is one of the interesting to study. A lot of research has been done using books, journals, articles and conference paper. All of this thing is from a trusted platform such as IEEE, Scopus, Google Scholar, and UMP library website.

3.3. Antenna design

After make research and understand the parameter need for the antenna, the antenna was design based on several step. First need to know the antenna specification for WBAN such as resonance frequency, type of material, the dielectric constant for material and height of material. Second calculated the patch and width of antenna. Lastly, using CST SS, the antenna can be design and analysis.

3.3.1. WBAN design specification

For wearable and health monitoring application, the microstrip patch antenna is the best choice to use because it's followed the WBAN antenna specification which is need to be light weight, compact size and also ease of fabrication [4]. When speak about wearable antenna, it's important to choose the material that is suitable for the body surface, so the material used for antenna design need to be a material that can be bending such as cotton, PDMS, rubber, etc. For this project, three type of substrate material was choose which is rubber, PDMS and jeans. When bending the antenna, the parameter will be change. When antenna attach to the body, the radiation of antenna also can harm the body. So, it's important to consider the effect of bending and SAR value when design the WBAN antenna.

3.3.2. Calculation of microstrip patch

Before make a calculation, need to know which type of antenna will be used and the parameter such as resonance frequency, material for substrate, dielectric constant, and height of substrate need to be consider. The type of antenna used for this design is rectangular patch antenna. The value for input impedance is 50 **Ω**. The frequency range used is from the ISM range which is 2.45GHz. The substrate height (h) and dielectric constant (εr) is based on the substrate material.

The step to calculate the width and length of patch antenna are [9]:

- Calculate of the Patch Width (W)

$$W = \frac{c}{2fr}\sqrt{\frac{2}{\varepsilon r+1}} \qquad 3.1$$

c=speed of light in free space

εr =is the relative permittivity of the fabric material under test

- Calculate the effective dielectric constant (εreff)

$$\varepsilon reff = \left[\frac{\varepsilon r+1}{2}\right] + \left[\frac{\varepsilon r-1}{2}\right]\left[1+\frac{12}{W}\right]^{-1/2} \qquad 3.2$$

h=thickness of the substrate

- Calculation of actual Length of Patch (L)

$$L = \left|\frac{c}{(2fr\sqrt{\varepsilon reff}}\right| - 2\Delta L \qquad 3.3$$

εreff = is the effective permittivity of the material under test

- Calculation of extension length ΔL

$$\Delta L = 0.412h\left[\frac{(\varepsilon reff + 0.3)}{(\varepsilon reff - 0.258)}\right]\left[\frac{\frac{w}{h} + 0.264}{\frac{w}{h} + 0.8}\right] \qquad 3.4$$

- The effective patch length (Le)

$$Le = L + 2\Delta L \qquad 3.5$$

3.4. Antenna simulation

To design and simulate the antenna, the software used is CST Studio Suite 2019. CST SS is one of the most famous software for design and analysis the antenna. It can be seen in research paper when majority of them used CST Studio for antenna design. CST SS is a high-performance 3D EM analysis software package for analysing, designing and optimizing electromagnetic (EM) component and systems. In this project the analysis consists of several part which is design the antenna for 2.45GHz for every antenna, testing the antenna under bending condition, analysis the SAR value using human body layer model, and lastly test the antenna performance using human body arm model.

3.4.1. Requirement for WBAN

To design the WBAN antenna, the first thing needs to know is the parameter used for WBAN specification. It’s important to know the parameter because it will be a guideline for the design requirement, so the design and analysis will be based on this requirement. The appropriate antenna parameter for this WBAN antenna as shown in table below:

Table 3: WBAN antenna specification

Parameter	Design requirement
Type of antenna	Microstrip Patch Antenna
Feeding method	Microstrip line feeder
Material	Patch: Copper
	Substrate: PDMS, Jeans, Rubber
	Ground: Copper
Dielectric constant for substrate (εr)	PDMS: 2.71
	Jeans: 1.6
	Rubber: 3.0
Height of the dielectric substrate (h)	Short
Operation Frequency	ISM Band (2.45 GHz)
Specific Absorption Rate (SAR)	<2 W/kg
Impedance of the Antenna	50 Ω
Return Loss, S11	< -10 dB
Voltage Standing Wave Ration (VSWR)	<2

3.4.2. Step to design using CST Studio Suite

Step 1: Open CST SS2019 + Click New and Recent + Click New Template

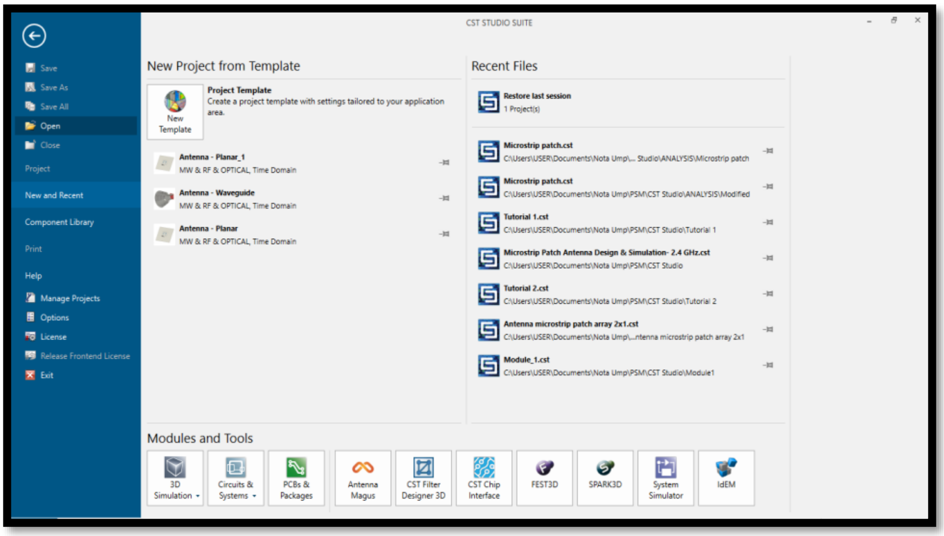


Figure 9: Create new project

Step 2: Click Microwaves & RF/Optical + Choose antenna + Press next

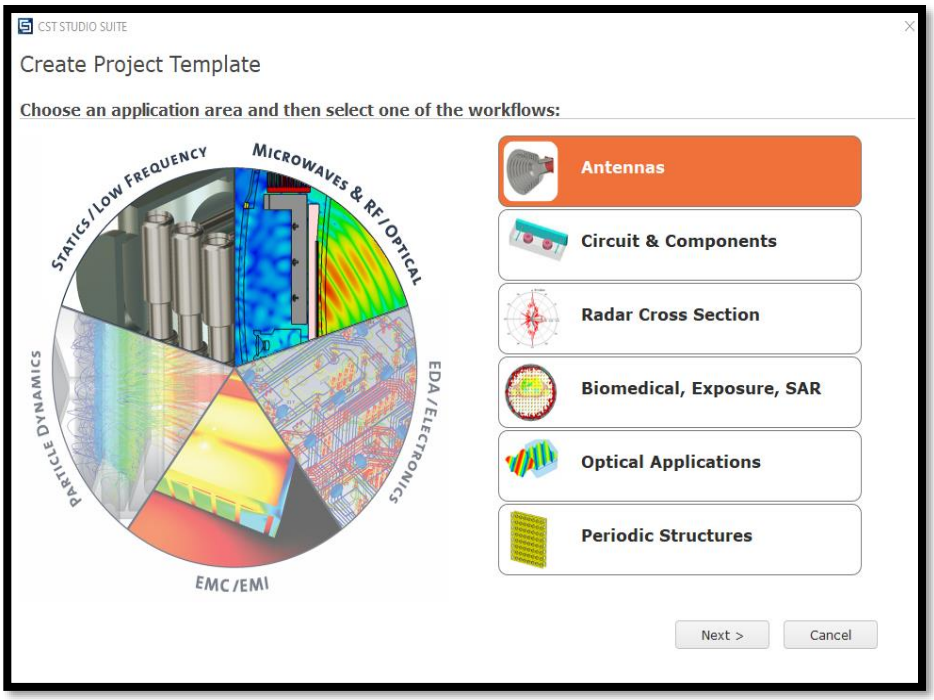


Figure 10: Choose application area

Step 3: Click Planar (Patch, slot, etc) + Click Next

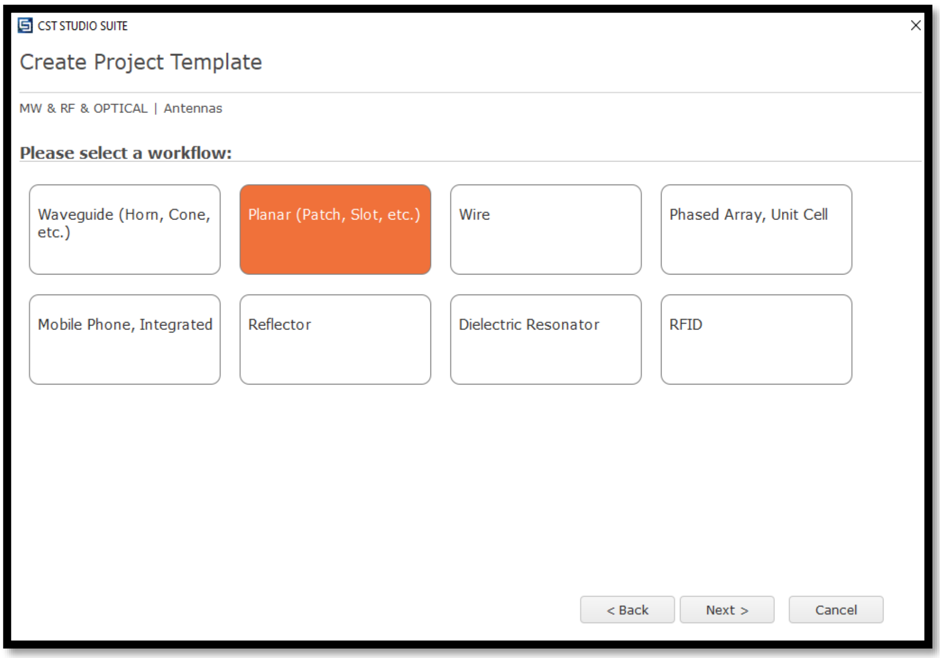


Figure 11: Select workflow

Step 4: Click Time Domain + Click Next

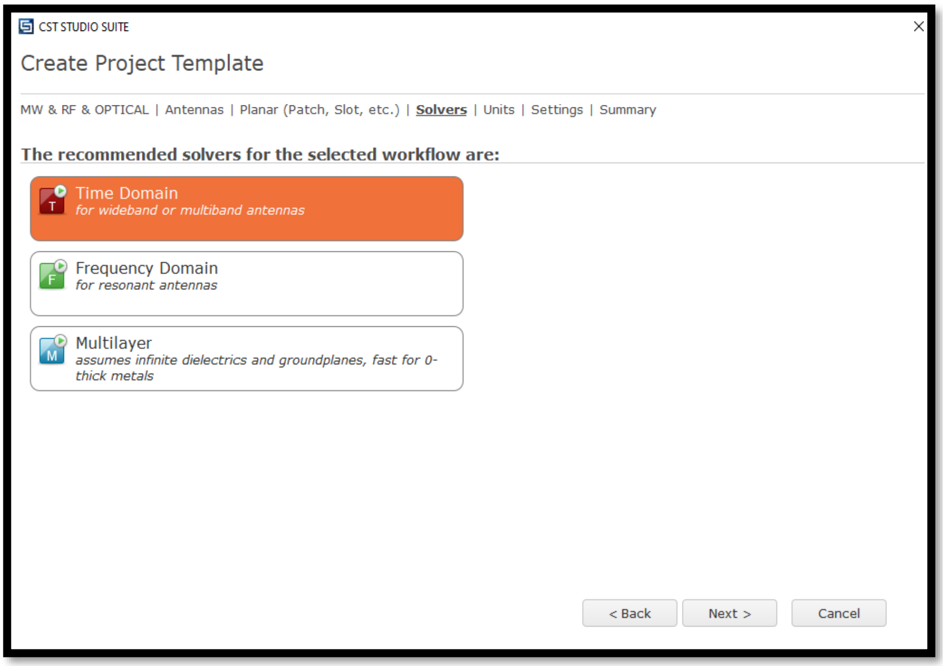


Figure 12: Select recommended solver for selected workflow

Step 5: Select the suitable unit + Click Next

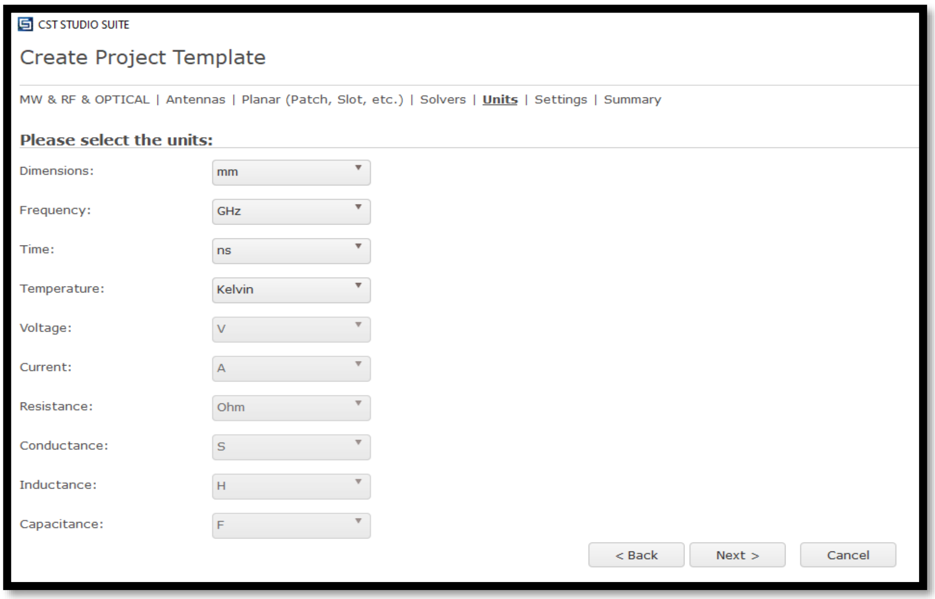


Figure 13: Select the units

Step 6: Select value for Frequency Min, Max, Choose the Monitors + Click Next

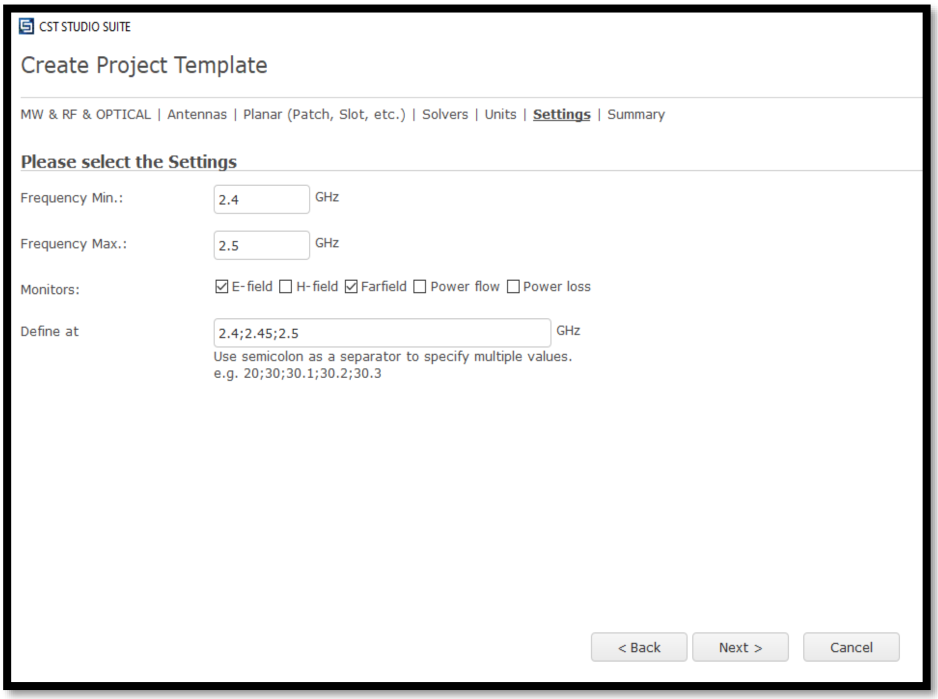


Figure 14: Select frequency range

Step 7: Make sure all information is correct + Click Finish

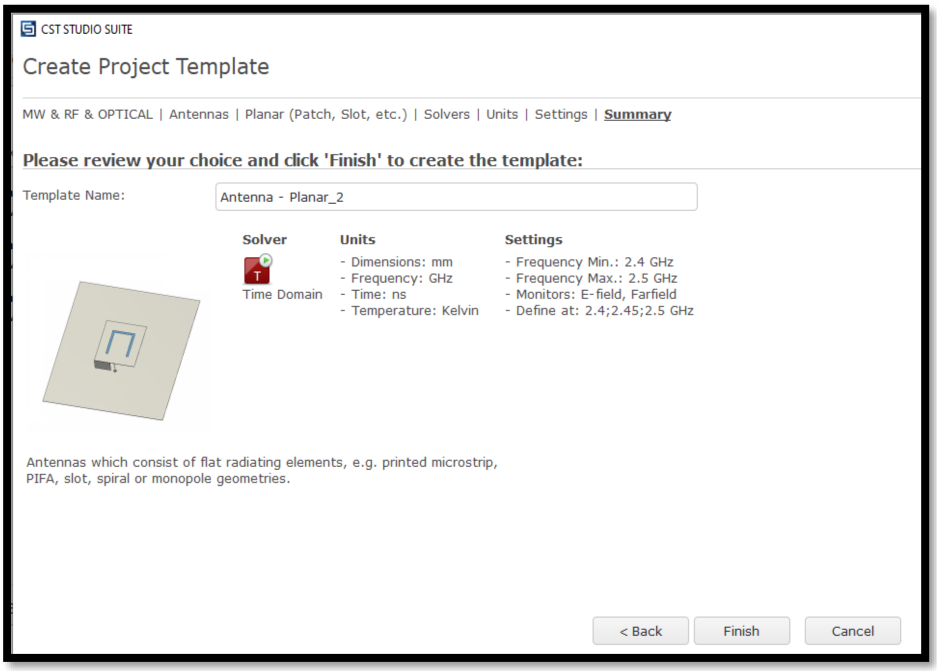


Figure 15: Confirm the information

Step 8: Start Design and Analysis

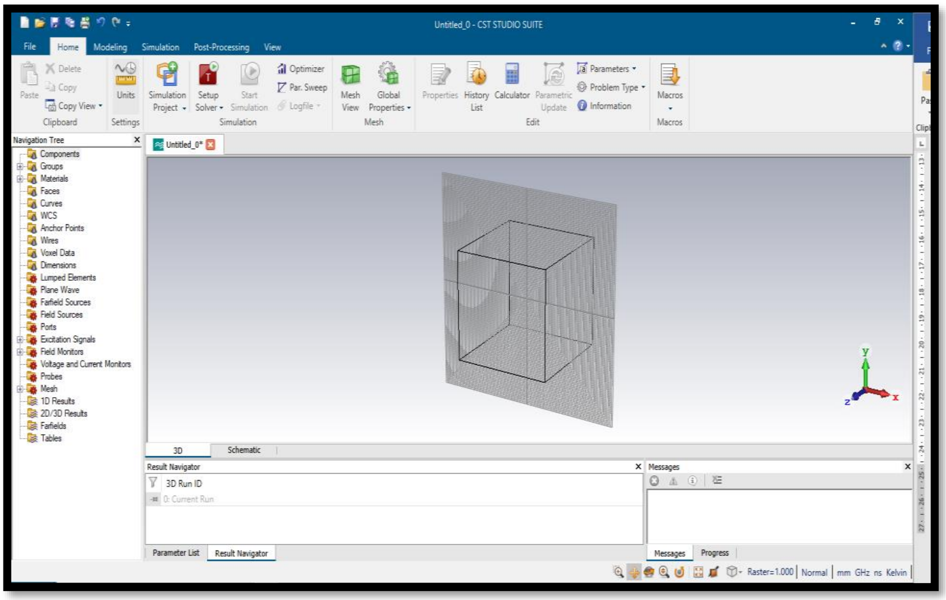


Figure 16: CST SS Space

3.4.3. Design antenna for 2.45GHz

The requirement for the WBAN antenna in this project is to design the antenna in the ISM band, which is the frequency range between 2.4GHz and 2.5GHz. The proposed antenna substrate is designed using polydimethylsiloxane (PDMS) substrate with a dielectric constant of 2.71, loss tangent of 0.0134 and a thickness of 1mm [4], rubber substrate material with a permittivity of 3.0, loss tangent of 0.02 and a thickness of 2.70mm [14], and jeans substrate with a permittivity of 1.7, loss tangent of 0.025 and a thickness of 1mm [17]. The first step to analysis is the need to design an antenna that operates at 2.45GHz. The parameters and scale for this antenna are based on the original design in [14]. However, the resonance frequency used in this article is 2.4 GHz. To get a frequency that operates at 2.45GHz, the approximated dimension of the antenna width and patch is calculated using the microstrip patch formula. Then the original design needs to be scaled and further modified to obtain the frequency at 2.45GHz.

3.4.4. Testing antennas under bending conditions

When we speak about WBAN antenna, it's important to test the antenna under bending conditions because the antenna needs to be attached to the body and the human body is not always flat [15]. Because of the irregular shape of the human body and the fact that there are different human sizes on this planet, the antenna must be tested at a variety of bending radii. The bending condition is analysed using five radiuses of conformal, which are 20mm, 30mm, 45mm, 60mm, and 70mm[20]. The antenna is bent on the cylinder surface based on the radius given.

3.4.5. Analysis of the SAR value using human body layer model

Another condition that needs to be analysed for WBAN antenna is the effect of the human body on antenna performance. This antenna is placed on the human body. The radiation from this antenna can harm the human body, so it is important to calculate the SAR value. For this project, the human body layer was chosen to calculate the SAR value. To speed up the computation, the tissue model was simplified to four layers for simulation

[29]. This human body layer consists of four layers, which are skin, fat, muscle, and bone. The total dimension of this model is 85x65x4 mm^2. The properties of this human tissue layer are based on the material library in the Ansys HFSS simulator [30]. The properties are as shown in table 4.

Table 4: Properties (material) for the tissue-model

Materials	Skin	Fat	Muscle	Bone
ε_r	37.95	5.27	52.67	18.49
σ(S/m)	1.49	0.11	1.77	0.82
Density (kg/m3)	1001	900	1006	1008
Thickness (mm)	2	5	20	13

3.4.6. Antenna performance using a human arm model

The goal of this section is to test the performance of the antenna when attached to the human body. Because the antenna is so close to the human body, it has certain impacts on it as well. The human body can disturb the communication link between the antenna and the outside world and also cause lossy [15]. The properties for this human body arm are based on table 4, so a four-layer cylinder with a radius of 40 mm is simulated to imitate the arm of the human body. To test the performance, the antenna cannot be attached directly to the body. The gap between the antenna and the human arm is 5 mm because the SAR value will drop by doing that [30]. To reduce the interaction between the antenna and the human body, article [31] employs metamaterial structure design and integrates it to the back of the antenna ground. The metamaterial surface known as electromagnetic bandgap (EBG) ground planes is used as a high impedance surface to shield the body from radiation and reduce the SAR value [32]. Researchers are using ferrite sheet or Perfect Electric Conductor (PEC) reflector as a shielding layer between the antenna and the human body [32]. The parameters that will be analysed in this section are the resonance frequency, return loss, gain, directivity, antenna radiation, and SAR value.

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Introduction

The antenna design and analysis will be covered in this chapter. The analysis will be based on the antenna parameters such as bandwidth, resonance frequency, gain, return loss, radiation pattern, VSWR, bending effect, and also SAR value. Analysis will cover the variety of materials that are suitable to be used for WBAN antennas, such as PDMS, jeans, and rubber. The analysis for all antennas will cover many conditions, such as in the air, bending conditions, attaching the antenna to the human body layer, and also conditions when the antenna is attached to the human arm model. The comparison for every design will be recorded.

4.2. Simulation result

4.2.1. Design 2.45 GHz antenna

The first step to analysing the antenna is by designing the antenna at 2.45GHz. All three types of antennas were designed at a resonance frequency of 2.45GHz. The design is based on article [14]. The final design for every antenna is as shown in Figure 17 for rubber substrate, Figure 18 for PDMS substrate, and Figure 19 for jeans substrate antenna.

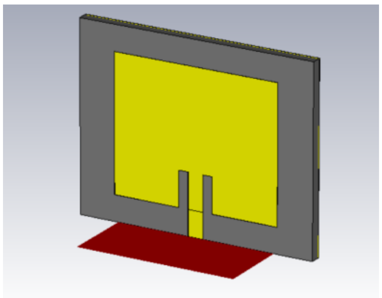


Figure 17: Antenna using rubber substrate

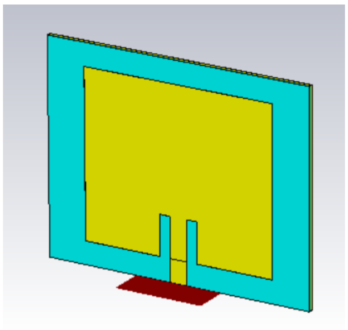


Figure 18: Antenna using PDMS substrate

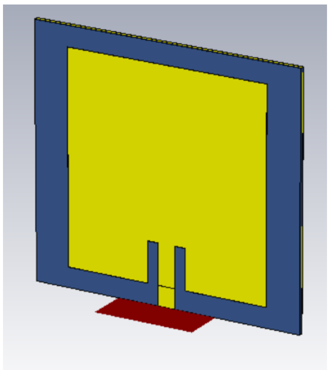


Figure 19: Antenna using jeans substrate

To get the frequency of 2.45GHz for every antenna, the antenna needs to be calculated first using the microstrip patch antenna formula. However, after running the design using CST SS, the frequency is not exactly 2.45GHz. The antenna needs to be adjusted until a frequency of 2.45GHz is achieved. Figure 20 shows the effect of changing the patch width size of the rubber antenna. The return loss (S11) and resonant frequency are the parameters that will be observed in this analysis. All other parameters are constant except for the patch width length. When the patch width is 40mm, the resonance frequency is 2.462GHz with a return loss of -36.748dB, but after increasing to 42mm, the frequency changes to 2.453GHz with a return loss of -22.776dB. When the patch width size is increased to 43.26mm, the frequency and return loss value are 2.447GHz and -18.848dB. It can be concluded that when the patch width is decreased, the value for resonance frequency will increase but the return loss will decrease.

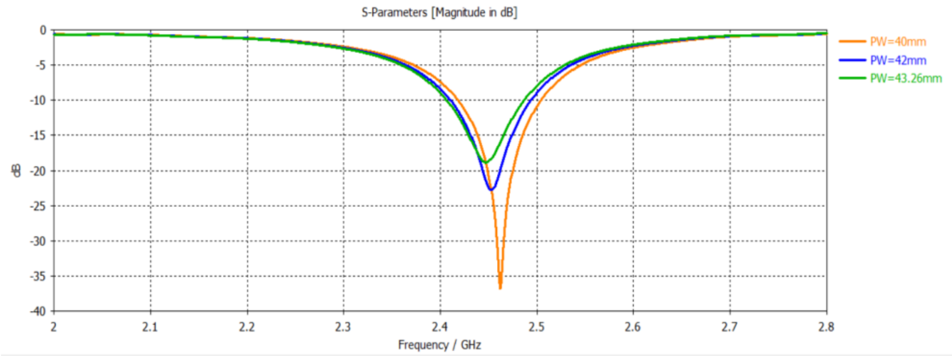


Figure 20: Effect of changing patch width size

The size comparison parameters for all antennas after reaching a frequency of 2.45GHz are shown in Table 5. Rubber shows the lowest patch size with a dimension of 42x34.10mm, followed by PDMS with a dimension of 43x36.83mm and the biggest one is jeans with a dimension of 46.13x3.82mm. The dimensions of the ground and substrate for all antennas are constant. We can conclude that the size of the antenna is reduced when the dielectric permittivity is high.

Table 5: Parameter for 2.45GHz antenna

Parameter	Rubber	PDMS	Jeans
Operating Frequency (GHz)	2.4531	2.4529	2.45
Dielectric Permittivity	3	2.71	1.7
Rectangular Patch Width (mm)	42	43	45
Rectangular Patch Length (mm)	34.10	36.83	46.13
Feeding Width (mm)	3.82	3.82	3.82
Feeding Length (mm)	6.45	5.09	4.37
Dielectric and Ground Plane Width (mm)	60	60	60
Dielectric and Ground Plane Length (mm)	47	47	55
Dielectric Thickness (mm)	2.70	1	1
Ground Thickness (mm)	0.064	0.064	0.064

4.2.2.1. Performance analysis of Rubber substrate εr =3

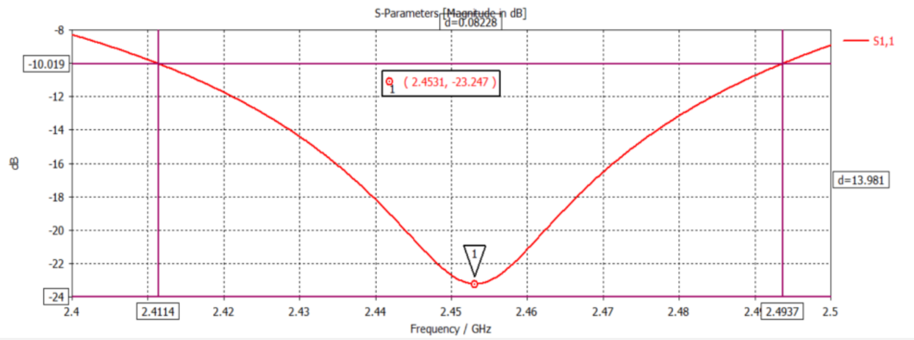


Figure 21 : Simulated S-parameter results

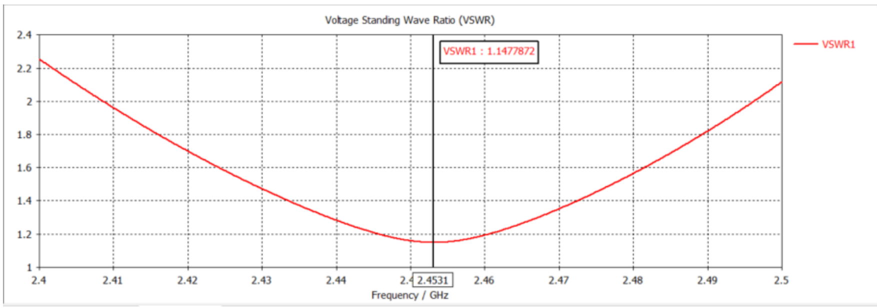


Figure 22: VSWR value

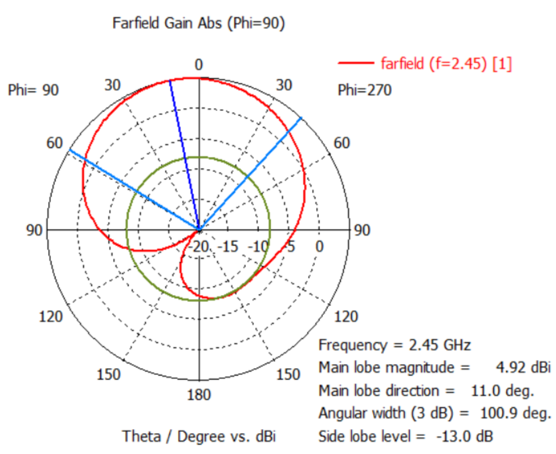


Figure 23: Radiation pattern in azimuth plane

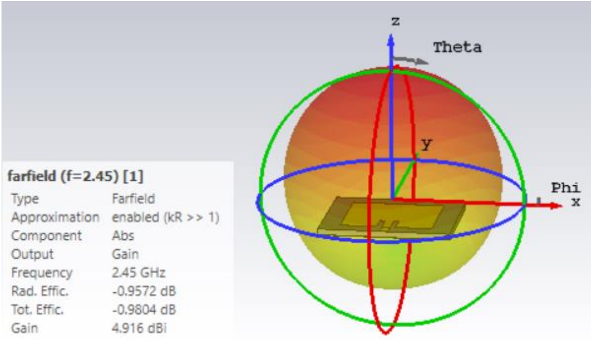


Figure 24: Antenna gain

Figure 21 shows the resonance frequency for the rubber substrate antenna is 2.453GHz with a return loss value of -23.247dB. Figure 22 shows that the VSWR value is 1.148, which is acceptable. Figure 23 shows that power is radiated in the upper hemisphere and at 2.45GHz, the power beam is directed toward 0 degree with a magnitude of 4.92 dBi. Figure 24 shows the antenna gain value is 4.916 dBi.

4.2.1.2. Performance analysis of PDMS substrate εr =2.71

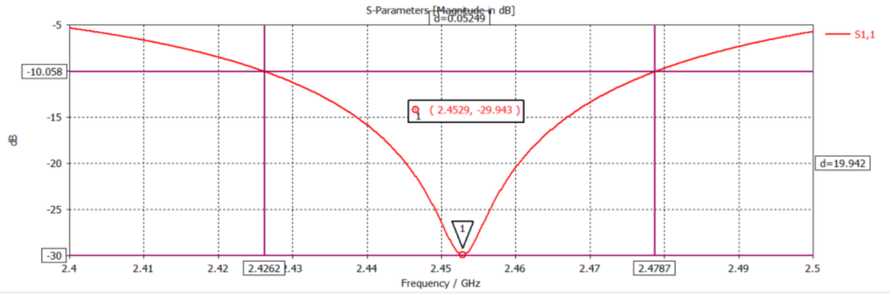


Figure 25: Simulated S-parameter results

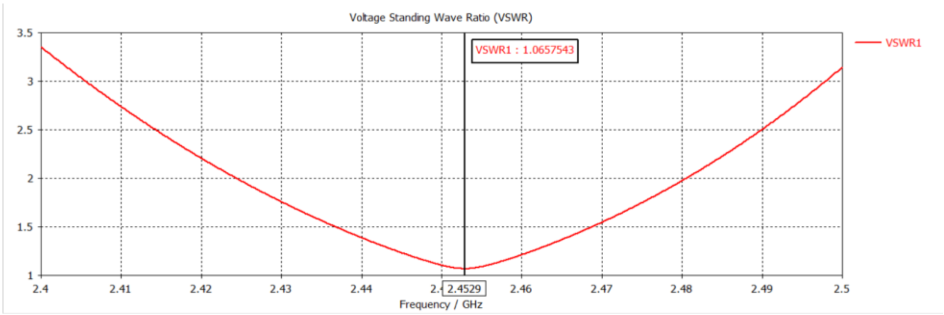


Figure 26: VSWR value

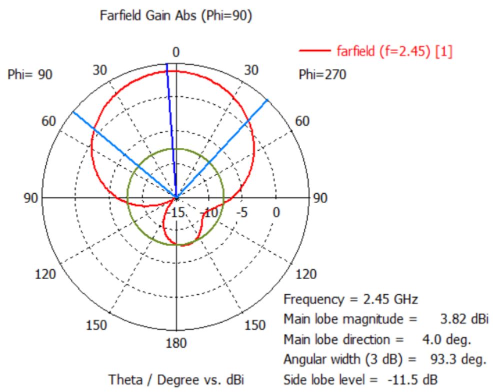


Figure 27: Radiation pattern in azimuth plane

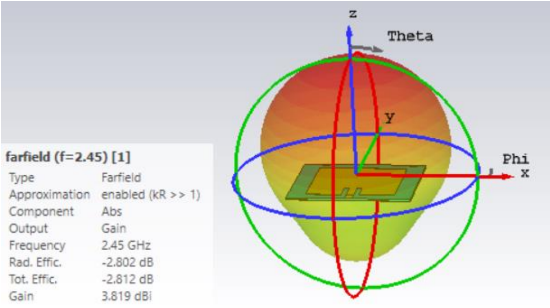


Figure 28: Antenna Gain

For a PDMS substrate, the return loss is found to be -29.94dB at a resonance frequency of 2.453GHz. The bandwidth is between 2.426 and 2.479 GHz. Figure 26 shows the VSWR value is 1.067. The radiation pattern for figure 27 shows power is radiated more on the upper side. The antenna gain for this antenna is lower than the rubber antenna since the gain value for this antenna is only 3.819dBi.

4.2.1.3. Performance analysis of Jeans substrate εr =1.7

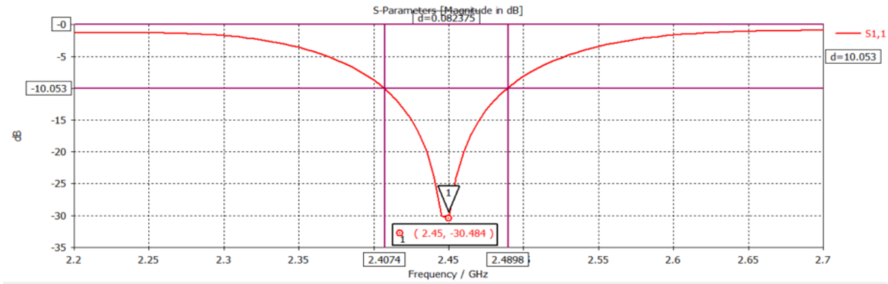


Figure 29: Simulated S-parameter results

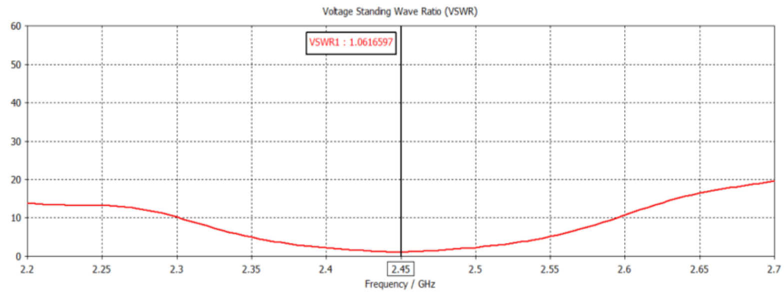


Figure 30: VSWR value

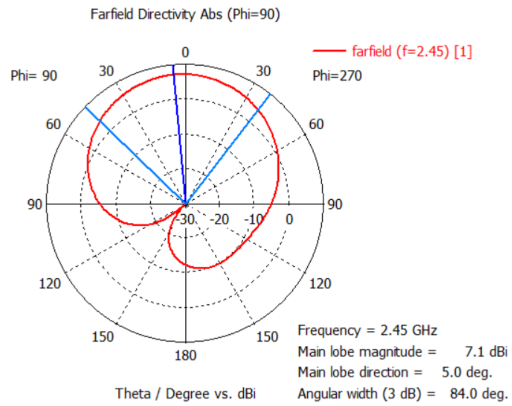


Figure 31: Radiation pattern in azimuth plane

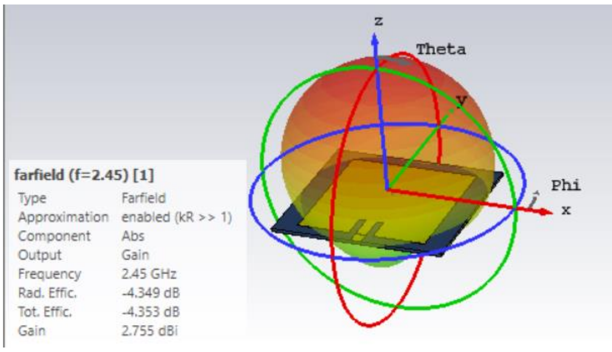


Figure 32: Antenna Gain

From the figure, the antenna shows a good impedance matching with a return loss of-30.48dB at resonance frequency of 2.45GHZ, which is better than the antenna for rubber and PDMS substrate. The bandwidth for this design is between (2.407 and 2.49) GHz. The VSWR value in this antenna is 1.062, which is lower than for PDMS antennas with a VSWR value of 1.066, and the highest value is rubber at 1.147. The radiation pattern in figure 31 shows that the main lobe has a greater magnitude than the other antennas, with a magnitude of 7.1dB at 2.45GHz. The antenna gain is 2.755dBi, which is lower than the gain for rubber and PDMS. To conclude, all antenna can be operated at 2.45GHz with the acceptable parameter value.

4.2.2. Bending the antenna

In this part, the performance of the antenna is tested under bending conditions. The bending condition is analysed using five radiuses of conformal, which are 20mm, 30mm, 45mm, 60mm, and 70mm[20]. The parameter such resonance frequency, reflection coefficient and VSWR value will be discuss in this part.

Figure 33 shows the s-parameter for the rubber substrate antenna. When bending the antenna at a radius of 20mm, the resonance frequency is 2.449GHz with a return loss of -20dB. The value for the antenna drops to 2.441GHz with a return loss of -20.568dB for a radius of 30mm, 2.435GHz with a return loss of -21.105dB for a radius of 45mm, and 2.434GHz with a return loss of -18.706dB when bending at a radius of 60mm. The resonance frequency value increased to 2.437GHz with a resonance frequency of -19.408dB when the antenna is bent at a radius of 70mm. All resonance frequency and return loss for this antenna are acceptable because it’s in the ISM band, which is 2.4GHz to 2.5GHz, even if the antenna is bending in certain conditions. The VSWR for all bending condition in this part show the highest value is below than 1.3 which is acceptable for an antenna.

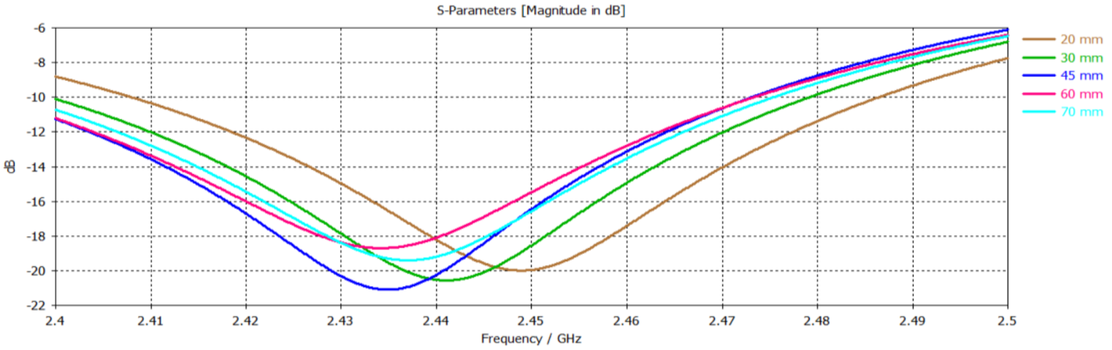


Figure 33: S-parameter for rubber antenna

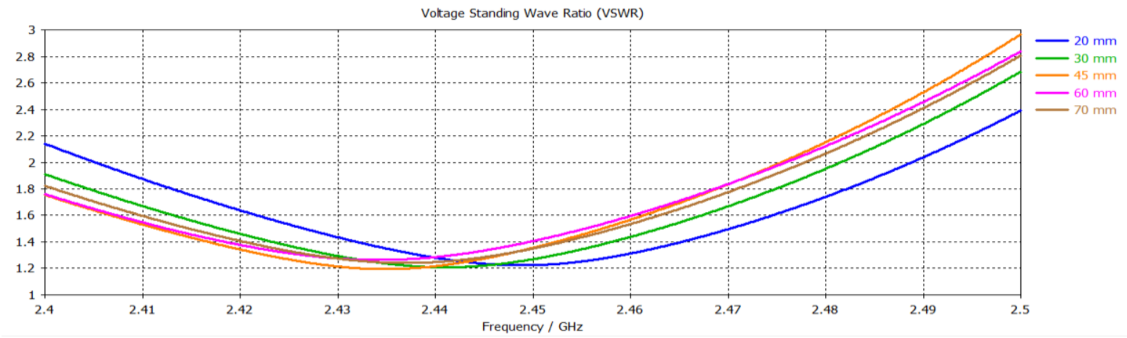


Figure 34: Rubber VSWR value in bending condition

For PDMS antennas, the resonance frequency when bending the antenna in a radius of 20mm, 30mm, 45mm, 60mm, and 70mm is 2.423GHz, 2.412GHz, 2.403GHz, 2.401GHz, and 2.403GH. The return loss value is -16.903dB, -20.714dB, -28.733dB, -25.814dB, and -27.356dB. The antenna range for all bending conditions for this antenna is between 2.4GHz and 2.43GHz, which means it’s still in the ISM band range. In figure 36, the PDMS VSWR value in bending condition shows the highest value is 1.613 when bending at 20mm and the lowest is 1.076 when bending at 45mm.

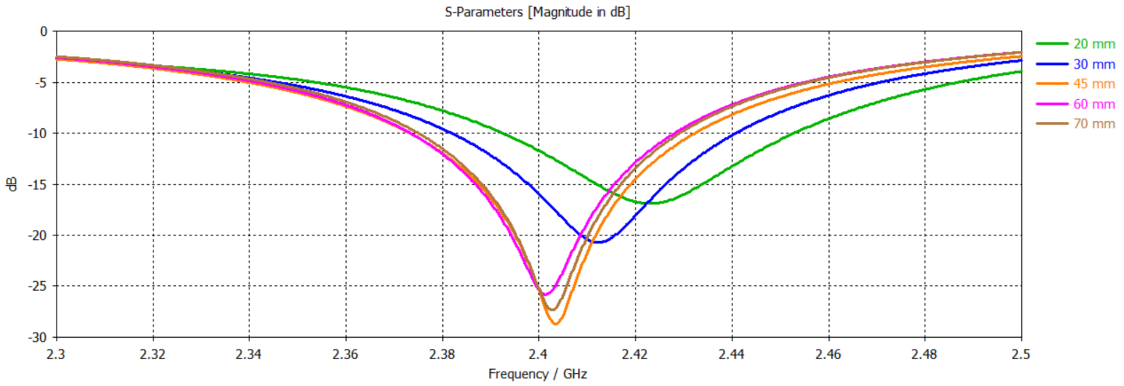


Figure 35: S-parameter for PDMS antenna

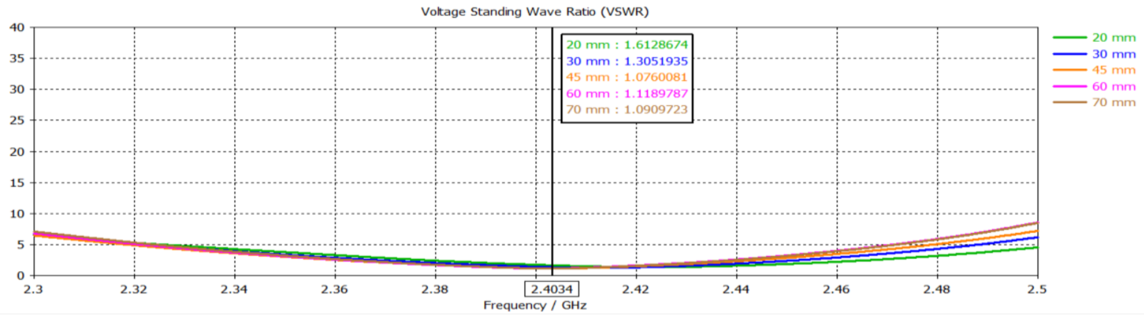


Figure 36: PDMS VSWR value in bending condition

Figure 37 shows the S-parameter for the Jeans substrate antenna. The resonance frequency for all bending conditions in this antenna is between 2.4GHz and 2.41GHz, which is in the range of the ISM band. The return loss value under -10dB for all conditions is acceptable, which means the performance for this antenna is acceptable when the antenna is bent. VSWR value in figure 38 shows the good value for all bending condition because the value is below than 2. To conclude, the frequency for all antennas will shift to the left when the antenna is bent.

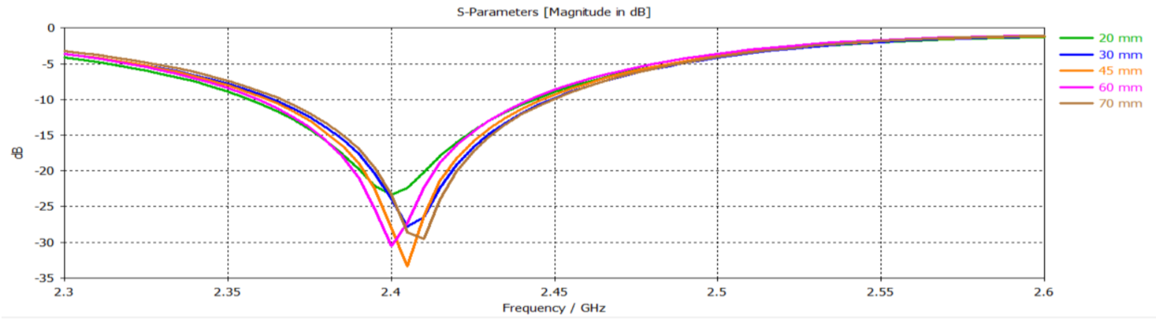


Figure 37: S-parameter for Jeans antenna

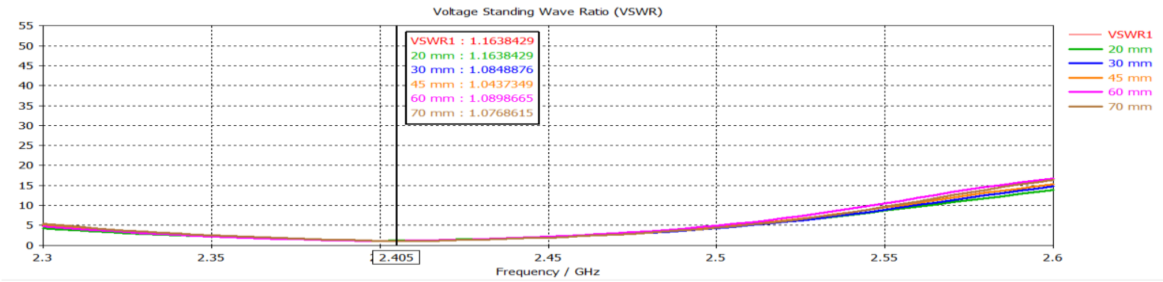


Figure 38: Jeans VSWR value in bending condition

4.2.3. Calculated SAR value using human body layer model

In this section, the human body layer that consists of skin, fat, muscle, and bond is constructed in CST SS as shown in figure 39 below. The properties and diameter for this design are based on table 4.

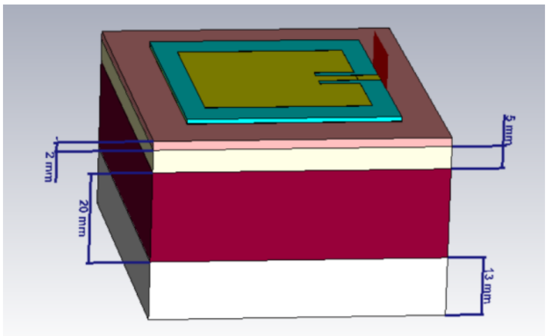


Figure 39: Human body layer model

Table 6: SAR value for rubber antenna

Rubber	**SAR (W/kg) at frequency 2.4, 2.45 and 2.5 (GHz)**		
	2.4	**2.45**	**2.5**
For 1g of tissue	1.13	1.42	1.31
For 10g of tissue	0.577	0.69	0.598

To investigate the radiation effect of the designed antenna on the human body, the value was recorded at three frequencies, which are at 2.4GHz, 2.45GHz, and also 2.5GHz. Table 6 shows the SAR value for rubber antennas is 1.13W/kg, 1.42W/kg and 1.31W/kg for 1g tissue. For 10 g of tissues, the SAR value is 0.577W/kg, 0.69W/kg, and 0.598W/kg for frequencies of 2.4GHz, 2.45GHz, and 2.5GHz.

Table 7: SAR value for PDMS antenna

PDMS	**SAR (W/kg) at frequency 2.4, 2.45, 2.5 (GHz)**		
	2.4	**2.45**	**2.5**
For 1g of tissue	0.955	1.54	1.27
For 10g of tissue	0.408	0.642	0.517

Table 7 shows the SAR value for antenna that used PDMS substrate. The maximum SAR value for this antenna at 2.4GHZ, 2.45GHz, and 2.5GHz is 0.955W/kg, 1.54W/kg and 1.27W/kg for 1g tissue and 0.408W/kg, 0.642W/kg and 0.512W/kg for 10 g tissue. These SAR values are very low compare to maximum SAR limit of 2W/kg in the European standard for 10 g tissue.

Table 8: SAR value for jeans antenna

Jeans	**SAR (W/kg) at frequency 2.4, 2.45 and 2.5 (GHz)**		
	2.4	**2.45**	**2.5**
For 1g of tissue	0.798	1.08	1.03
For 10g of tissue	0.345	0.449	0.417

Table 8 shows the SAR value for the jean's substrate. At 2.4 GHz, the SAR value is 0.798 W/kg for 1g of tissue and 0.345 W/kg for 10g of tissue. For 2.45 GHz, the SAR value is 1.08 W/kg for 1g tissues and 0.449 W/kg for 10g tissues. For 2.5 GHz, the SAR value is 1.03 W/kg for 1g of tissue and 0.417 W/kg for 10g of tissue. The SAR value for the jean's substrate shows the lower value compared to rubber and PDMS. All the SAR values for these 3 substrates are very low compared to the maximum SAR limit of 2 W/kg in the European standard for 10g of tissue and 1.6 W/kg in the US standard for 1 g of tissue. It can be concluded that all SAR value in this design follows the requirement.

4.2.4. Analysis performance using human arm model

This section is to analyse the performance of the antenna using the human arm model. The parameters that will be analysed are resonance frequency, reflection coefficient, VSWR, gain, and directivity. The simulated design for the human arm model is as shown in figures 40 and 41 below. The antenna is placed 5 mm from the human arm model to increase the antenna performance and avoid close contact and also to decrease the antenna radiation and SAR value. To fill the gap, the Styrofoam with thickness of 5mm is used because of its permittivity value is closed to the air which is εr =1.1 [29].

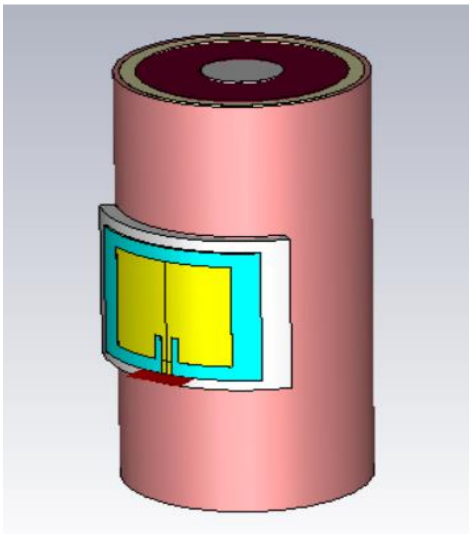


Figure 40: Side view of human arm model

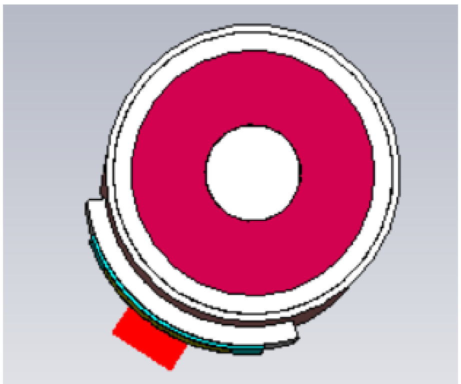


Figure 41: Top view of human arm model

Figure 42 shows the S-parameter for three types of substrates, which are rubber, PDMS, and jeans. The resonance frequency for rubber is 2.419 GHz, which is in the range of the ISM band. However, the frequency for PDMS and jeans decreased to 2.357 GHz and 2.387 GHz when we attached the antenna to the human arm model. The reflection coefficient value for jeans shows the lowest value, which is -40.67dB, followed by PDMS, which is -20.33dB, and lastly, rubber, at -16.85dB. The bandwidth for rubber is (2.376-2.464) GHz, for PDMS is between (2.33-2.38) GHz, and for jeans is (2.348-2.43) GHz. Rubber antenna substrate can maintain the frequency in the ISM band when attached to a human arm model.

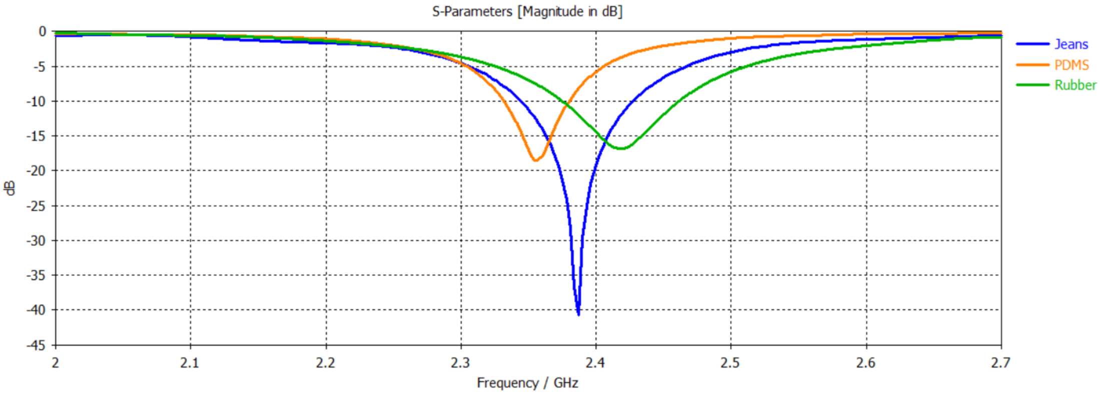


Figure 42: S-parameter for three substratee

Table 9 below shows the parameter results for resonance frequency, reflection coefficient, gain, directivity, and VSWR value for antennas that used rubber, PDMS, and jeans substrate. The value for resonance frequency and reflection coefficient has been discussed before. Rubber substrate antenna shows the higher gain value, which is 3.626dBi, followed by jeans at 1.926dBi and also PDMS at 1.77dBi. The directivity for jeans, 6.282dBi, shows the higher value than rubber and PDMS, which are 5.769dBi and 6.11dBi. The results for VSWR show the good value for each antenna because the value is in the range of 1 and 2.

Table 9: Result when attaching the antenna to the human arm model

Parameter	**R=40mm**		
	Rubber	**PDMS**	**Jeans**
Resonance Frequency (GHz)	2.419	2.357	2.387
Reflection coefficient (dB)	-16.854	-20.33	-40.668
Voltage standing wave ratio (VSWR)	1.335	1.213	1.019
Gain (dBi)	3.626	1.77	1.926
Directivity (dBi)	5.769	6.11	6.282

Table 10 shows the SAR value for rubber, PDMS, and jeans when the antenna is attached to the human arm model. This SAR value for all antennas is very satisfying because it is lower than the maximum limit value. PDMS and jeans show very low SAR values compared to rubber. In conclusion, all these antennas are not dangerous to the human body, even if the antenna is bent by 40mm, but there must be a distance of at least 5mm to maintain the performance of the antenna.

Table 10: SAR value for human body arm model

Material	**Frequency at 1g and 10 g of tissue**					
	2.4GHz		**2.45GHz**		**2.5GHz**	
	1g	**10g**	**1g**	**10g**	**1g**	**10g**
Rubber	1.277	0.703	1.302	0.715	1.071	0.585
PDMS	0.286	0.219	0.141	0.085	0.124	0.059
Jeans	0.368	0.185	0.266	0.139	0.152	0.084

CHAPTER 5

CONCLUSION

5.1. Introduction

To conclude, before designing a WBAN antenna, need to know the parameters needed, such as the material, type of feeding method, type of antenna, dielectric constant, resonance frequency, and etc. Because this antenna is attached to the body, the effect of antenna radiation on the body and the effect of the antenna in bending conditions are important to consider. The antenna size and material are also important in designing WBAN because they will affect the user's comfort. As a result, the antenna must be small enough, and the material used must be soft and bendable so that it does not cause discomfort when applied to the body's surface.

Three microstrip patch antennas have been designed with different substrate permittivity, which is 3 for rubber, 2.71 for PDMS and 1.7 for jeans. Rubber is the smallest in size when designed at 2.45GHz, followed by PDMS and jeans. It can be concluded that the size of the antenna will decrease when the dielectric permittivity is increased. For antenna performance when bent to a certain radius, it shows that the resonance frequency will drop, which means the frequency value will shift to the left when the antenna is bent, but the value for all three types of antennas is still acceptable. The SAR value for all designs is also acceptable because all values are below the maximum SAR limit of 2W/kg in the European standard for 10g tissue and 1.6W/kg in the US standard for 1g of tissue. Antenna performance when attached to a human arm model shows the acceptable SAR value for all antennas, but the resonance frequency value for this antenna is decreased. The bandwidth for rubber and jeans shows that this antenna can still be operated in the ISM band, but for the PDMS antenna, it will operate in another band when attached to the human body arm model. Based on this project, the best antenna design to be proposed for WBAN is rubber because of its performance after testing in many situations.

5.2. Future recommendation

For WBAN antenna, too many research has been done to produce the best antenna but the perfect antenna doesn't exist. Majority researcher used microstrip patch antenna for WBAN antenna because of its performance and can be built using many materials especially textile material. When moving or doing physical work, the wearable antenna will also move and change the antenna performance. So, the antenna material is very important for wearable antenna. Apart from flexible materials, waterproof materials also should be considered since water can affect the resonance frequency of an antenna. WBAN antenna also should small in size. The miniaturization antenna is needed since the user need to wear this antenna to the body. One of the miniaturization methods is by adding slot to the patch layer, it will reduce the resonance frequency which leads to reducing the size of the antenna[33]. Another miniaturization techniques are by using high permittivity substrate. The size for antenna also can be reduce by using high permittivity material[34]. The radiation produce by antenna will harm the human body tissue, so some improvement needs to be done to antenna to minimize the antenna radiation. One of the methods that can be used is by using metamaterial surface knows as electronic bandgap (EBG) ground planes to shields the body from radiation and reduce the SAR value.

5.3. Impacts to society and/or environment

Nowadays, WBAN antennas are becoming more popular among researchers. Many designs have been proposed for several years, and a lot of things have been done to make the best version of antenna. For WBAN, the most popular antenna type to be used is the microstrip patch antenna because of its low profile, low cost, smaller in dimension, and ease of fabrication. One of the substrates used for this design is rubber because of its material properties. Rubber is a natural polymer that is suitable material for antenna substrate due to its high resilience, wide stretch ratio, good chemical stability, good weather ability, waterproof, heat resistance, and can easily bending. The most interesting fact about rubber is its extracted naturally make it environment-friendly [26] Next, materials such as rubber, jeans, and PDMS are used in this project because this material is soft and can be bent to increase the comfortable level for the users.

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APPENDIX A
SAMPLE APPENDIX 1

Gantt Chart for PSM 1

	Week														
Task	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
PSM 1 breafing season	■														
Choose project title and Supervisor	■	■	■	■											
Briefing about the title by Supervisor			■												
Find article related to WBAN				■	■	■	■	■							
Read article about WBAN				■	■	■	■	■	■	■	■	■	■	■	■
Study parameter needed for antenna							■	■	■	■	■	■	■	■	
Study about COMSOL								■	■	■					
Do tutorial using COMSOL								■	■	■	■	■	■	■	
Make a slide presentation												■	■		
PSM 1 presentation														■	
Make a report and logbook									■	■	■	■	■	■	■
Report and logbook Submission															■

Gantt chart for PSM 2

	Week													
Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14
PSM 2 breafing session	■													
Find article as a design guidelines	■	■	■											
Make tutorial using CST SS		■	■											
Make design for rubber substrate			■	■										
Make design for PDMS substrate				■	■									
Make design for Jeans substrate					■	■								
Test all design under bending condition						■	■	■						
Calculated SAR value for all antenna								■	■					
Analysis the result										■	■	■	■	
Make a slide presentation												■	■	
PSM 2 presentation													■	
Write report and logbook										■	■	■	■	■
Write the technical paper												■	■	■
Report and logbook Submission														■

APPENDIX B
SAMPLE APPENDIX 2