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DESIGN AND REALIZATION OF WEARABLE ULTRAWIDEBAND ANTENNA TRIANGULAR PATCH FOR HEALTH APPLICATIONS WITH DEFECTED GROUND STRUCTURE METHODS

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Abstract

Wearable antenna is currently a very popular topic because it has the advantages of small size, light weight, and flexible shape. Because of their versatility, wearable antennas are often used in healthcare, as well as military applications. In this research, a wearable triangular patch antenna is designed at the Industrial, Scientific, Medical (ISM Band) 2.4 GHz frequency using Cordura Delinova 2000 textile as a substrate and copper tape as a conductor for the patch and ground plane. To obtain ultra-wideband characteristics, the Defected Ground Structure technique is used. From the simulation results carried out under normal conditions, a bandwidth of 1403.9 MHz is obtained with a VSWR value of 1.004 and a gain of 2.355 dBi. By adding a phantom with hand characteristics, the simulation results show a bandwidth of 1354.1 MHz, VSWR 1.36, Gain 7.35 dBi, and SAR 0.4 W/Kg at a distance of 30 mm from the phantom. From the measurements made under normal conditions, a bandwidth of 684.3 MHz, a VSWR of 1.1045 and a gain of 2.01 dBi are obtained. From the on-body measurement using wrist, the antenna obtains a bandwidth of 615.2 MHz and VSWR of 1.4027, at a distance of 30 mm from the phantom. Based on the parameters obtained in the measurement and simulation, the antenna can be used in the 2.4 GHz frequency.

Keywords: Ultra-Wideband (UWB), Wearable Antenna, Cordura Delinova 2000, Triangular Patch Mikrostrip, Textile Antenna

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1. Introduction

The presence of Internet of Things (IoT) technology opens up new opportunities in the world of telemedicine. One of the fastest growing telemedicine technologies today is remote health monitoring technology [1]. For Remote Health Monitoring applications, the Wireless Body Area Network (WBAN) which is also IoT-based is able to detect biomedical signals such as heart rate, breathing, and vital signs wirelessly using sensors located on the patient's body. The sensor must be flexible, and can follow the contours of the human body when carrying out daily activities.

WBAN technology is usually applied to make it easier for doctors, medical personnel, or the patient's family to monitor the patient's health in real-time [2]. WBAN consists of On-body and Off-body sensors that can be used to get medical data such as body temperature, blood pressure, respiration, heart rate, glucose levels, and Electro Cardio Gram (ECG) [3]. The sensor chip device is attached to the patient's body, where the sensor chip will send data through a transmitting antenna and then be captured by a receiving device. The antenna must be flexible and light so that it is comfortable to wear by the user. Such antenna technology is called a wearable antenna. which have several advantages such as low profile, low cost, easy to manufacture, and can work at a wide frequency [4-5]. Wearable antennas also can be bent because the substrate is made of a flexible and thin material. With this flexibility, the antenna can adjust to changes in body shape so that it can still work well. In general, this antenna is used in Industrial, Scientific, and Medical (ISM) bands because the ISM band is considered the most suitable, free from licenses, and also has sufficient bandwidth for WBAN.

In research [1], an antenna made of textiles was designed at a frequency of 2.45 GHz which aims for

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telemedicine applications using wrist phantoms. Research [6] demonstrates an antenna with paper material and designed at a frequency of 2.45 GHz for telemedicine applications, while in research [7-8], several antennas were designed with nylon conductive, and vinyl polymer material, at a frequency of 2.4 GHz for health monitoring applications using EBG structure. However, the discussion related to the antenna bending and phantom is still not yet elaborated, even though it greatly affects the antenna parameter values. In research [1], antennas have been designed to works in ISM bands and having a large bandwidth, but still use relatively thick materials, namely by using jeans.

Therefore, in this research, an ultra-wideband wearable antenna at the ISM frequency of 2.4 GHz is designed with flexible substrate materials that are relatively thinner than the usual microstrip antenna substrate. This antenna will be applied to the health sector, especially telemedicine. An antenna will be tested on the arm to support WBAN applications with a good SAR (Specific Absorption Rate) value and a very wide bandwidth and flexibility testing will be carried out on the antenna. The aspects discussed are VSWR parameters, bandwidth, gain, and radiation pattern.

2. Experimental Method

In the design and realization of an ultra-wideband antenna, several stages must be carried out as shown in Fig.1. After conducting a literature study, then determining the specifications of the antenna in the form of antenna parameters, while the specifications and parameters determined are bandwidth, gain, VSWR, and radiation pattern. After determining what kind of specifications will be used, then calculations are carried out to get the dimensions needed during the simulation. After getting the required dimensions, the software is designed and simulated. After the simulation is done, the simulation results will be obtained, if it is not fulfilling the target specifications, optimization will be carried out. Optimization is done by changing the pre-existing dimensions. Optimization is complete when the specified specifications are difficult to match.

2.1 Antenna and Material Specification

The main specification in this study is the SAR value which has to be lower than 1.6 W/kg according to the *Federal Communication Commission* (FCC) regulations [9]. This value is the maximum threshold for the effects of electromagnetic wave radiation on human body tissues. For the operating frequency, the

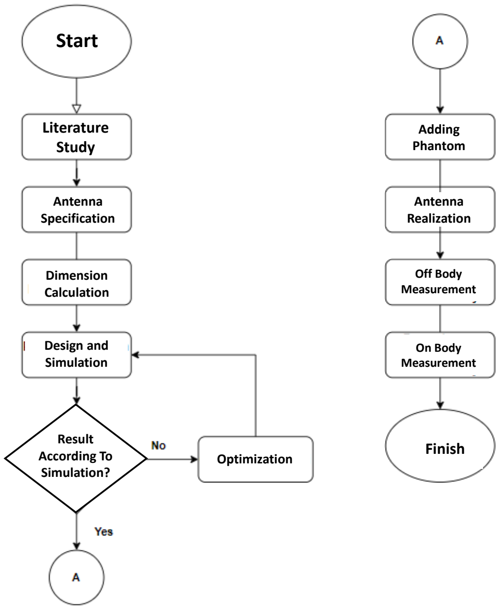


Fig. 1. Flowchart of this research

Ultra-wideband (UWB) classification can be defined by using two criteria. The first criteria are defined by FCC at a frequency of 3.1 GHz – 10.6 GHz with a minimum bandwidth of 500 MHz [10], [11][11], while the second definition said that to have a UWB characteristic an antenna must have a Fractional Bandwidth above 50% [12]. Several research has demonstrated the implementation of wearable antenna in UWB application. Research [13] demonstrates a low profile UWB antenna for WBAN application. In this study, it is expected that a wearable antenna has UWB characteristics with a bandwidth of more than 500 MHz. The general specification of the final design is shown in Table 1.

In the process of fabricating the wearable antennas, materials are the things that must be considered. The selection of materials used is based on physical specification (thickness), quality of materials, prices of materials, and availability of materials in the market.

Table 1. Antenna Specification

Parameters	Specification
Frequency	2.4 GHz
Gain	≥ 2 dB
VSWR	1-2
Bandwidth	≥ 500 MHz
SAR	≤ 1.6 W/kg
Input Impedance	50 *Ω*

Table 2. Material Characteristics

Component	Material	Relative Permittivity (ε_r)	Thickness
Conductor	Copper	-	0.1 mm
Substrate	Cordura Delinova 2000	1.6	0.5 mm

Parameters that need to be considered in selecting the right substrate are thickness, loss tangent, dielectric constant. In general, the dielectric constant used in the design of microstrip antennas is in the range of $2.2 \leq \varepsilon r \leq 12$. In this design, the conductor material used for the ground plane, feedline, and patch is copper. while the substrate is made from Cordura Delinova 2000. The characteristics of the material used in this design are specified in Table 2.

2.2 Feeding Method

In this research, the feeding method used is the microstrip line. This feeding technique is used because it is simple and easy to implement. it connects the patch to the connector and port at the edge of the substrate.

3. Antenna Design

3.1 Initial Antenna Design

In this study, a triangular patch shape is used to operate at the frequency of 2.4 GHz with a bandwidth greater than 500 MHz. The dimension parameter such as patch side length (a), and patch height (t), could be obtained using equations (1) – (2)

$$a = \frac{2c}{3 \times f_0 \times \sqrt{\varepsilon_r}} \quad (1)$$

$$t = 0{,}5 \times a \times \sqrt{3} \quad (2)$$

Where c is the speed of light (3x10^8 m/s), f_0 is the frequency in Hertz, ε_r is the dielectric constant of the material. In order to calculate the size of the ground plane (Wg and Lg), feed line width (W_f), and also feedline length (l_f), equation (e) – (9) can be used.

$$Wg = 6h + a \quad (3)$$

$$Lg = 6h + t \quad (4)$$

$$Wf = \frac{2h}{\pi}\{B - 1 - \ln(2B - 1)$$

$$\left[+\frac{\varepsilon_r - 1}{2\varepsilon_r} \times \left[\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right]\right\} \quad (5)$$

$$B = \frac{60\pi^2}{z_0\sqrt{\varepsilon_r}} \quad (6)$$

$$l_f = \frac{\lambda_g}{4} \quad (7)$$

$$\lambda_g = \frac{\lambda_o}{\sqrt{\varepsilon_r}} \quad (8)$$

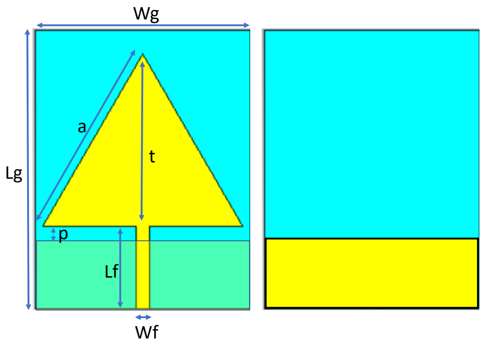
$$\lambda_o = \frac{c}{f_0} \quad (9)$$

Where h is the height of the substrate, z_0 is the input impedance equal to 50 Ohm and λ_o is the wavelength of the antenna. After calculating the dimension, the next step is cutting the ground plane by using defected ground structure method. Defected Ground Structure is a method to enhance the bandwidth by performing defects or removing part of the ground plane to suppress surface waves [14], [15]. In this study, the DGS technique was used to obtain ultra-wideband characteristics, however, the radiation pattern changed into bidirectional because by cutting the ground structure, there is no longer any reflector of electromagnetic waves. The initial parameter data and the design for the triangular patch microstrip antenna could be seen in Table 3 and Figure 1. The simulation result of the dimension antenna in Table 3 can be seen in Figure 2.

In the results, the Return Loss obtained was -52.6, VSWR 1.004, and the Bandwidth was 1,403.9 MHz.

Table 3. Initial Parameter Data of Triangular Patch Microstrip Antenna

No	Name	Symbol	Value (mm)
1	Side Length	a	45
2	Patch Height	t	57
3	Ground Plane Width	Wg	48
4	Ground Plane Length	Lg	60
5	Feed Width	Wf	2.859
6	Feed Length	Lf	47.01
7	Distance Between DGS and Patch	p	1.9



(a) (b)

Figure 1. Parameter Design of Triangular Antenna: (a) Front Side (Patch), (b) Back Side (Ground Plane)

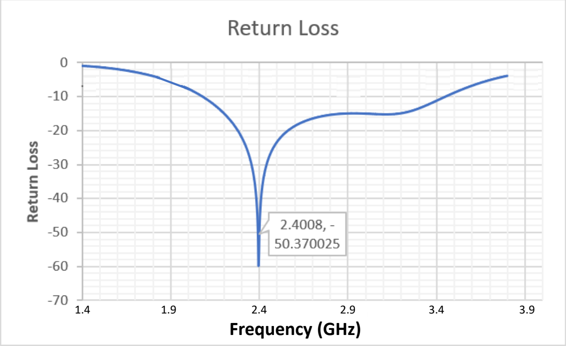


Figure 2. Return Loss of The Initial Design

3.2 On Body Antenna Simulation

In order to simulate the effect of the body on the antenna parameter, a phantom is needed, Phantom must be designed to resemble the shape and characteristics of the human body, such as skin, muscle, fat, bone as well as its permittivity, permeability, and conductivity characteristics. This study uses a Phantom wrist with the electrical properties as stated in Table 4 at a frequency of 2.4 GHz[16] .

Table 4. Electrical Properties of Wrist Phantom

Tissue	**Permitivity**	**Conductivity (S/m)**	**Density (km/m^3)**
Fat	5.2853	0.10235	930
Muscle	52.791	1.705	1050
Skin	38.063	1.4407	1090

The phantom is placed behind the antenna, then SAR is calculated at a distance of 0 mm, 15 mm, 20 mm, and 30 mm from the antenna. The simulation results can be shown in Table 5. From the table, it can be concluded that the antenna can work well when the distance between the antenna and the Phantom is more than 15 mm where the SAR value is below 1.6 W/Kg. Besides, further distance has a better VSWR value and wider bandwidth.

Table 5. Parameter Change with Different Phantom Distance

Distance (mm)	**VSWR**	**SAR (W/kg)**	***Bandwidth* (MHz)**
0	1.7	8.7	1266.4
15	1.7	1.64	1326.5
20	1.5	0.9	1352.8
30	1.36	0.4	1354.1

3.3 Antenna Bending Simulation

One of the advantages of the Textile Patch Antenna is its flexible and lightweight characteristics. To prove these characteristics in this study, bending analysis is also conducted to analyze its effect on the antenna parameter such as VSWR, and bandwidth. The bending effect is analyzed at several bending radii which are 40 mm, 80 mm, 120 mm, 180 mm, and 240 mm as shown in Figure 3. Table 6 shows the effect of antenna bending on the antenna circuit parameters. From the table, it can be seen that the greater the radius of the bending, the VSWR value decreases while on the other hand the bandwidth increases. From the simulation, it can be concluded that the antenna is still following the specifications when bending is applied.

3.4 Antenna Realization

After the simulation and analysis are done, the next step is the realization of the antenna. The antenna is fabricated using Cordura Delinova 2000 as substrate and copper tape as the conductor (patch and ground plane). Figure 4 shows the fabrication result of the antenna. Measurement of the triangular patch antenna parameters was carried out at Telkom University Antenna Laboratory and LIPI Antenna Laboratory Bandung.

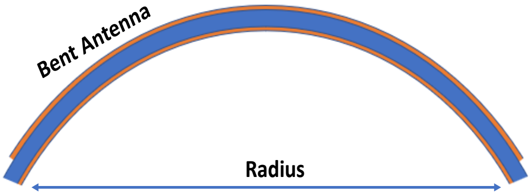


Figure 3. The radius of the Bent Antenna

Table 6. Antenna Bending Effect to The Antenna Circuit Parameter

Radius (mm)	**VSWR**	***Bandwidth* (MHz)**
40	1.04	1373.8
80	1.059	1402.6
120	1.0262	1386.7
180	1.0381	1392.1
240	1.0396	1399.1

(a) (b)

Figure 4. Antenna Realization: (a) Front Side (Patch), (b) Back Side (Ground Plane)

4. Result and Analysis

Based on the simulation results in Figure 5, there are differences in the VSWR and Bandwidth results between normal and on body conditions. From the graph, it can be seen that under normal conditions the VSWR value is 1.004 with a bandwidth of 1403.9 MHz, while in the on-body condition the VSWR value is 1.36 with a VSWR of 1354.1. The decrease in the value of VSWR and the value of the bandwidth when the on-body condition is caused by the Phantom affects the impedance value of the antenna.

The measurement result is shown in by Figure 6. The measurement is also done in two conditions: in normal conditions and in on-body state, namely by measuring the wrist. Under normal conditions without Phantom, the VSWR value is 1.1045 with a bandwidth of 684.3 MHz. In the on-body condition with the wrist, the VSWR results are 1.4027 with a bandwidth of 615.2 MHz. Comparing the simulation results with the measurements, there is a decrease in bandwidth and also an increase in the VSWR value. The decrease in bandwidth is caused by the use of body parts in measurements that are not in accordance with the simulation and also accounting for the manufacturing deficiencies. The manual antenna manufacturing process affects the parameter antenna so that it is not as perfect as the simulation. The measurement parameter values are worse than the simulation results, but the fabricated antenna can still be used because it is still following the expected specifications.

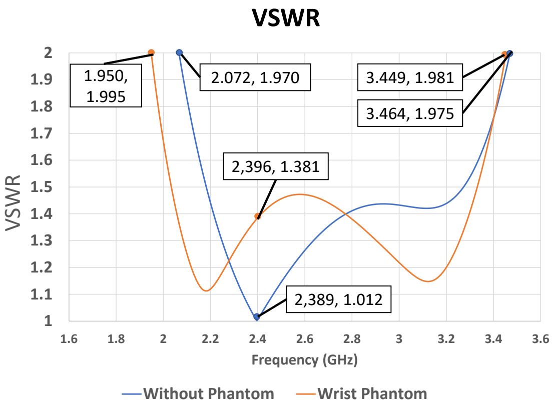


Figure 5. VSWR Measurement of Simulated Antenna

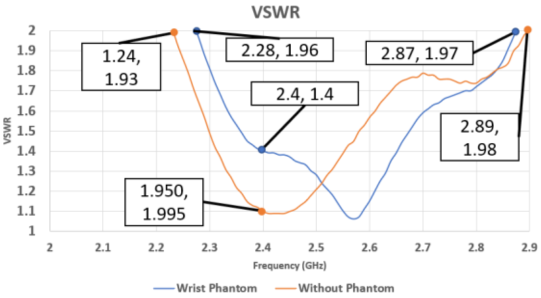
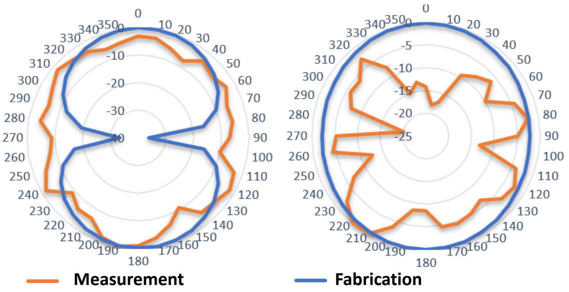


Figure 6. VSWR Measurement of Fabricated Antenna

Radiation pattern measurements were carried out at far-field distances in azimuth and elevation by rotating the masting antenna at every 10o. The comparison between simulation results and measurements can be seen in Figure 7. From the figure, the results obtained from the measurement of the radiation pattern on elevation plane are bidirectional with the maximum value at an angle of 220 ^{o} and the minimum value at an angle of 280°. In the simulation results, the maximum value is at an angle of 180° and the minimum value is at an angle of 210°.

The measurement of the simulation gain value and measurement can be seen in Table 7. In the table, it can be seen that the simulation gain value is greater than the gain value in the measurement. Several things affect the results of the gain measurement, namely the condition of the antenna that is less than perfect because it is a textile antenna, the condition of the room that is not in the measurement room so that there is attenuation in the measurement.



(a) (b)

Figure 7. Radiation Pattern of Antenna: (a) Azimuth, (b) Elevation

Table 7. Gain Result Simulation and Measurement

Condition	**Frequency**	**Gain Value**
Simulation	2.4 GHz	2.355 dBi
Measurement	2.4 GHz	2.012 dBi

5. Conclusions

This research has successfully investigated the application of an antenna with a triangular patch using textile material Cordura Delinova 2000 as a substrate for Wireless Body Area Network. By using an additional phantom wrist in simulation, the antenna can still work well when the distance between the antenna and the Phantom is more than 15 mm where the SAR value is below 1.6 W/Kg. From the bending simulation, it can be concluded that there is not much changing happening in both VSWR and bandwidth when the bending is applied. The fabrication result also confirms that the antenna still works in accordance with the specifications when measured on top of the human wrist. In short, the antenna with a triangular patch can be used for telemedicine applications.

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