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by

A Flexible Lungs Shape Radiator Structure Printed on a Textile Materials

Abstract—**This study aims to design a wearable antenna suitable for security purposes, namely preventing crime and spy mission. The antenna device can be used in flexible, lightweight, and comfortable manner that works on the 2.4-2.5 GHz ISM band frequency. The antenna was designed using the CST Studio Suite electromagnetic 3D simulation software. The size of the antenna used is 71.50 mm x 98.81 mm, made of flannel layer textile with a dielectric constant 1.47 and a loss tangent 0.02 and a thickness of 1.36 mm. This is used as a substrate. Meanwhile, the copper tape was applied as a radiator layer and ground plane conductor, respectively. The simulation results of the off-body condition exhibited the excellent output, such as VSWR) value 1.09, the return loss -26.90 dB, and an impedance bandwidth 89 MHz. On the other hand, for the simulation results of the on-body condition for the center distance of 5 mm, the VSWR is 1.112, the return loss and bandwidth are -25.49 dB and 80.6 MHz, respectively. While the results of the fabrication of the off-body condition, the VSWR value is 1.14, the return loss is -25.55 dB, and an impedance bandwidth of 82.32 MHz. Moreover, for the results of the fabrication of the on-body condition for the center distance, which is 5 mm, the VSWR is 1.32, the return loss and bandwidth are -22.65 dB and 75.8 MHz, respectively. The simulation results also show that the designed antenna can work at a frequency of 2.4 GHz and is perfectly safe to use on the human body, especially on the wrist, by considering at all the values from antenna's simulation and measurement results.**

Keywords— Flexible Radiator, Wearable Antenna, ISM band, Textile material, Copper Tape, and Security Application.

I. INTRODUCTION

Nowadays, technology has developed so rapidly along with the development of science, where one of these technologies is the antenna. The development of this technology covers various aspects of life and is very influential in the human need to communicate with each other and provide information. This condition triggers the thought of various ideas to develop information technology that is beneficial to human life, one of which can be applied to the security sector. In designing a wearable antenna, the ability to transmit or transmit electromagnetic waves is one of the important things **Error! Reference source not found.**. There are several types and designs of wearable antennas, but textile antennas are one type that has more advantages in its application when used on the body. This type has dimensions that are quite small, light, and flexible, so that in its use, users will not feel disturbed. Microstrip antenna has advantages such as low profile and low cost of fabrication **Error! Reference source not found.**. Meanwhile, textiles and flexible antennas are also prone to stretching. Due to the frequently deformed conditions in wearables, the material is conductive. The main drawback of stretching wearable antennas is their low radiation efficiency when they are stretched **Error! Reference source not found.**. Its compactness and resistance to extreme environments (ruggedness) expand its use in other fields such as aerospace and satellite communications.

In a previous study, the proposed Wireless Power Transmission (WPT) system consists of an array of microstrip antennas, called a Rectifier Antenna (Rectenna), and an RF circuit that uses a solar cell as the power source of the circuit. SSL, radiation pattern, and VSWR are parameters used to evaluate the performance of the rectifier antenna in the simulation and prototype measurements **Error! Reference source not found.**. Previously, a study has been conducted that discusses the microstrips lung antenna where the research builds a typical lung antenna model that can be applied to a Wireless Metal Detector (WMD). The development of the WMD system is the most important tool for detecting metallic materials in the surrounding environment. This is very useful for security reasons for humans from attacks using sharp metal or bomb terror **Error! Reference source not found.**. Then, another research made a microstrip antenna sensor designed to detect temperature, where the antenna sensor is proposed to be embroidered on a cotton substrate and developed to operate at an ISM frequency of around 2.45 GHz **Error! Reference source not found.**. In this study, the material of the substrate which is sensitive to temperature is used to influence the resonant frequency point. In this way, solutions for heat monitoring can detect body temperature **Error! Reference source not found.**. In recent years, many studies have discussed the improvement of polymers as potential antenna materials in achieving good functional characteristics in different fields. An example is the design and manufacture of dual-band flexible antennas made from polymer magnetic dielectric media nanocomposites. A flexible antenna made by covering a Kapton substrate with a nanocomposite layer based on a magnetodielectric polymer. The magnetodielectric polymer-based nanocomposite is made of a carbon-coated cobalt (CCo) material and coated with a conjugated polymer, polyaniline (PANI) **Error! Reference source not found.**.

There are a number of patch antenna structures that have recently been researched and previously developed based on biologically inspired models, e.g. the lung antenna model **Error! Reference source not found.**. Many reference materials for antennas have used nanocomposites and textiles, so that these two materials are used for the manufacture of wearable antennas. This research focuses on discussing and conducting research on wearable antennas with flannel-type textile materials. Microstrip antenna is one of the most popular types of antennas in the general telecommunications community with patch variations. Microstrip antennas are also easy to manufacture and have a small size when compared to other types of antennas. The microstrip antenna consists of three layers of material, namely the patch element layer, substrate, and ground plane [10]. Therefore, the author focuses on discussing and making a study of wearable antennas with flannel-type textile materials. The choice of this material is as a substrate because the material is used in everyday life. This study proposes a convenient, flexible, and lightweight antenna that can be implemented to prevent crime. The antenna performance parameters include VSWR, Bandwidth, and

Return Loss which are simulated and then verified by measuring the fabricated antenna parameters.

II. Antenna Design And Fabrication

A. Antenna Design

This study uses Wireless Body Area Network (WBAN) communication consisting of On Body and Off Body Centric which is a device that will be applied to one part of the human body for communication purposes to the network above the body **Error! Reference source not found.**. To perform this calculation simulation, it is necessary to install components that expose electromagnetic radio waves with maximum limit requirements so that the body remains safe from radiation.

The antenna will be attached to the wrist and work on the ISM (Industrial, Scientific and Medical) frequency, which is another frequency that is not included in the telecommunications sector. These frequencies are included in one of the Unlicensed National Information lists, as described in TABLE I. below:

The first step in the design of this antenna is to determine the specifications, shape, dimensions, and material of the antenna. The proposed antenna design is in the form of a microstrip array with a warp shape. The material used as a substrate is a textile material in the form of flannel. Based on the purpose of using this antenna, the frequency used in the ISM band is 2.4 GHz. The Lungs shape antenna model is the newest model currently being developed. This model is constructed based on the pre-existing patch antenna types.

To obtain the dimensions of the antenna in accordance with the desired specifications, the design is carried out using the CST Studio Suite software. The basis for calculating the dimensions of the antenna is based on a circular antenna.

Several aspects need to be considered in designing antennas that can be used as part of the human body. The antenna must be unobtrusive, flexible, and operate with a minimum of degradation near the human body. Wearable antennas are also challenging in terms of fabrication. The availability of space at a particular body location, the effect of the body, and performance degradation due to structural deformation are issues that need to be considered in the design process[12]. To overcome this problem, the antenna is made of flannel cloth with a dielectric constant of 1.47 and a loss tangent of 0.02 with a thickness of 1.36 mm as a substrate and copper tape as a ground and patch. The advantage of this substrate is that it is a material that is easy to shape, resistant to heat, and breathable and easily absorbs sweat, so that when used on the human body, it has a good absorption.

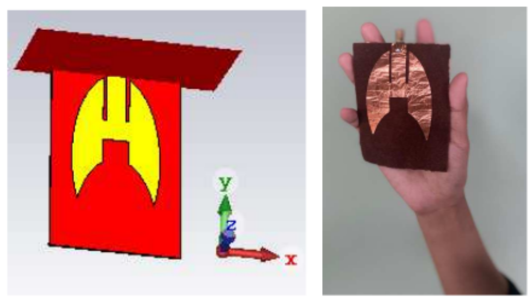
Simulations were carried out to determine the antenna performance parameters. Antenna design optimization is carried out to obtain performance parameters according to the desired criteria. After several optimization experiments, the width of the feeder greatly affects the value of the simulation results. The optimal antenna design and dimensions are shown in Fig.1 part (a). The simulation also provides both the 3D and 2D radiation patterns of the antenna when the off-body condition is unidirectional, which means that the radiation pattern it has is a beam pattern that points in one direction. This is shown in Fig.2.

B. Antenna Fabrication

Antenna fabrication was performed by attaching a patch and ground to the substrate. The SMA female port is soldered to the antenna patch and ground as shown in Fig.1 part (b).

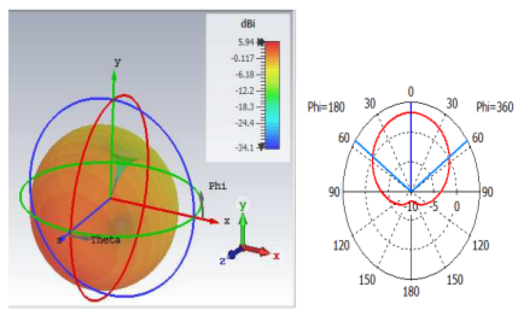
TABLE I. LIST OF UNLICENSED NATIONAL INFORMATION

Unlisenced Band	Frequency Parameters (GHz)	
	Frequency	***Total Bandwidth***
Industrial Scientific and Medical (ISM)	0.902 – 28 2,4 – 2,4835 5,725 – 5,85	0.2345
Unlicensed Personal Communication Services	1.910 – 1.930 2.390 – 2.400	0.030
Unlicensed National Information Infrastructure (UNII)	5.15 – 5.25 GHz 5.25 – 5.35 GHz 5.725 – 5.825 GHz	0.300
Milimeter Wave	59 – 64 GHz	5



(a). Optimized lungs antenna (b). Fabricated antenna

Fig. 1. Antenna design layout



(a). 3D Pattern (b). Polar Pattern

Fig. 2. Antenna Radiation Pattern

TABLE II. ANTENA DIMENSIONS

No.	Material	Antena Dimensions (mm)		
		Length	**Width**	**Thickness**
1	Copper Tape	10.24	42.9	0.035
2	Kain Flanel	98.81	71.5	0.8
3	Copper Tape	98.81	71.5	0.035

TABLE III. OFF-BODY SIMULATION VALUE AND FABRICATION

	Data Retrieval

	Simulation	Fabrikation
VSWR	1.09	1.14
Return Loss	-26.90 dB	-25.55 dB
Bandwidth	89 MHz	82.32 MHz

III. Results And Analysis

The fabricated antenna test is carried out by measuring the performance parameters of the antenna in two conditions, namely when the antenna is not attached to the wrist (off-body) and the antenna is attached to the wrist (on-body) where there are layers of bone, muscle, flesh, and skin. The purpose of this test is to determine the reliability of the antenna when working under various normal conditions.

A. Simulation Results and Off-Body Fabrication

The measurement result of the manufactured antenna which are compared with the simulation results in off-body conditions is shown in Figure 3. The VSWR values from the simulation results and the fabrication results have almost the same values, namely 1.09 and 1.14, where the VSWR value has met the desired value, namely ≤2. Furthermore, the return loss value which has a requirement of -10 dB, in this simulation the value is obtained of -26.90dB. And the bandwidth value from the simulation results is 89 MHz which indicates the value is good and has exceeded the specified requirements, which is >50MHz. The dominant measurement results have slightly smaller results when compared to the simulation results. Moreover, the fabrication results obtained a VSWR value of 1.14 which is slightly larger than the VSWR results during the simulation. Furthermore, the Return Loss value is at -25.55 dB, where the value is slightly different from the simulation, but is still in a safe range. Finally, the Bandwidth value is also slightly different from the simulation results, which is 82.32 MHz. In general, the performance parameter values in off body conditions meet the required criteria.

B. Simulation Results and On-Body Fabrication

Figure 4 shows the Value of VSWR in On-Body Conditions. The simulation results for the VSWR value are better than the fabrication results. The fabrication value tends to have a higher value, one of the reasons is because the antenna made is homemade, so there are some mistakes during the antenna manufacturing process. The VSWR simulation results show that when on-body conditions without any distance or air gap show a VSWR result of 1.16, which is the optimal VSWR value. As for the results of the fabrication of the VSWR value, when the on-body condition shows a VSWR value that is in accordance with the distance between the antenna and the wrist, when the antenna distance approaches the wrist, the VSWR value will increase. Meanwhile, when the antenna distance is away from the wrist, the VSWR value is getting better.

Same as the final VSWR value, Fig.4 is a graph that also shows that the value for the return loss fabricated results tends to be slightly worse than the simulation results. But the values obtained, both simulation and fabrication results, have met the required parameters. The simulation results show that the Return loss simulation value has good results and is in accordance with the required parameter values, where Return loss (S11) must have a value of ≤-10 dB, while the largest on body simulation results are -21.69 dB. That means, the results obtained by this antenna are still safe to be brought closer to the human body. Then the fabrication results show that the return loss fabrication value has quite good results. Although the results of the fabricated return loss value this time are still below the simulation results, they are still in accordance with the required parameter values, where Return loss (S11) must have a value of ≤-10 dB, while the minimum on body simulation results are -18.95 dB, meaning The results obtained by this antenna are still safe to be brought closer to the human body.

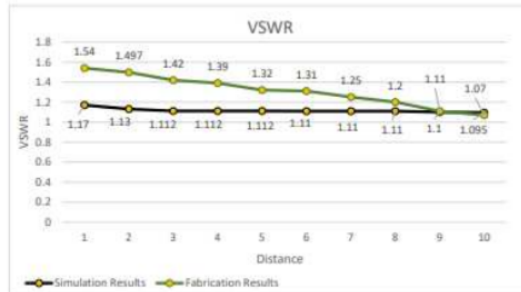


Fig. 3. Value of VSWR in On-Body Conditions

Fig. 4. Value of Return Loss in On-Body Conditions

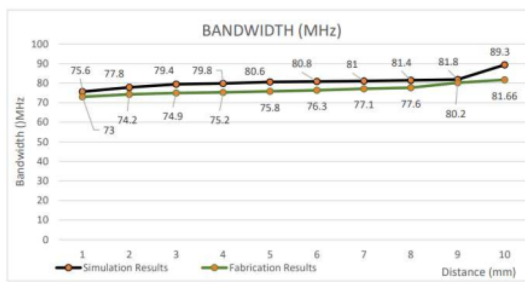
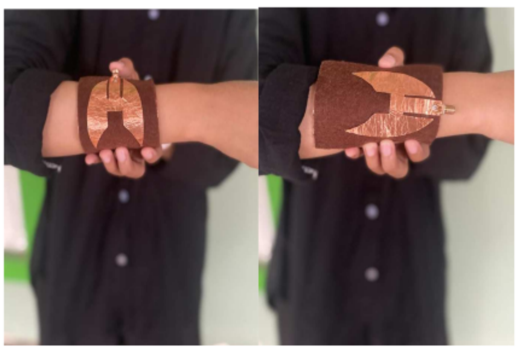


Fig. 5. Bandwidth Value on On-Body Condition

Figure 5 shows the bandwidth value of the simulation results and the results of the fabrication at the on-body state. The test is carried out for 10 data samples, where the minimum result is 75.6 MHz for simulation results and 73 MHz for fabrication results. The value obtained has met the bandwidth criteria, namely the optimal value of the antenna for the application of ISM is >50 MHz. Furthermore, the maximum results obtained are 81.66 MHz for simulation results and 89.3 MHz for fabrication results. There is a slight difference in the results obtained, but the values obtained are in accordance with the optimal results of bandwidth. Therefore, this antenna is safe to use on the human wrist, both with and without air gaps in the antenna.

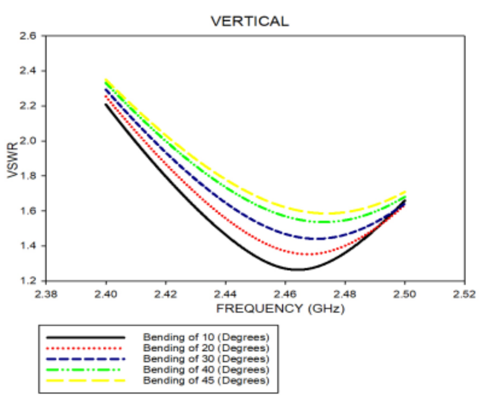
C. *Antenna Flexibility Test*

To prove the flexibility of the antenna, it is necessary to test the flexibility of the antenna by comparing the values of several parameters. The sample used for testing is the forearm with a diameter of 6 cm, with antenna bending at 10°,20°,30°,40°, and 45°. When the antenna is bent, there are 2 bending conditions, namely when the vertical and horizontal conditions as shown in Figure 6. The measurement procedure is the same as the measurement of VSWR and Return Loss. The only difference is that the antenna is bent according to each degree of bending. Figure 7 shows a graph of the results of VSWR and Return Loss with vertical antenna testing. It can be seen the greater the bending, the higher the VSWR and return loss values, even approaching the optimal results. Figure 8 shows the results of VSWR and Return Loss on horizontal antenna testing, where the results obtained are 5 bending experiments, the amount of which bends greatly affects the VSWR and Return Loss values obtained. After observing the results of vertical and horizontal antenna testing, the test value in the vertical state is greater than the horizontal test. One of the effects is that in the vertical state, the patch antenna follows the bend of the arm, in contrast to the horizontal condition, where the bend occurs only in the antenna substrate, and the patch follows the straight arm.

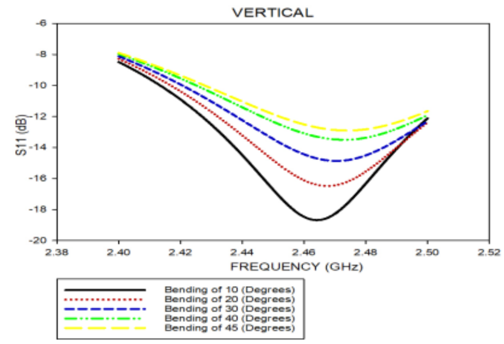


(a). Vertical Test (b). Horizontal Test

Fig. 6. Antenna Usage Display

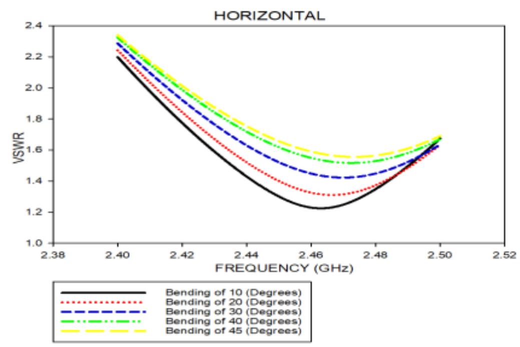


(a). VSWR

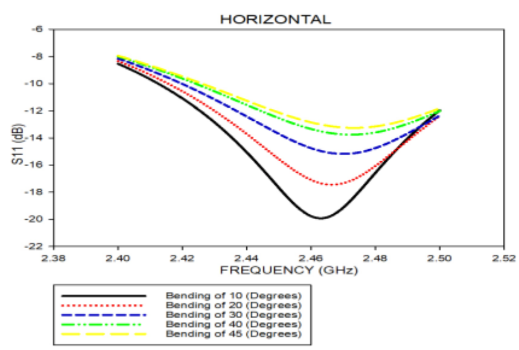


(b). Return Loss

Fig. 7. Vertical Flexibility Test Graph



(a). VSWR



(b). Return Loss

Fig. 8. Horizontal Flexibility Test Graph

IV. Conclusion

The flexible lung-shaped radiator structure printed on a flannel textile material has been successfully fabricated. It is suitable to operate at the 2.4-2.5 GHz ISM band frequency. Flexibility and comfortability of the antenna can be obtained by using a soft flannel substrate. The results of measuring antenna performance parameters in two different conditions, i.e. off-body and on-body respectively, exhibited the great values that meet the criteria of security application. The

VSWR value in the off-body condition is 1.09 with a return loss value of -26.90 dB. While in the on-body condition, the antenna uses a wrist layer with a VSWR value of 1.54, Return loss of -18.95 dB, and a bandwidth of 73 MHz. For the flexibility test, it is found that the value of VSWR and Return Loss when the vertical state is greater or close to the optimal value, when compared to the horizontal state. This is due to the greater bending of the patch antenna when it is vertical. This research can be investigated for further development, such as the use of other fabric substrates such as materials that have thinner material than flannel, as well as additional testing on other body parts.

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