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Wearable Antenna on Nylon Fabric Based on Aluminium Foil Tape at GPS L1 Frequency

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Abstract

GPS L1 is a satellite system that serves to determine location, navigation, and time. It operates at 1.5 GHz frequency. In GPS L1, a minimum of three satellites are needed for accurate positioning of objects. During positioning, the GPS discards considerable electromagnetic waves. Actually, these electromagnetic waves can be converted into electrical energy using energy harvester so that the energy produced by the GPS L1 satellite can be used as a source of renewable energy.

Therefore, an antenna that function as an energy harvester is needed to capture the electromagnetic energy produced by GPS L1 satellites, convert that energy into an electric current, and then store it into a rechargeable battery or as a power supply to a device. It aims to utilize the available electromagnetic energy and facilitate the use of devices or modules whose power supply can be automatically recharged if the electromagnetic energy emitted by the GPS L1 satellite is obtained.

In this paper presents a microstrip antenna that uses patches made from aluminum foil tape and nylon fabric as substrate. The purposed antenna simulation results have a good agreement with the measurement results. Furthermore, in free space and on body conditions, antenna can be operated properly, even though it has a small gain value.

Keywords; *wearable antenna, GPS L1, nylon substrate, aluminum foil tape*

I. INTRODUCTION

Wearable antenna is a type of antenna specifically designed to be integrated in clothing and equipment used in every day. Until now, research of wearable antenna still being discussed. In some paper, there are those who use wearable antenna in remote health monitoring system [1] and for military purposes [2]. Based on the type of substrate used, there are those that use fabric, rubber, flexible plastic, solid foam, and paper as the substrate of wearable antenna. Whereas in patch there are gold, nickel, titanium, copper, and aluminum. In this paper, used nylon fabric as substrate and aluminum foil tape as patch and ground plane. Wearable antenna designed to operate on the GPS L1 frequency, which is 1,575.42 MHz [3]. The things discussed in this paper include the results of simulations and measurements on normal condition and on-body condition, as well as the SAR value obtained and characteristic changes when the antenna is bent.

II. DESIGN AND SIMULATION

A. Design of Wearable Antenna

Wearable antenna was design at GPS L1 frequency. This antenna using nylon fabric as a substrate with dielectric permittivity $\boldsymbol{\varepsilon_r}$ = 3.6 [2], tangent loss = 0.04 [4], and height h= 0.1 mm. In this paper, antenna using five-layer fabric, so the thickness of substrate used is 0.465 mm. For patch of antenna using aluminum foil tape with thickness t = 0.033

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mm. Aluminium foil tape is chosen as the investigated material as it easy to be obtained and has a low cost. The antenna design uses rectangular patches and full ground plane, and is designed using CST Studio Suite 2018 software. The results of this design have been optimized to achieve the desired characteristic values. Figure 1 shows a designed of purpose antenna and Table 1 details the dimensions of antenna.

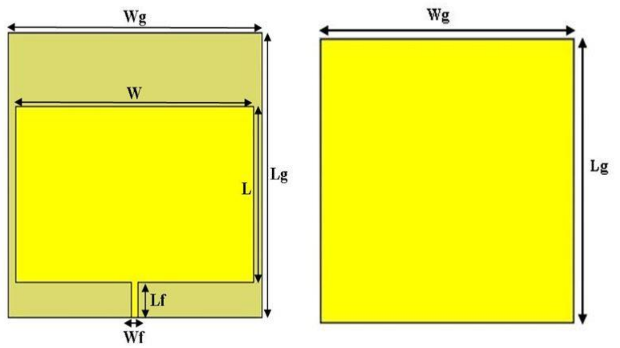

Fig 1.Wearable Antenna Design.

TABLE1 ANTENNA PARAMETER

Antenna Parameter	Symbol	Value (mm)
Patch length	Lp	49.216
Patch width	Wp	75
Ground plane length	Lg	80
Ground plane width	Wg	80
Feed length	Lf	10
Feed width	Wf	2
Nylon fabric thickness	h	0.465
Aluminum foil tape thickness	t	0.033

B. Result of Simulation on Free Space Condition

Based on the results of the optimization, the antenna specifications have been reached. This is stated in Figure 2 which VSWR 1,134, with a bandwidth of 53.6 MHz. In addition, in Figure 3 it is also shown that the gain is 1.258 dBi with a unidirectional pattern. Through the results, the antenna can be fabricated.

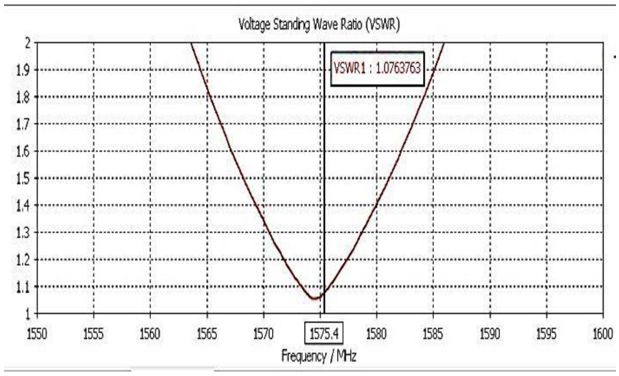

Fig 2 VSWR Graph Simulation Result

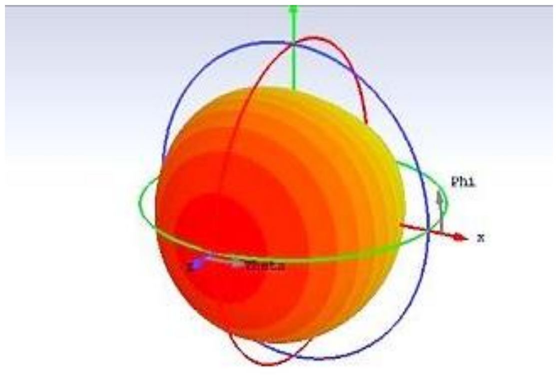

Fig 3 Radiation Pattern Simulation Result

C. Result of Simulation on Body Condition

The addition of phantom added to the results of the optimized antenna simulation aims to determine the SAR value of the antenna. The SAR value must be known to obtain a safe distance when the antenna is placed close to the human body part. If the SAR value meets the required specifications, the antenna can be fabricated and measurements can be made on on-body conditions.

The phantom layer of the arm consists of skin, fat, muscle, and bone. Based on [5], the simulation used the skin thickness is 2mm, fat thickness is 2 mm ,muscle thickness is 20 mm , and bone radius is 7 mm The simulation uses a gap of 0 mm, 1 mm, 5 mm, 10 mm and 20 mm.

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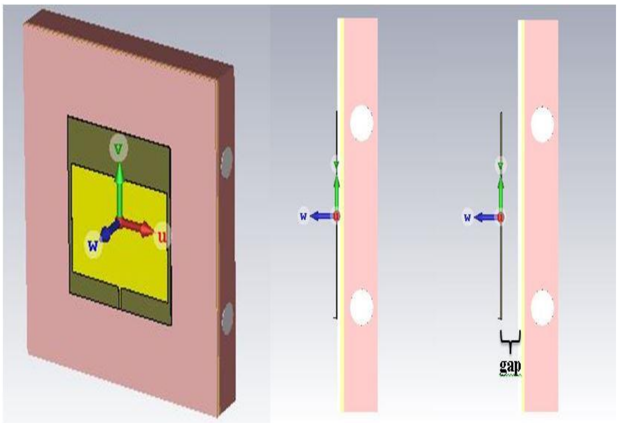

Fig 4 Antenna Simulation with Phantom

Table II shows the decreasing characteristic of the antenna compared to the antenna simulation results in free space conditions. The decrease in antenna characteristic values is caused by disruption of the near field when the antenna is close to the body. It is show that the wider the gap between the antenna and the body, the higher the characteristic value of the antenna. Based on the simulation, the SAR value is below 1.6 W / kg so that the antenna is safe to use if placed directly on the body.

TABLE II SIMULATION RESULT USING PHANTOM

Gap (mm)	Return Loss (dB)	VSWR	Gain (dBi)	SAR (W/kg)
0	-18.047	1.286	-0.388	0.455
1	-18.69	1.262	-0.186	0.297
5	-20.39	1.211	0.193	0.182
10	-22.99	1.152	0.814	0.251
20	-25.45	1.112	2.005	0.149

III. FABRICATION AND MEASUREMENT

In this section, the results of the measurement of wearable antenna that has been fabricated will be discussed. Wearable antennas are manually fabricated. Installation of connectors is not soldered, but uses hot glue because aluminum foil tape cannot be soldered. The purpose of the antenna measurement is to be able to know and compare the parameter values of the simulation results and measurement results. The measured antenna parameter is a near field consisting of return loss, VSWR, bandwidth and the far field consisting of gain and radiation patterns. In Figure 5, the results of manual fabrication are shown:

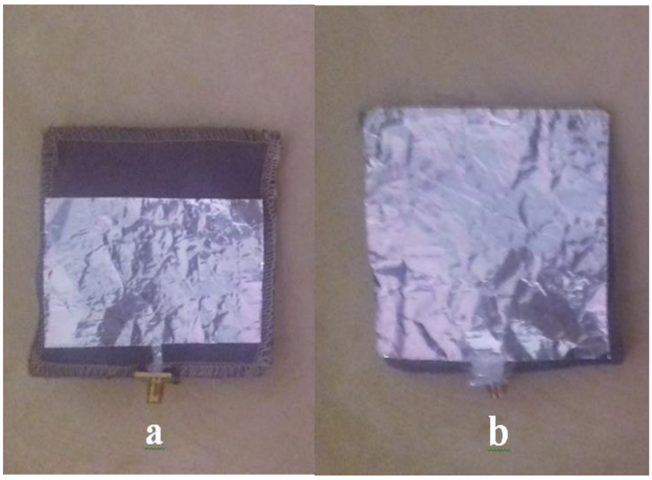

Fig 5 Fabrication Result

A. Measurement On Free Space Condition

Figure 6 presents that when an antenna is measured in the condition of free space, the antenna can operate well at a frequency of 1.575 GHz. This is evidenced by the measurement results that have met the specified characteristics. Based on the measurement, the return loss value is of about -25,906 dB with VSWR is of about 1,111, while the simulation results obtained have a return loss value is of about -28,686 dB with VSWR is of about 1,076. The difference in simulation and measurement results is caused by manual antenna fabrication. In addition, connectors that cannot be installed firmly on the antenna cause a mismatch so that some of the transmit power is reflected. This causes an increase in return loss and VSWR value. The percentage of bandwidth obtained based on the measurement results is 3.79% and has a greater value than the simulation which has a bandwidth percentage of 1.33%.

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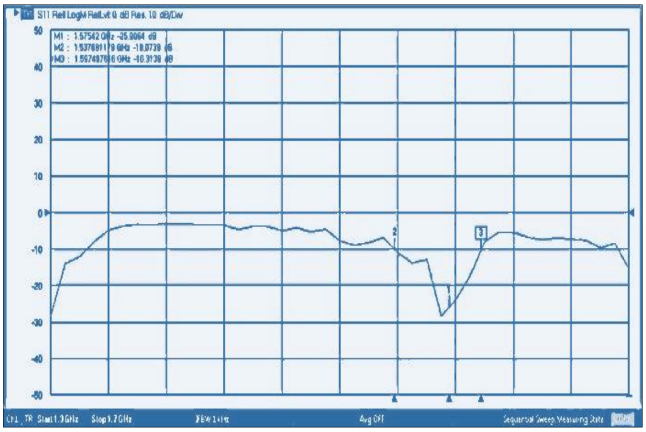

Fig. 6 Near Field Measurement Result On Free Space Condition

Figure 7 and Figure 8 shows the shape of a radiation pattern similar to the highest power level at the angle 0° or in the position facing the reference antenna. While the lowest power is located at an angle of 180°, which is right when backing the reference antenna. The highest value obtained is of about -33.5 dBm and the lowest power is of about -53.4 dBm. In both figures, it appears that main lobes tend to lead in one direction only. Based on this, it can be determined that the antenna radiation pattern is unidirectional. Through the results of measurements of radiation patterns obtained, the antenna characteristics are as expected.

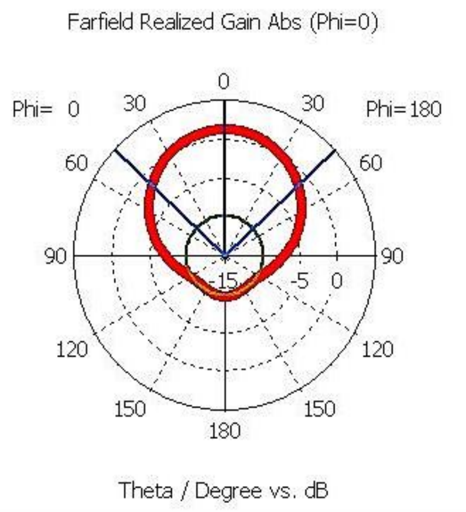

Fig. 7 Radiation Pattern on Simulation

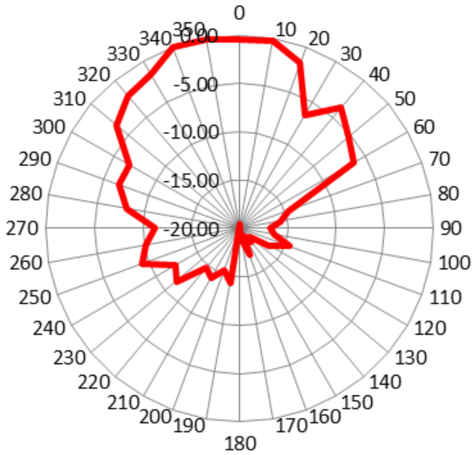

Fig. 8 Radiation Pattern on Measurement

In Table III lists the results of the measurement of gain in the condition of free space and obtained a gain is about of 1.074 dBi. The measurement results have decreased in value from the simulation. This is due to the incompatibility of the antenna dimensions at the time of fabrication. In addition, the factor of the connector that is not too tightly connected to the antenna can affect the power received by the antenna.

TABLEIII GAIN MEASUREMENT ON FREE SPACE CONDITION

Measurement	Power Level (-dBm)
1	33.47
2	32.23
3	33.44
4	32.41
5	33.03
Average	32.858
Gain (dBi)	1.074

Based on the results of simulations and measurements, obtained a relatively small gain value. The relationship between permittivity and gain values indicates that the greater the permittivity value of a substrate material, the smaller the gain value produced [6]. Another thing that causes a low gain value is due to the thin substrate thickness. This is because the increase in substrate thickness directly proportional to the increase in gain [6] [7].

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B. Measurement On Body Condition

In this section, the results of measuring the antenna when placed on the arm without a gap will be explained. In Figure 9 shows how to measure the near field characteristic to the on-body condition.

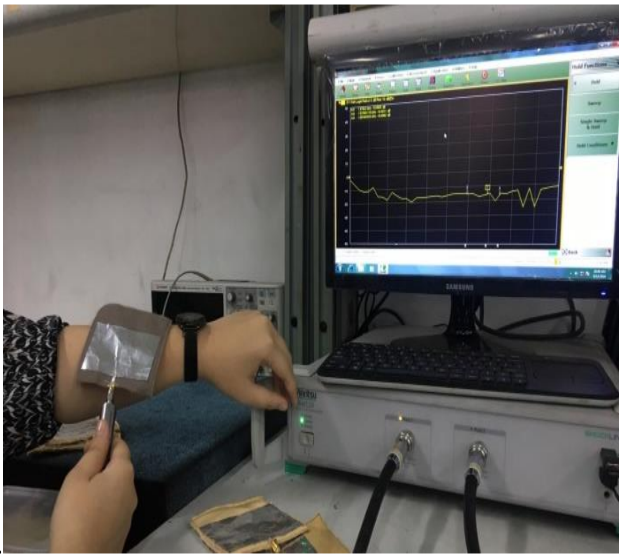

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Fig 9 Near Field Measurement On Body Condition

Figure 10 reports the measurement results when the antenna is placed directly on the surface of the arm without a gap. Through these measurements, the antenna can operate at a frequency of 1.575 GHz with a return loss value is about of -15,565 dB and VSWR is about of 1,401. The percentage of bandwidth generated when the on-body condition is of about 3.8%. If the measurement results are compared with the measurement results during normal conditions, it can be seen that there is an increase in the value of return loss and VSWR. This can occur as an effect because of the amount of power absorbed by the body so that the efficiency of the antenna decreases. Placing the antenna on the arm also changes the field distribution near the antenna, which affects the antenna input impedance. The unstable input impedance causes mismatch on the transmission line so that it will affect the increasing VSWR value.

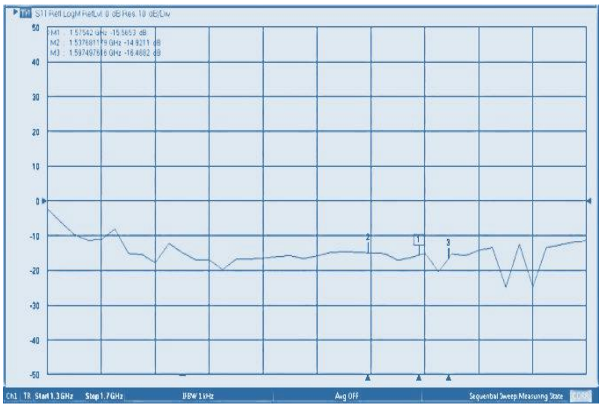

Fig 10 Near Field Measurement Result On Body Condition

When the results of on-body measurements are compared with the results of simulations using phantom, it can be seen that there is an increase in the value of return loss and VSWR. This is caused by several factors, such as making an antenna that is less precise, antenna connectors that cannot be installed firmly causing mismatch and differences in body surface conditions during simulation and measurement. The difference in the conditions in question is that when the simulation uses phantom. Phantom has a flat surface different from when measuring using an arm that has an uneven and curved surface. In Figure 11 shows how to measure gain in on body conditions. In this measurement, the distance between the antenna tested and the reference antenna is 1 m and the send power is set at 0 dBm in the signal generator.

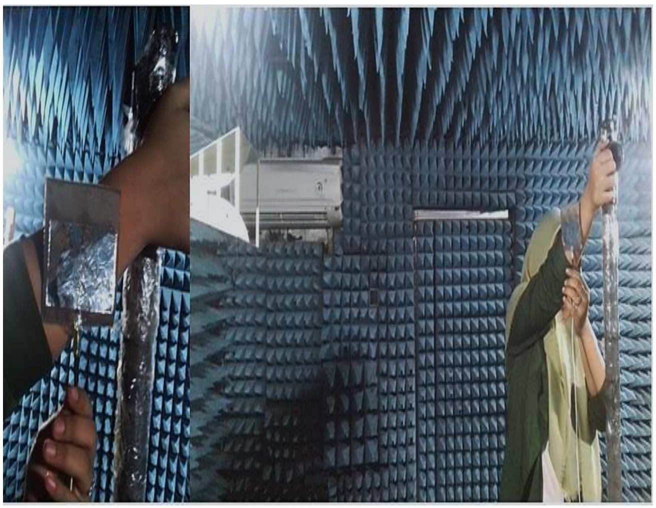

Fig 11 Gain Measurement On Body Condition

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The results of the gain measurements on body condition obtained is of about 0.344 dBi. The measurement results decrease compared to the value of gain in free space conditions. The thing that causes a decrease in the gain value is the same as the decrease in the VSWR value on the on body condition

TABLE IV.GAIN MEASUREMENT ON BODY CONDITION

Measurement	Power Level (-dBm)
1	33.51
2	34,34
3	34.01
4	33.23
5	33.14
Average	33.646
Gain (dBi)	0.344

IV. FLEXIBILITY

Wearable antennas have flexible properties, so they can be bent. To prove antenna flexibility, in this paper measured near field and far field antenna when attached to a tube made of thick cardboard with a diameter of 5 cm, 7 cm and 9 cm. Selection of tube size based on human arm size [3]. Figure 12 show the measurement mechanism when near field and far field.

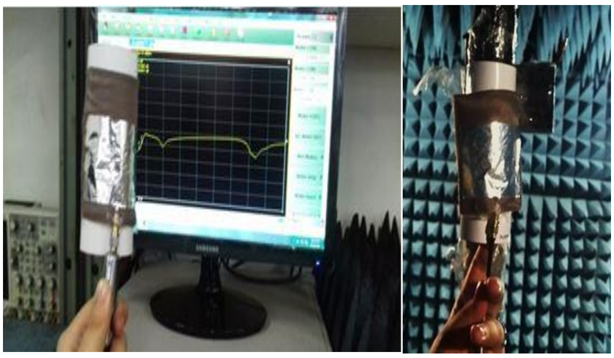

Fig 12 Flexibility Measurement

Through the results above, it is shown that there is a decrease in the antenna characteristic values at the time of bending. This is because the patch form and antenna feed are reduced because they have to adjust to the shape of the tube, so that the matching impedance of the antenna decreases and causes the VSWR value and return loss to rise. Increasing the increasing VSWR value also states that the reflected power is greater so that it affects the power received by the antenna. There is a wide narrowing of the patch which in fact has a function as a transmitter and receiver of electromagnetic waves causing a loss of some of the power received by the antenna. This is a reason that can explain the decreasing gain value. However, the antenna can still emit power even though the nylon and cotton substrate antennas have relatively small gain values.

TABLE V FLEXIBILITY MEASUREMENT

Parameter	Diameter		
	5 cm	7 cm	9 cm
Return Loss	-13.37	-13.25	-14.34
VSWR	1.568	1.556	1.483
Gain	0.22	0.68	1.06

V. CONCLUSION

Antenna with nylon substrate is able to operate on the GPS L1 frequency in free space or on body conditions. However, the resulting gain tends to be small because of the thin substrate thickness and high permittivity value. In addition, the condition of the on-body characteristic value decreases when compared to the condition of free space. This is due to the mismatch in the transmission line. However, the antenna is still capable of operating properly even though it has a small gain.

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