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Development of Large Aperture Microstrip Antenna for Radio Wave Energy Harvesting

Intan Savitri[1], Radial Anwar[1, *], Yahya S. Amrullah[2], and Dwi A. Nurmantris[1]

Abstract—Radio wave energy harvesting has become one of the most fascinating fields of research, especially in developing antenna for its front end subsystem. This paper presents the development of a single large aperture antenna for energy harvesting system. Three substrate layers FR4-air-FR4 are employed to increase the antenna gain. Measurement result shows that the proposed antenna is able to obtain gain of about 9.61 dBi at 1.575 GHz (GPS L1 frequency), with low return loss of about −17.12 dB. The achieved bandwidth is about 128 MHz. The antenna characteristic is suitable for energy harvesting application.

1. INTRODUCTION

Radio wave energy has been considered as one of the alternative sources to fulfill the increasing demand of energy. The development of instrumentation to capture the radio wave and convert it into usable energy has become one of the fascinating fields of research. Antenna is one of the most explored in this instrumentation development, as it plays an important role in capturing the electromagnetic wave and converts it into electrical wave. Some antenna designs have been proposed to be employed in energy harvesting systems, including antenna geometry modification [1–6], dual-band and multi-band antennas [7–11] and the utilization of array antenna system [12].

In this paper, a new antenna design is proposed to be used as the front-end section of an energy harvesting system. The antenna is designed to collect the RF energy from GPS L1 at 1.575 GHz. Single large aperture concept and three substrate layers consisting of air between FR4 are utilized to obtain high gain. Measurement result shows that the proposed antenna indeed inherits high gain, up to 9.61 dBi, which might alsobe used to monitor solar activity [13, 14], or even to collect solar RF energy.

2. ANTENNA ARCHITECTURE

The proposed antenna utilizes a circular shape patch to increase the bandwidth and full ground plane, so the minor lobes on the antenna radiation pattern can be minimized. Air gap technique [15, 16] is adopted to obtain relatively high gain. The gain is improved further by increasing the physical aperture of the antenna larger compared to the conventional microstrip antennas operating at the same frequency [17–20].

Figure 1 shows the front view of the proposed antenna design. Length of the substrate is 205 mm, and the width is 275 mm. Radius of the circular patch is 40.8 mm, and it is placed at a distance of 72 mm from the feeding point. The patch is exited through a microstrip line with width of 6.8 mm. The side view of the proposed design is depicted in Figure 2. The thickness of the cooper patch is 0.035 mm, which is the same as the ground plane. The FR4 thickness is 1.6 mm, and the air gap distance is 13 mm, from which the highest achievable gain is provided. Summary of the proposed antenna geometry parameters is listed in Table 1.

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* Corresponding author: Radial Anwar (radialanwar@tass.telkomuniversity.ac.id).
[1] School of Applied Science, Telkom University, Bandung, Indonesia. [2] Research Center for Electronics and Telecommunication Indonesia Institute of Sciences, Bandung, Indonesia.

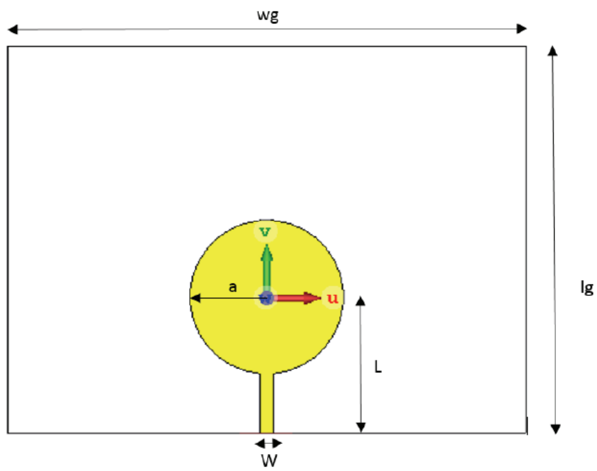


Figure 1. Front-view of the proposed antenna.

Figure 2. Side-view of the proposed design.

Table 1. Summary of the antenna parameters.

Parameters	Values (mm)
Length of the substrate (lg)	205 (1.07625λ)
Width of the substrate (wg)	275 (1.44375λ)
Patch radius (a)	40.8 (0.2142λ)
Distance from feed to center of the patch (L)	72 (0.378λ)
Width of microstrip line (W)	6.8 (0.0357λ)
Thickness of cooper	0.035 (0.00018375λ)
Thickness of FR4	1.6 (0.0084λ)

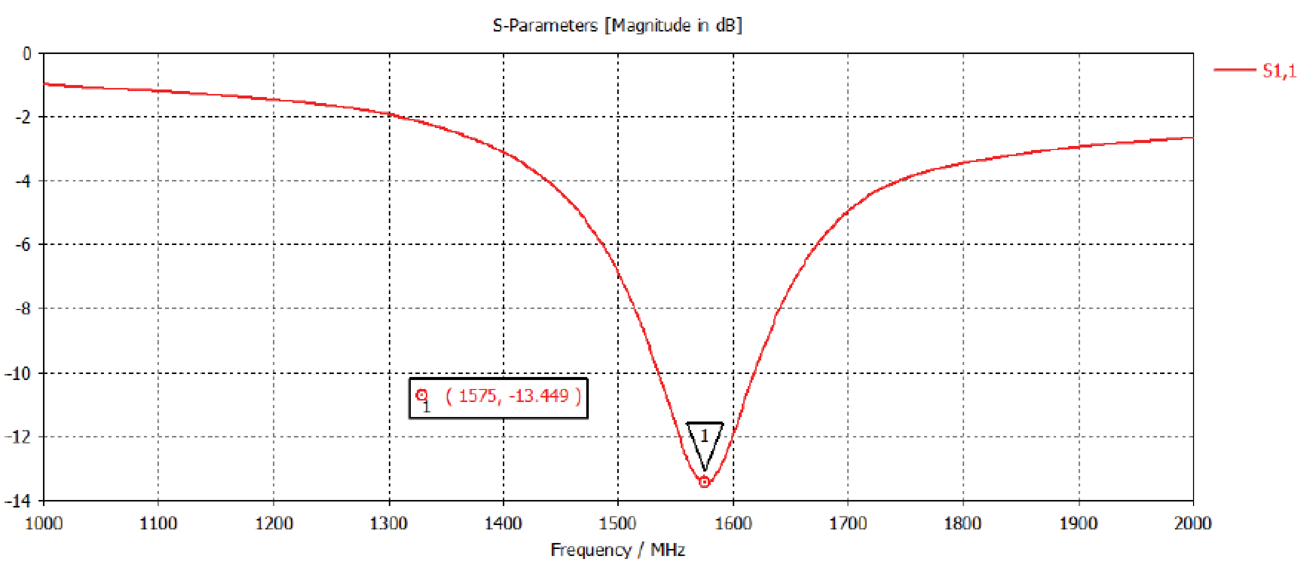


Figure 3. Return loss of the proposed design.

3. RESULT AND DISCUSSION

Simulated return loss of the proposed antenna is shown in Figure 3, while its gain is depicted in Figure 4. Return loss less than −10 dB has been obtained at 1.526 GHz–1.626 GHz, with peak about −13.449 dB at 1.575 GHz. At this frequency, the achieved gain is about 9.002 dB. Table 2 lists the variation of air gap on the antenna gain. It can be seen that the 13 mm gap provides the highest gain of the proposed antenna. This gap also provides the widest bandwidth, about 100 MHz.

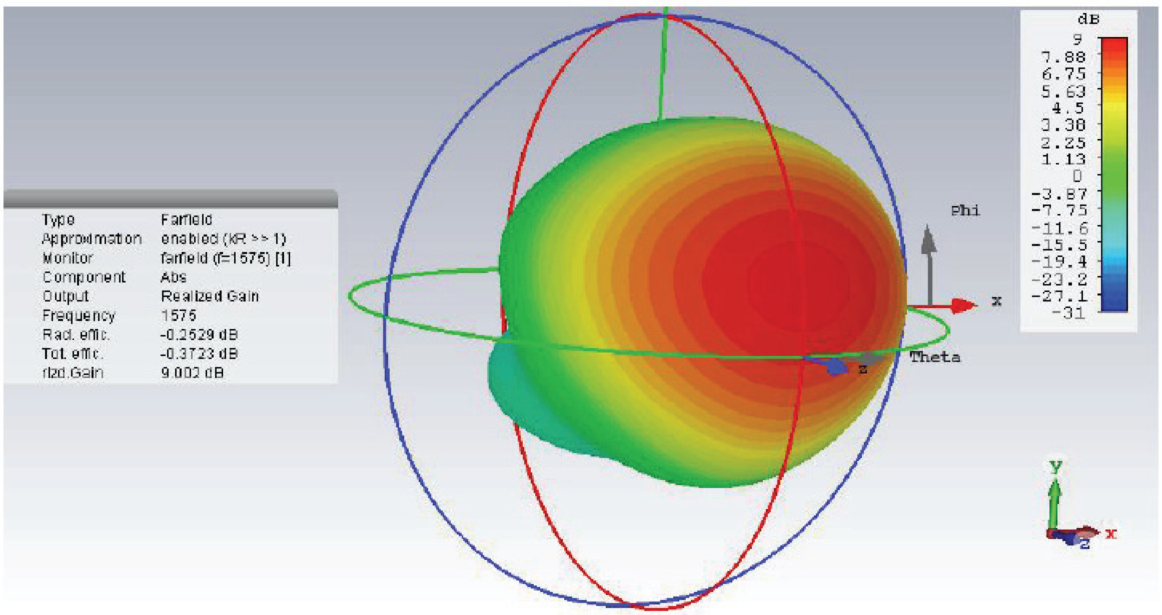


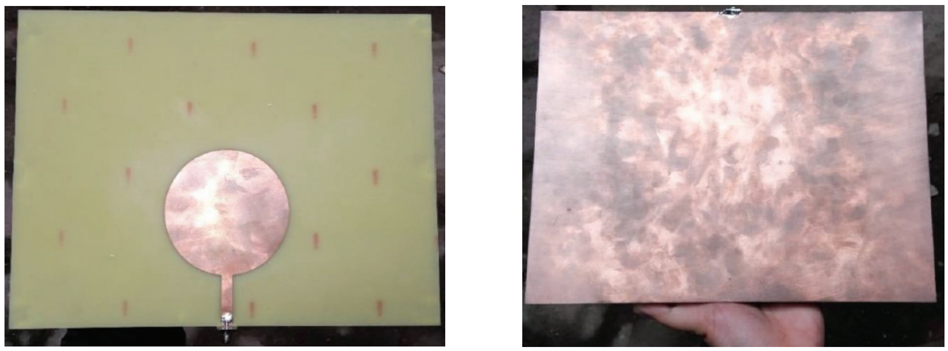
Figure 4. Gain of the proposed design.

Table 2. Effects of the air gap variation.

Air gap (mm)	Return loss (dB)	Bandwidth (MHz)	Gain (dBi)
7	−28.27	89	8.540
8	−21	92	8.702
9	−19	97	8.816
10	−16	89	8.901
11	−15	99	8.954
12	−14	95	8.979
13	−13	100	9.002
14	−12	95	8,989
15	−10	95	8,981

As the air gap is varied, the bandwidth and gain do not show significant changes. However, the return loss is increased as the air gap increases. This effect is similar to that when the parts of a dipole antenna are separated relatively far. Separating these two parts will change the capacitance of the antenna and hence change its impedance. As the impedance value moves away from 50 ohms, the mismatch becomes greater,and return loss is increased. This may also be the reason for what happens in the proposed antenna. As it consists of two parts separated by air, the mismatch is also increased as the gap is widened.

The proposed design has been fabricated and measured. Figure 5 shows the front and back views of the antenna, with the side view shown in Figure 6. The two parts of the proposed antenna are combined by using plastic screws and nuts, measured at gap length exactly of 13 mm. Since there is no available connector with suitable size, a sma connector with large ground section is used and modified.



(a) (b)

Figure 5. (a) Front-view of the constructed antenna. (b) Back-view.

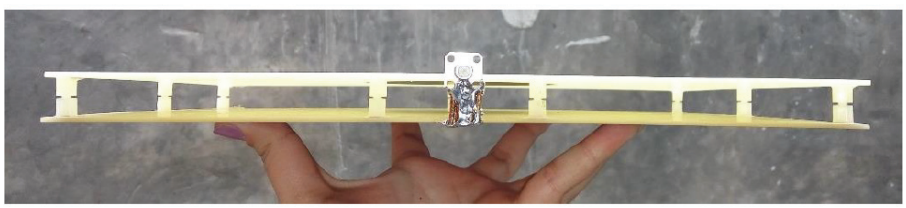


Figure 6. Side-view of the proposed antenna.

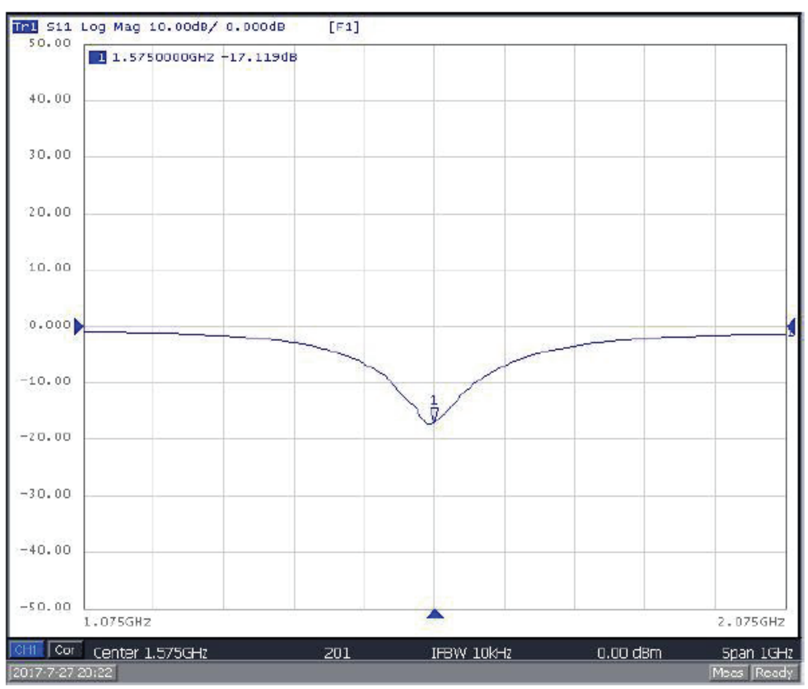


Figure 7. Measured return loss of the proposed antenna.

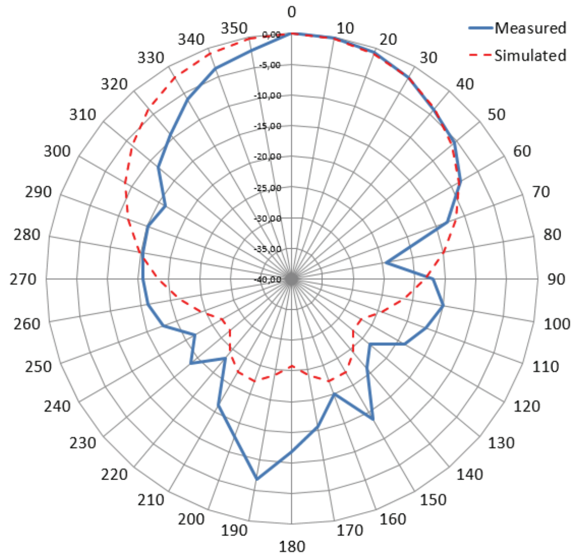


Figure 8. Radiation pattern of the proposed antenna (Azimuth).

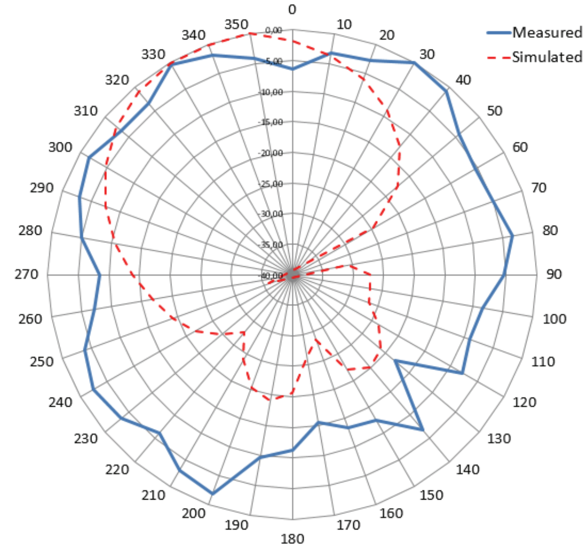


Figure 9. Radiation pattern of the proposed antenna (Elevation).

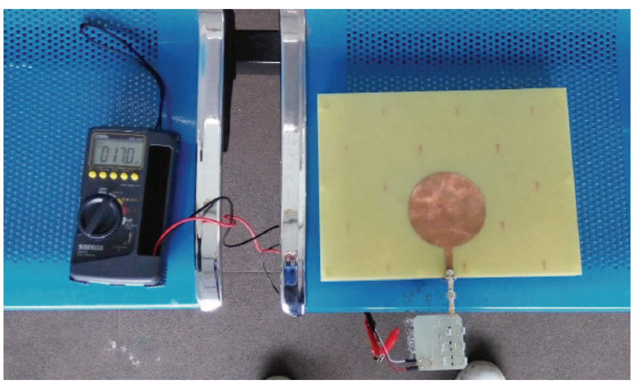


Figure 10. Measurement test using 3-stage rectifier.

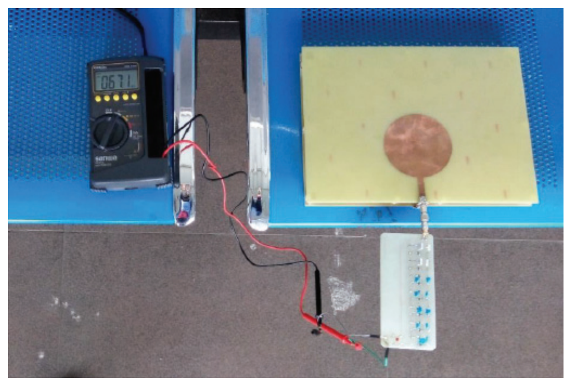


Figure 11. Measurement test using 7-stage rectifier.

A few cooper wires are soldered together to create a plate which is soldered to the ground section of the sma connector. This method is successful in solving the connector problem, as shown in measurement results.

The fabricated antenna has been measured in terms of return loss, bandwidth, radiation patterns and gain. Snapshot of return loss measurement result is depicted in Figure 7. The obtained return loss is −17.119 dB at 1.575 GHz, with bandwidth about 128 MHz (8.1%), which are better than simulation results.

Azimuth and elevation pattern of the proposed design have been measured, as shown in Figures 8 and 9, respectively. Based on simulation, it inherits unidirectional pattern with a few small back lobes. The coverage is about $57° \times 60°$. Measurement result shows broader patterns with stronger minor lobes, probably due to the non-ideal condition of the measurement environment. The maximum measured gain is about 9.61 dB, which is also better than simulated result.

The proposed antenna has been tested with a 3-stage rectifier and a 7-stage rectifier, as shown in Figures 10 and 11, respectively. The tests were conducted outside the Wireless Telecommunication Laboratory, Telkom University. Since the post for this antenna was not yet available, the antenna was laid on a chair, and the received voltages were measured. Table 3 lists the samples of the measured voltages obtained with both rectifiers.

Table 3. Samples of measured voltage.

Sample	Output (mV)	
	3-stage rectifier	7-stage rectifier
1	16,8	43,3
2	14,0	61,7
3	17,6	67,1
4	18,3	60,1
5	20	57,1
6	16,4	56,8
7	18,1	72
8	17,0	62,5
9	17,3	64,1
10	19,5	63,9
Average	17,5	60,86

4. CONCLUSION

Design and development of a large aperture microstrip antenna with three substrate layers is presented in this paper. The result shows that it can work properly with low return loss and relatively high gain. The expected characteristics are obtained, and hence the proposed antenna is suitable to be used as the front-end section of an energy harvesting system.

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