Rectenna Design of GSM Frequency Band 900 MHz for Electromagnetic Energy Harvesting

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***Abstract*—**Rectenna can be used as electromagnetic energy harvesting. The principle of this electromagnetic energy harvesting can be applied at 900 MHz GSM frequency band. To create a rectenna that can work on 900 MHz frequency band, it is necessary to design a rectifier circuit that can work at that frequency band and to use a 900 MHz GSM antenna.

***Index Terms*—**Rectenna, energy harvesting, GSM

I. Introduction

Electromagnetic waves is not fully utilized by GSM Mobile Station devices so there is widespread dispersion of electromagnetic waves. These excess electromagnetic waves can be used as energy sources. To utilize electromagnetic waves as energy sources, electromagnetic energy harvesting technique, which consists of capturing, converting, and collecting electromagnetic waves, can be used.

Rectifier antenna (rectenna) can be used for energy harvesting. It is a combination of rectifier and antenna. The antenna is used to receive electromagnetic waves while the rectifier is used to convert the received energy into DC voltage. [1]

II. Literature

A. Rectenna

Rectenna is a technology that utilizes electro-magnetic waves to be converted into electrical energy. Rectenna consists of a rectifier and an antenna, where the rectifier serves to convert electromagnetic waves captured by the antenna into direct current (DC), while the antenna serves as the captor of the electromagnetic wave [2]. Generally, rectenna design consecutively consists of antenna, impedance matching circuit, rectifier, and filter, followed by load [3].

B. Rectifier

Rectifier is a device that serves to convert an alternating voltage source signal (AC) into a signal DC voltage source (DC). The used rectifier is a full wave rectifier with four diodes.

C. Antenna

Antenna is defined by Webster's dictionary as "a metallic device for radiating or receiving radio waves". Meanwhile, according to IEEE, the antenna is defined as "a means for radiating or receiving radio waves".

In this paper, antenna is defined as a device that processes the transfer of signals into electromagnetic waves through free space and can be received by other antennas and vice versa. Transmission line of antenna can be either a coaxial or waveguide that is used to transport electromagnetic energy from a transmitting source to an antenna, or from an antenna to a receiver [4]. Usually, the transmitting source and the receiver are other antennas.

D. Capacitor

Capacitors are passive electronic components that are capable of storing electrical energy in an electric field. This can be done because there is an internal imbalance of the electrical charge. Capacitors are often used as a medium for storing electricity, filtering, tuning, and connecting signals from one circuit to another.

Capacitors have several different types. They are fixed capacitors, variable capacitors and electrolyte capacitors [5].

III. Methodology

The study conducted in this research is about designing rectenna as electromagnetic energy harvester at GSM frequency of 900 MHz [6].

As the rectenna needs to operate on GSM frequency band of 900 MHz, the four diodes in the rectifier are germanium glass diode type 1N4148 while the antenna is GSM antenna [7]. Schematic of rectifier circuit can be seen in Fig. 1.

The four germanium glass diodes type 1N4148 in the rectifier circuit are arranged as shown in Fig. 1. In the input section, a female SMA port is installed to connect the antenna with this rectifier circuit [8]. The two pin headers are installed to function as the output. They are installed in parallel with the capacitor to obtain the output

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voltage value of rectenna as a result of electromagnetic energy harvesting. The rectifier design can be seen in Fig. 2.

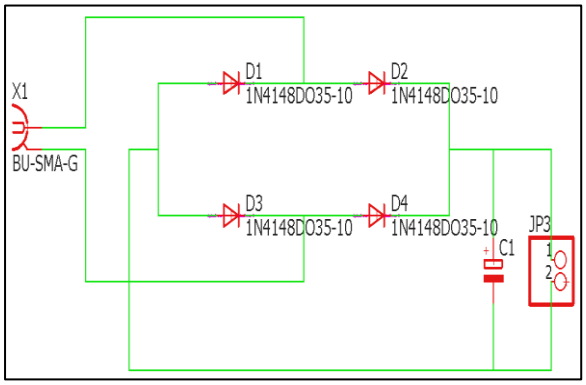

Fig. 1. Rectifier schematic.

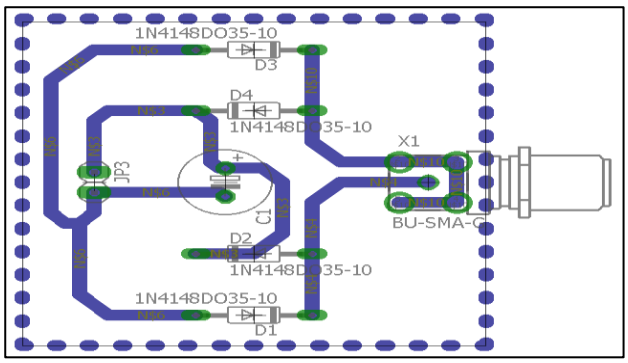

Fig. 2. Rectifier design.

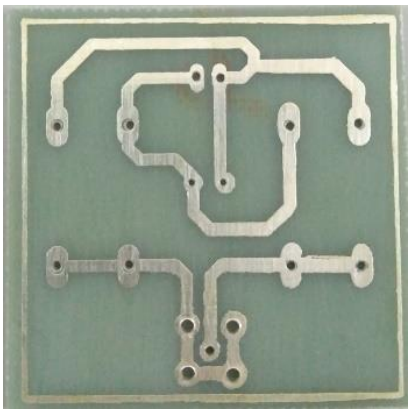

Fig. 3. PCB fabrication

Fig. 4. Rectifier circuit fabrication.

After the process of designing the rectifier design, the next process is the fabrication of rectifier circuit. Fig. 3 shows a PCB fabrication for the rectifier circuit and Fig. 4 shows the rectifier circuit fabrication result, whose components are installed in accordance with the required specifications and positions on the fabricated PCB [9].

IV. Result and Analysis

Measurements on rectenna were performed 5 times. The first test is to measure rectenna's DC output voltage without using GSM module device, which also means that it receives electromagnetic waves only from the environment or from nearby Base Transceiver Station [10]. During this test, the rectenna's output voltage is measured four times and the average output voltage value is taken.

The second test is to measure rectenna's DC output voltage with idle-conditioned active GSM module being near the rectenna. The third test is similar to second test but the GSM module is in transmitter condition. The fourth test is similar to third test but the GSM module is in receiver condition. In these three tests, the rectenna's output voltage for every 1 cm distance from when the GSM module is placed right next to the rectenna, which means the distance is 0 cm, to a distance of 10 cm.

The fifth test is to measure rectenna's received power level. This test is done following the same conditions as the first test until the fourth test.

A. Rectenna's DC Output Voltage without GSM Module

In this test, the average voltage value is 6.7 mV. The schematic dan test results' detail can be seen in Fig. 5 and Table II respectively. The highest rectenna's output voltage value is 6.9 mV and the smallest rectenna's output voltage value is 6.4 mV.

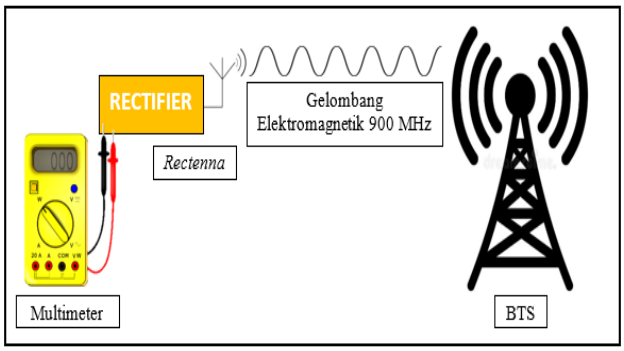

Fig. 5. Schematic of Rectenna's DC output voltage measurement without GSM module.

Table I: Measurement Results of Rectenna's DC Output Voltage without GSM Module Device

Rectenna's Output Voltage (mV)				
Data 1	**Data 2`**	**Data 3**	**Data 4**	**Average**
6.4	6.7	6.9	6.6	6.7

B. Rectenna's DC Output Voltage with Idle-Conditioned GSM Module

This test has a varied distance between rectenna and GSM module device with the closest distance being 0 cm

and the farthest distance being 10 cm. At the nearest distance, the output voltage value is 56.8 mV, which is also the highest output voltage value, while at the furthest distance, the output voltage value is 0.7 mV, which is also the smallest output voltage value. The details can be seen in Fig. 6 and Table II.

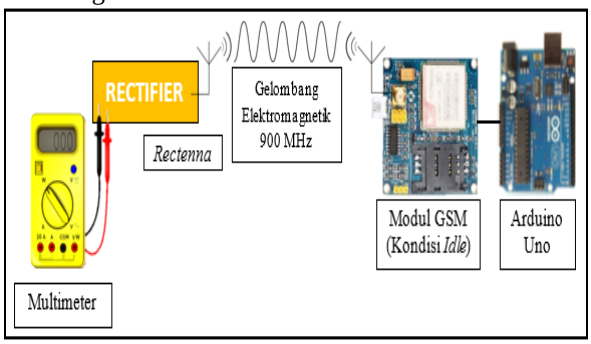

Fig. 6. Schematic of Rectenna's DC output voltage measurement with Idle-conditioned GSM module.

TABLE II: MEASUREMENT RESULTS OF RECTENNA'S DC OUTPUT VOLTAGE WITH IDLE-CONDITIONED GSM MODULE DEVICE

No.	Distance (cm)	Rectenna's Output Voltage (mV)
1.	0	56.8
2.	1	28.7
3.	2	25.6
4.	3	12.3
5.	4	8.6
6.	5	5.2
7.	6	5.5
8.	7	3.4
9.	8	2.9
10.	9	2.2
11.	10	0.7

As seen in Fig. 7, which shows the graph of rectenna's output voltage value when it is placed near a GSM module in idle condition, rectenna's output voltage value is inversely proportional to the magnitude of distance. The larger the distance between the rectenna and the GSM module device, the smaller the rectenna's generated output voltage.

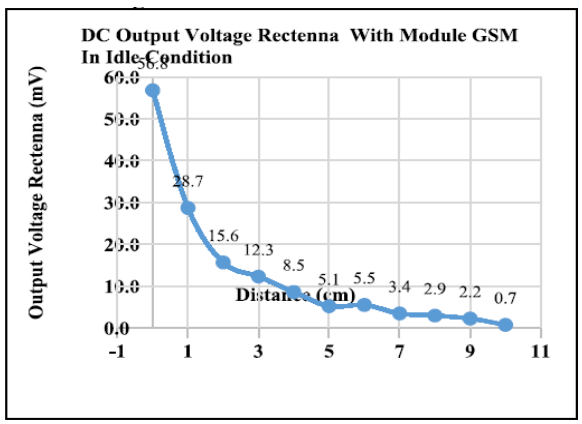

Fig. 7. Rectenna's DC output voltage with GSM module in idle condition.

C. *Rectenna's DC Output Voltage with GSM Module as Transmitter*

In this test, rectenna's output voltage value at the nearest distance is 68.0 mV and it is 3.9 mV at the furthest distance. These two values are also the highest and the smallest rectenna's DC output voltage value of the available test results in this test. The detailed schematic and test results can be seen in Fig. 8 and Table III.

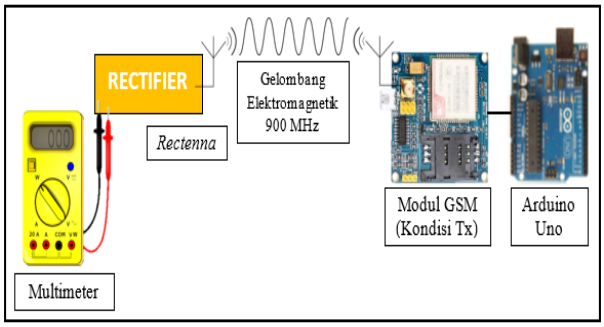

Fig. 8. Schematic of Rectenna's DC output voltage measurement with GSM module as transmitter.

TABLE III: MEASUREMENT RESULTS OF RECTENNA'S DC OUTPUT VOLTAGE WITH GSM MODULE DEVICE AS TRANSMITTER

No.	Distance (cm)	Rectenna's Output Voltage (mV)
1.	0	68.9
2.	1	37.4
3.	2	24.4
4.	3	19.7
5.	4	14.9
6.	5	11.9
7.	6	11.5
8.	7	8.7
9.	8	6.0
10.	9	5.4
11.	10	3.9

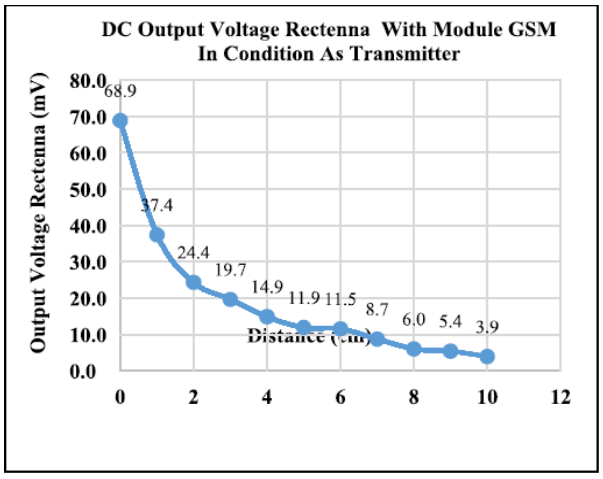

Fig. 9. Rectenna's DC output voltage with GSM module in transmitter condition.

As seen in Fig. 9, which shows the graph of rectenna's DC output voltage when it is placed near a GSM module

in transmitter condition, rectenna's output voltage is inversely proportional to the distance. The larger the distance between the rectenna and the GSM module device, the smaller the rectenna's generated output voltage. Compared to the test with idle-conditioned GSM module device, this test generally yields higher output voltage result.

D. *Rectenna's DC Output Voltage with GSM Module as Receiver*

In this test, rectenna's output voltage value at the nearest distance is 66.3 mV, which is also the highest rectenna's output voltage value, while at the furthest distance, it is 3.8 mV, which is also the smallest rectenna's output voltage value. The detailed schematic and test results can be seen in Fig. 10 and Table IVIV.

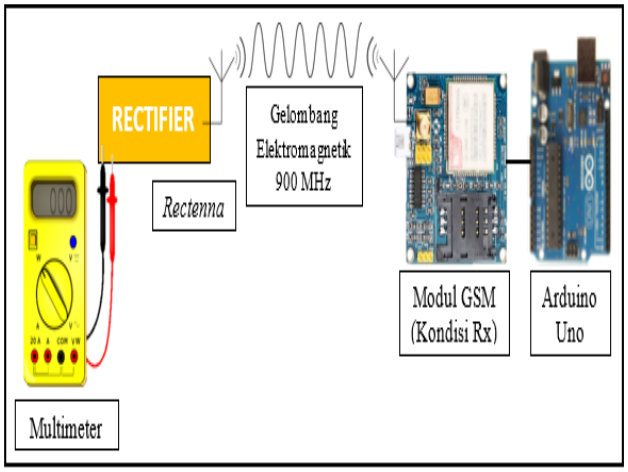

Fig. 10. Schematic of Rectenna's DC output voltage measurement with GSM module as receiver

TABLE IV: MEASUREMENT RESULTS OF RECTENNA'S DC OUTPUT VOLTAGE WITH GSM MODULE AS RECEIVER

No.	Distance (cm)	Rectenna's Output Voltage (mV)
1.	0	66.3
2.	1	34.1
3.	2	23.6
4.	3	19.9
5.	4	14.8
6.	5	11.8
7.	6	12.0
8.	7	8.5
9.	8	5.8
10.	9	5.5
11.	10	3.8

Fig. 11 shows the graph of rectenna's DC output voltage when it is placed near a GSM module in receiver condition. Similar to the previous two tests, rectenna's output voltage is inversely proportional to the distance between the rectenna and the GSM module device. The larger the distance, the smaller the rectenna's generated output voltage.

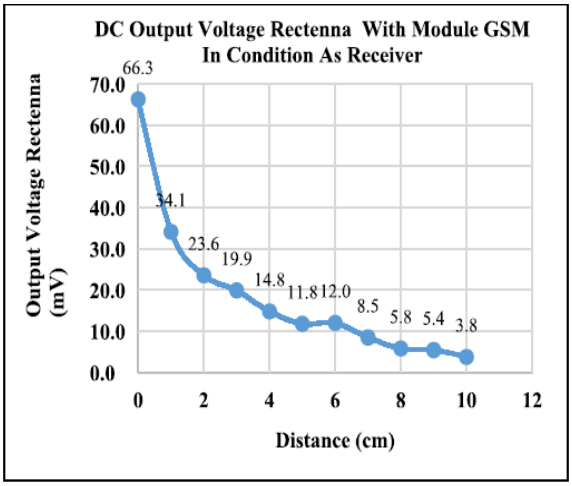

Fig. 11. Rectenna's DC output voltage with GSM module in receiver condition.

Although the results of this test are higher than the results of the test with idle-conditioned GSM module device, the overall results of this test is slightly lower than the test with GSM module in transmitter condition's overall results. This happens because when the GSM module device is in transmitter and receiver condition, the GSM module emits or captures electromagnetic waves with greater voltage than when it is in idle condition. Therefore, the rectenna produces a larger output voltage. The comparison can be seen in the graph in Fig. 12.

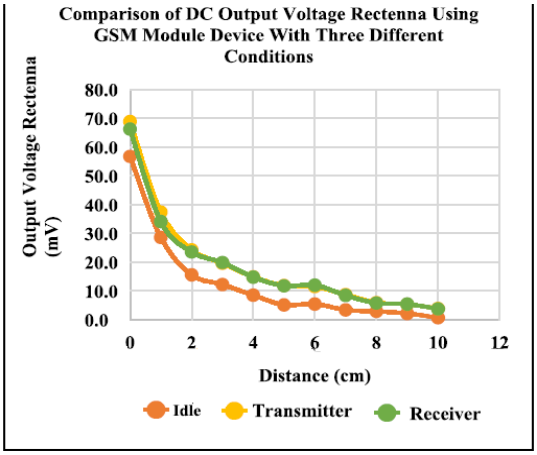

Fig. 12. Comparison graph of Rectenna's DC output voltage for tests with GSM module device.

E. *Rectenna's Received Power Level Measurement*

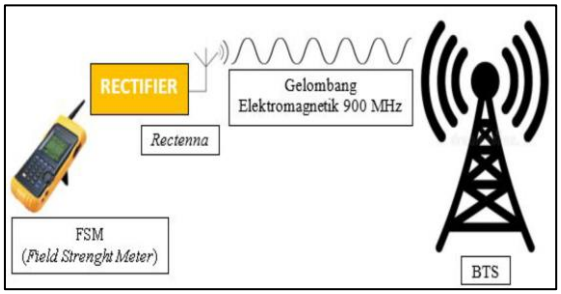

Fig. 13. Schematic of Rectenna's received power level measurement when there is no nearby GSM module device.

In the test for rectenna without GSM module device, the average rectenna's received power level is -93.7 dBm, the highest is -93.4 dBm and the lowest is -94.1 dBm. The schematic of the test can be seen in Fig. 13 and the details of rectenna's received power level is shown in Table V.

TABLE V: MEASUREMENT RESULT OF RECTENNA'S RECEIVED POWER LEVEL FOR TESTS WITHOUT GSM MODULE DEVICE

Rectenna's Received Power Level (dBm)				
Data 1	**Data 2**	**Data 3**	**Data 4**	**Average**
-93.6	-94.1	-93.4	-93.8	-93.7

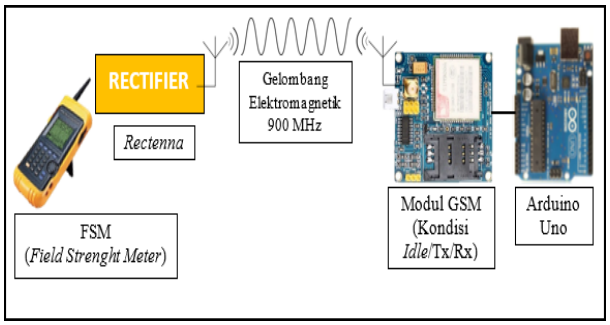

Fig. 14. Schematic of Rectenna's received power level measurement when there is GSM module device nearby.

Fig. 14 shows the schematic of rectenna's received power level measurement when there is a GSM module device nearby. Table VI shows the details of rectenna's received power level for the three subsequent tests, which are rectenna with GSM module device in idle condition, in transmitter condition, and in receiver condition. When the GSM module device is in idle condition, the highest rectenna's received power level is -88.1 dBm and the lowest is -92.8 dBm. When the GSM module device is in transmitter condition, the highest rectenna's received power level is -89.0 dBm and the lowest is -93.1 dBm. When the GSM module device is in receiver condition, the highest rectenna's received power level is -88.3 dBm and the lowest is -93.9 dBm. The comparison of the three test results can be seen in Fig. 15.

TABLE VI: MEASUREMENT RESULT OF RECTENNA'S RECEIVED POWER LEVEL FOR TESTS WITH GSM MODULE DEVICE

No.	**Distance (cm)**	**Rectenna's Received Power Level (dBm)**		
		Idle	**Transmitter**	**Receiver**
1.	0	-91.2	-89.0	-88.3
2.	1	-89.1	-89.3	-89.3
3.	2	-89.4	-90.1	-89.6
4.	3	-88.1	-90.0	-89.4
5.	4	-89.4	-89.8	-90.6
6.	5	-89.5	-91.4	-92.0
7.	6	-91.4	-91.4	-91.1
8.	7	-91.4	-91.9	-92.0
9.	8	-92.2	-92.5	-92.3
10.	9	-92.2	-93.0	-93.0
11.	10	-92.8	-93.1	-93.9

As seen in Table VI and Fig. 15, the value of rectenna's received power level tends to be inversely proportional to the distance. The greater the distance between the rectenna and the GSM module device, the smaller the rectenna's received power level.

Unlike the comparison of rectenna's DC output voltage, rectenna's received power level when the GSM module device in idle state has slightly higher average value than the other two conditions. This is because when the GSM module device is in idle state, the GSM module captures higher power level than when it is in transmitter condition and in receiver condition.

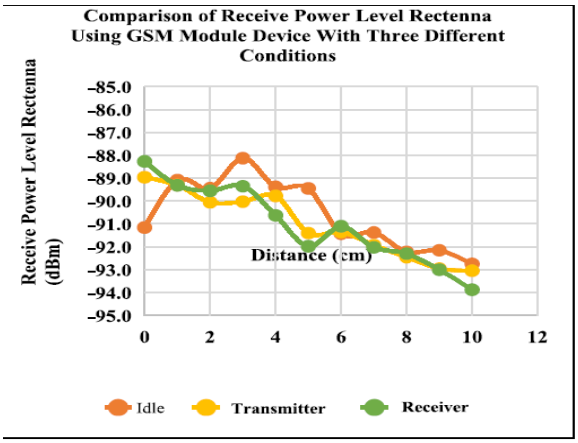

Fig. 15. Comparison of Rectenna's received power level for tests with GSM module device.

V. CONCLUSION

From the research, it can be concluded that for test without GSM module device, rectenna's average output DC voltage is 6.7 mV and its average received power level is -93.7 dBm.

The distance between rectenna and GSM module device is inversely proportional to rectenna's output DC voltage and tends to be inversely proportional to rectenna's received power level. The farther the distance, the smaller the output voltage and the received power level.

GSM module device's three conditions, which are idle condition, in transmitter condition, and in receiver condition, also affect rectenna's output voltage value and rectenna's received power level. The output voltage value when the GSM module is in idle condition is far lower than the other two conditions because the GSM module emits or captures electromagnetic waves with smaller voltage than when it is in the other two conditions. The highest output voltage value was produced by rectenna when the GSM module device is in transmitter condition while the highest rectenna's received power level is obtained when the GSM module device is in idle condition.

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