Energy harvesting using microstrip rectenna circular patch on GSM 1800MHz frequency

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Abstract. This research discusses the design of rectenna with microstrip antenna with frequency BTS work frequency in Malang city by using a rectifier to convert electromagnetic power into DC output on GSM1800 working frequency and use the energy storage design to be stored. Harvesting this energy is alternative energy conversion. The produced electrical power can be used by low-powered-devices. Since the obtained power is small, additional circuits will be used so that the obtained power can be stored in energy storage. The power obtained from this research is around 1 to 16 mV. It is obtained from BTS around the Malang city.

1. Introduction

The main energy source used by humans as fuel is a non-renewable natural resource, which will gradually decrease in number and will run out. Therefore, there are a lot of researches to overcome this problem such as using alternative energy derived from renewable natural resources [1,2].

Radio frequency is one of the energy sources that has big potential to be used as an alternative energy due to its large number around the community. The usable radio frequency range is from 3 Hz to 300 GHz, which includes TV frequency, GSM, CDMA, 3G, Wi-Fi, and so on [3,4].

In the previous research, Daniel W. Harrist used a quarter-wave antenna designed in such a way as to produce quarter waves that operate at a frequency of 915 MHz. This antenna generates around 5-6 mV DC voltage per second. In another previous research, Rawan Nugraha made rectenna, complete with rectifier, DC amplifier, and antenna. It is capable of working from 900 MHz - 5 GHz and its maximum yield is 790.75 mV. In this research, the obtained power will be increased to 2 V so it can be stored in an assembled battery. As well in another previous research, Aisah designed rectenna of the GSM frequency band 900 MHz for electromagnetic energy harvesting that the resulting output DC voltage is 6,7 mV [5,6].

In this research, a circular microstrip antenna with a rectifier and DC amplifier was made, with an antenna capable of working on GSM frequencies of 1800 MHz. Hopefully, the design of this circular Rectenna microstrip can utilize electromagnetic wave radiation from the Base Transceiver Station (BTS) of the Global System for Mobile communications (GSM) as a new source of voltage [7].
1.1. Microstrip antenna
The microstrip antenna is one of the most popular antennas at the moment. This is due to the fact that microstrip antennas are very suitable for telecommunication devices that currently pay attention to form and size [7,8].

Based on the origin of the word, microstrip consists of two words, namely micro (very small/thin) and strips (blades/pieces). The microstrip antenna is generally divided into three parts, namely patch, substrate dielectric, and ground plane [9].

1.1.1. Patch. In general, patches are made from conductors such as copper or gold which have various forms. The shape of the patch can vary. It can be a circle, square, rectangle, triangle, or annular ring. A patch serves to radiate electromagnetic waves into the air. Patches and feed channels are usually located above the substrate. Patch thickness is made very thin (t << λ0; t = patch thickness) [9].

1.1.2. Substrate dielectric. This substrate is made of dielectric materials. Its height (h) is usually between 0.002λ0 - 0.005λ0. It serves as a GEM channel media from castings. Its thickness influence the bandwidth on antenna parameters. The thicker it is, the higher the antenna’s bandwidth [10-12].

![Figure 1. Design of antenna microstrip circular patch.](image1)

Modes that can support circular patch antennas can be seen by interpreting the patch, ground plane and material between the two-cavity circles. The value of a small substrate (h << λ) is TMz where z is taken perpendicular to the patch. Circular ribbons there is only one level of freedom to control (patch radius). Doing this does not change the order of modes but it changes the absolute value of each resonant frequency. Figure 1 shows an image of a microstrip antenna [3,4,9].

1.2. Rectifier
A rectifier is used to change AC (Alternating Current) signal voltage into DC (Direct Current) voltage. The main components in the wave rectifier are voltage drop (transformer), wave rectifier (diode) and filter (capacitor). A full-wave rectifier uses 4 diodes that are installed in bridge shape [2,13].

1.3. Rectenna
A rectenna is a rectifier antenna - a special type of antenna used to convert electromagnetic energy into direct current (DC) electricity. They are used in wireless power transmission systems that transmit power through radio waves. A simple rectenna element consists of a dipole antenna with an RF diode connected across a dipole element [1,13].

![Figure 2. Block diagram of rectenna.](image2)
The diode rectifies the AC current induced in the antenna by microwaves to produce DC power, which gives the load strength connected throughout the diode. Schottky diodes are usually used because they have the lowest voltage drop and the highest processing speed, therefore they have the lowest power due to conduction and Rectenna switching designed for energy harvesting applications in GSM bands, UMTS / WCDMA bands, the latest ISM and LTE band [13]. Figure 2 shows the block diagram of how the rectenna work.

1.4. Energy harvesting
Energy harvesting is a process where energy is captured and converted directly into electricity to be used by small and medium devices such as autonomous wireless sensor nodes, consumer electronics, and vehicles. These energies come from external/unconventional sources such as radio waves (RF energy), heat energy, natural energy, solar energy, and other sources. Other than directly used in small to medium devices, the converted energy might be stored in durable storage cells such as capacitors, super capacitors, or micro-energy cells (MEC), which are in the forms of lithium solid-state batteries. Its system generally includes circuits whose function are to regulate power, protect storage devices and other functions [1-4].

2. Methods
Research methods include the stages and designing of the research starting from the beginning to the implementation of the system. The research phase was prepared with the intention that the research can be carried out in detail. The specific antenna and rectifier configuration is obtained through the process of calculating and designing antenna and rectifier specifications according to the desired specifications. Table 1 shows the desired antenna specifications.

| No | Parameter | Specification |
|----|-----------|---------------|
| 1  | Frequency | 1800 MHz      |
| 2  | VSWR      | < 2           |
| 3  | Return Loss | < -10 dB   |
| 4  | Impedance | 50 ohm        |

After determining the desired specifications, the antenna dimensions are calculated. The calculation results are inputted into CST software to do simulation. The simulation results are shown in Figure 3.

The rectifier is designed using a multimode. It is comprised of 4 Schottky diodes and 100nF capacitors, which are arranged as seen in Figure 4. Microstrip antennas are printed on FR-4 type and patch using copper, whose shape and dimensions can be seen in Figure 5 and Table 2.
Figure 4. Simulation of rectifier.

![Rectifier Simulation](image)

Figure 5. Fabrication of antenna.

![Antenna Fabrication](image)

Table 2. Fabricated microstrip antenna dimensions.

| Variable          | Dimension (mm) |
|-------------------|----------------|
| Diameter          | 43             |
| Length patch      | 19.98          |
| Width patch       | 2.87           |
| Width substrate   | 60             |
| Length substrate  | 71             |
| Width ground      | 60             |
| Length ground     | 20             |

The fabricated antennas and rectifiers were then connected as can be seen in the block diagram system in Figure 6.

![Prototype Design Block Diagram](image)

Figure 6. Prototype design block diagram.
3. Results and discussion

Tests on antenna include testing antenna parameters on simulated-antenna and fabricated-antenna. The tested parameters were Return Loss, VSWR, Radiation and Gain Pattern. Return loss is one of the parameters used to find out how much power is lost in the load and return as a reflection. This parameter can also determine to match between the antenna and transmitter.

![Graph of changes in return loss value](image1)

(i) Graph of changes in return loss value

![The direction of the designed antenna beam](image2)

(ii) The direction of the designed antenna beam

![Graph of changes in VSWR value](image3)

(iii) Graph of changes in VSWR value

![Graph of gain changes](image4)

(iv) Graph of gain changes

**Figure 7.** Graph of parameter value antenna.

The Return Loss value from the simulation results of the microstrip circular patch antenna that works on 1800 MHz frequency can be seen in Figure 7 (i). The Return Loss graph shows the return loss value from the initial frequency of 1700 Hz to 1900 Hz. Since the Return Loss in the frequency range of 1700 MHz up to 1900 MHz is below -10 dB, the antenna can work and the frequency is small during this frequency range. In the GSM frequency Up Link of 1710 MHz-1785 MHz and Down Link frequency of 1805 MHz-1880 MHz, the value of small return loss is around -16 dB to -26.6 dB during simulation while for during test on prototype, it ranges from -14.464 dB to -40.23 dB with it being -23 dB at the middle frequency of 1800 MHz.

To ensure that the designed antenna has good capabilities, its radiation pattern and polarization for 1800 MHz frequency, which can be seen in Figure 7 (ii) are checked. Based on Figure 7 (ii), the maximum value of the radiation pattern is 60° to – 60°. Based on this data, it can be said that this antenna is bidirectional with its circular polarization following the patch form of this antenna.

The VSWR test results on simulated-antenna and fabricated-antenna are shown in Figure 7 (iii). The simulation uses the initial frequency of 1700 MHz and the final frequency of 1900 MHz. VSWR is obtained in the frequency range of 1700 MHz up to 1900 MHz below 2. This shows that the antenna can still work and the small frequency is given during that frequency range. In GSM frequency Up Link
of 1710 MHz-1785 MHz and Down Link frequency of 1805 MHz-1880 MHz, the VSWR value is good, which ranges from 1.3 to 1.09 during the simulation and ranges from 1.45 to 1.05 during the test on the prototype with it being 1.01 at the middle frequency of 1800 MHz VSWR.

Based on Figure 7 (iv), it can be seen that the simulation results of square patch microstrip antennas have increasing gain during the frequency range of 1700-1900 MHz. Meanwhile, the fabricated antenna’s gain result is unstable but still has a good average value. This happened because when measuring unstable gain the measuring instrument for the gain itself.

From several rectenna tests without using op-Amp in the morning, afternoon and evening times, the power output samples were obtained as shown in Table 3.

Table 3. Testing results in several areas of Malang.

| Areas                        | Period 06.00-08.00 | Period 11.00-13.00 | Period 19.00-20.00 |
|------------------------------|--------------------|--------------------|--------------------|
|                              | Minimum voltage    | Maximum voltage    | Minimum voltage    | Maximum voltage    | Minimum voltage    | Maximum voltage    |
| Soekarno Hatta Rd.           | 1                  | 6                  | 1                  | 5                  | 1                  | 5                  |
| Ikan Trombro Rd.             | 1                  | 7                  | 1                  | 5                  | 1                  | 8                  |
| Sudimoro Rd.                 | 1                  | 15                 | 1                  | 12                 | 1                  | 16                 |
| Simpang Candi Panggung Rd.   | 1                  | 5                  | 1                  | 4                  | 1                  | 4                  |
| Mayjen Panjaitan Rd.         | 1                  | 4                  | 1                  | 2                  | 1                  | 5                  |
| Bogor Rd.                    | 1                  | 3                  | 1                  | 3                  | 1                  | 5                  |
| Bandung Rd.                  | 1                  | 3                  | 1                  | 2                  | 1                  | 5                  |
| Besar Ijen Rd.               | 1                  | 5                  | 1                  | 3                  | 1                  | 4                  |
| Bendungan Sutami Rd.         | 1                  | 4                  | 1                  | 2                  | 1                  | 3                  |
| Veteran Rd.                  | 1                  | 3                  | 1                  | 2                  | 1                  | 3                  |

The analysis of the tests of the output power produced by the rectenna is influenced by the number of BTS and the number of mobile users at the same frequency as the antenna working frequency. From the testing results, the lowest obtained power from all test areas at several different times is 1mV and the highest obtained power is 16mV, which is obtained at 19.00-20.00 at Sudimoro street area.

4. Conclusion

From the test results and discussion, it can be concluded that planning and making renewable energy systems using GSM 1800 MHz frequency-based microstrip antennas can be implemented and realized. The value of obtained return loss parameters from the fabrication at 1800 MHz frequency is -40.23 dB, which is higher than the simulation results whose value is only -23.2 dB at the same frequency. Antenna’s VSWR values in the frequency range of Uplink and Downlink are good, ranging from 1.3 to 1.09 during the simulation and from 1.45 to 1.05 during test on the prototype with it being 1.01 at the middle frequency of 1800 MHz. In the gain value test result, the gain value increases during the simulation and is unstable but still has good average value during the test with the fabricated antenna.

This antenna is bidirectional with circular polarization following the patch form. The test results of the rectenna’s produced voltage range from the lowest, 1mV, and the highest, 16 mV. The highest value is obtained during measurements at night and the lowest is obtained during the day. Power acquisition is influenced by the number of users using the same frequency as the rectenna’s working frequency, which is GSM 1800MHz frequency. To turn on load or LED, the power produced by the rectenna is added to the power supply of the Operational Amplifier. This research can be developed with other rectifier models to find better energy results. The used antenna material can be replaced with another substrate to get different and better energy absorption. Other tests can be carried out with different frequencies according to available frequencies around the environment. The prospect of the development of research results and application prospects of further studies into the next can be used
range frequency from 2G up to 5G, which is frequency used by Base Station in terrestrial spread in Indonesia. That can be used for alternative energy in the next future because of the increasing number of the base station.

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