Rectifier Using UWB Microstrip Antenna as Electromagnetic Energy Harvester for GSM, CCTV and Wi-Fi Transmitter

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Abstract**—**Rectenna (rectifier antenna) is a device that functions as an electromagnetic energy harvester that works by changing the RF waves that have shaped AC into DC electrical energy that is able to save and as a source of energy electronic devices or other recipients. Rectenna using the energy harvesting is in fabrication, can be applied in the 1700-2650 MHz frequency`s which include working frequencies in GSM devices, CCTV and Wi-Fi devices. To obtain an electromagnetic wave that works at a frequency of 1700-2650 MHz it needs Ultra Wideband (UWB) antennas who are able to work at a frequency > 500MHz. The design process includes an antenna and a rectifier that is a calculation, simulation, fabrication, and measurement. Main materials of the antenna are Phenolic White Paper - FR4 with a dielectric constant (ε_r) = 3.9 and the rectifier circuit using Schottky diodes HSMS-2850.

Index Terms—Antenna, rectifier, ultra wideband

I. INTRODUCTION

At the present time Fossil energy sources are the main source of energy and are often used for the operation of various technology products, however, it is limited and not environmentally friendly. Therefore, fossil energy has considerable cost and expense to the environment. While governments from around the world are intensive to reduce the use of fossil fuels as an energy source. Therefore, it is important to obtain renewable energy sources and environmentally friendly. Environmental friendly energy can be obtained from sources that are not limited in nature such as sunlight, wind, vibration, noise, or thermal energy. Today, with the development of technology, energy sources that exist in nature and environmental friendly are the radio frequency (RF).

Technologies to harness energy sources are usually called energy harvesting (energy harvesting). Large-scale deployment of RF communications throughout the past three decades causing RF energy is available in the "anywhere and anytime". One of the main tools to perform RF harvesting is rectenna which usually consists of a rectifier and antenna [1].

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Currently, it has many emerging devices using low-power wireless technology. One application is a source of energy from a variety of resources available to improve the function of the battery or without battery operation. The power available for these devices is usually very low in accordance with the output source that influenced by changes in the environment and mobility receiver circuit [2].

In this research will be discussed designing a rectenna that first made that rectenna that use the resources of Ultra wideband antenna that covers 1700-2650 MHz frequency used in GSM antennas, CCTV and WiFi as the wireless devices are often used in the market. So it does not need three types of different antennas to receive electromagnetic waves from GSM devices, CCTV and Wifi which have different frequencies anyway. Rectenna impact if at fabrication is able to adapt to the electromagnetic waves having a frequency work that is wide enough: 1700-2650 MHz so as to obtain more energy than using single antenna band ever made. And certainly more to minimize the cost of fabricating the antenna and environmentally friendly. In addition to the antenna, a component that is made is a rectifier that has the capability to rectify the AC waveform and a voltage doubling, therefore, the most effective components are determined by experiment. A rectifier is made also have high levels of resistance, capacitance, and excellent stability in order to conform to the expected output. Isolation made outside rectifier to protect components and rectifier circuit from electromagnetic wave radiation.

II. ANTENNA DESIGN AND FABRICATION

Antennas to be implemented on rectenna is microsrip ultra wideband antenna (bandwidth> 500MHz), which includes the operating frequency of GSM, Wifi and CCTV that frequency includes at 1800 MHz and 2400 MHz.

A. Antenna Design

The designs are made include mathematical design and software design using CST 2014. The mathematical design is used as a reference to determine the basic dimensions in simulating the software CST 2014, then to get the expected conditions of the antenna then add other shapes that were engaged in basic form on the patch and ground plane. Design of simulation results is what will be the main reference of the antenna fabrication process. Fabrication will be designed very precisely according to the results of the simulation in order to value that produced identically to the antenna on the simulation.

In this research, the patch used is a patch with the shape like a hat with a basic form circular patch, then later form the basis of this circular patch will join with elliptical shape underneath at optimization process. With the aim to get the width of the working frequency of the antenna ultra wide band that would eventually shape resembles the shape of a hat at the patch. where the radiating element radius dimensions can be obtained through the equation [3]:

$$a = \frac{F}{\left\{1+\frac{2h}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right)+1{,}7726\right]\right\}^{1/2}}$$

$$a = 2{,}04425$$

where :

a = radius of radiating element (cm)

h = the thickness of the substrate (m)

ε_r = relative permittivity of the dielectric substrate (F/m)

F = logarithmic function (F) of the radiating element

While the logarithmic function (F) of a circle radiating element can be expressed by the following equation:

$$F = \frac{8{,}791\times 10^9}{f_r\sqrt{\varepsilon_r}}$$

$$= 2{,}0467$$

where :

f_r = the working frequency of the antenna (GHz)

ε_r = relative permittivity of the dielectric substrate (F/m)

$$\mathrm{Lg} = 6\mathrm{h} + 2\mathrm{R}$$

$$= 50{,}485 \times 10^{-3}\ \mathrm{m} = 50{,}485\ \mathrm{mm}$$

With :

$$\mathrm{W_g} = 6\mathrm{h} + \frac{\pi}{2}R$$

$$= 41{,}6947 \times 10^{-3}\ \mathrm{m}$$

$$= 41{,}6947\ \mathrm{mm}$$

where:

L_g = The minimum side length of ground plane (m)

W_g = The minimum width of the ground plane (m)

R = radius circular patch (m)

H = the thickness of the substrate (m)

Line feeder used on the antenna has 50 ohm input impedance. So to calculate the dimensions of the transmission line in order to obtain a 50-ohm impedance mathematically formulated [3]:

$$B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_r}}$$

$$= \frac{60 \times 3{,}14^2}{50\sqrt{3{,}9}} = 5{,}991$$

Determine the width of the transmission line (W)

$$W = \frac{2h}{\pi}\left\{B - 1 - ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left[ln(B-1) + 0{,}39 - \frac{0{,}61}{\varepsilon_r}\right]\right\}$$

$$= \frac{2\times 1.6}{3{,}14}\left\{5{,}9911 - 1 - ln(2\times 5{,}9911 - 1) + \frac{3{,}9-1}{2\times 3{,}9}\left[ln(5{,}9911-1) + 0{,}39 - \frac{0{,}61}{3{,}9}\right]\right\}$$

$$= 3{,}3418\ mm$$

The shape of the microstrip antenna design that complements the form of the transmission channel, the channel impedance adjustment, the distance between the radiating element, the wavelength of the microstrip transmission line referring to the source.

Specifications substrates and materials conductor used in the design of microstrip antenna is as follows:

- Dielectric material: FR – 4
  The dielectric constant (ε_r) = 3.9
  The thickness of the dielectric (h) = 1.6 mm
  Loss tangent (tan δ) = 0.018
- Coating material substrate (conductor) copper:
  The thickness of the conductor material (t)= 0.0001 m
  copper conductivity (σ) = 5.80×10^7 mho m^{-1}
  material size = 29.7 x 21 mm

After calculation mathematically then do a simulation and optimization to get the expected results using CST software 2014 then get the following dimensions. design patch in primary forms a circle and ground plane is from [4]. The dimensions of the ground plane and patches are made to have different sizes to be obtained appropriate desired frequency:

TABLE I: ANTENNA DIMENSIONS

Variabele	Dimensions (mm)
Radius of patch	35
High elliptical patch	40
Wide elliptical patch	100
L	32
W	3.371
Width of the substrate	110
High of the substrate	105
Wide rectangular ground plane	46
High rectangular ground plane	50
High elliptical ground plane	30
Wide elliptical ground plane	76
High rectangular under elliptical ground plane	20

Antennas are made to have the main part is a circle shape and join the ellipse at the bottom that resembles the shape of a hat. Part ellipse on the patch directly connects the feeder line as a link to the patch on the antenna connector. Then ground plane consists from two forms, but forms ground plane is basically one that is rectangular and elliptical shape at the bottom ground plane in addition to the connection with the connector as well as support rectangular ground plane performance.

Antenna fabrication is done with the main ingredient FR4 coated with the copper double layer so on get the patch and ground plane of copper on both sides of her. (Fig. 1).

Fig. 1. Fabricated hat patch Microstrip antenna [4]

The antenna is connected by using the connector conductors of lead which is attached directly to the ground plane and line feed on the patch. Connector material also from the conductor that is brass with an input impedance of 50 ohms.

B. Antenna Performance Result

Antenna performance is expressed by the parameters of the antenna with the main objective to get antennas with UWB (ultra wideband) frequency that includes frequencies in the GSM 1800 MHz, CCTV, and Wifi 2.4 GHz transmitter. Antennas are made must also have the required performance for transceivers effective as an appropriate return loss, radiation pattern appropriate, the corresponding polarization, the gain is large enough and of course regarding the impedance is 50 ohms.

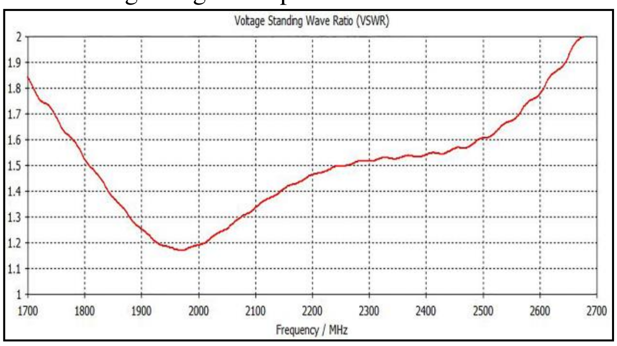

Fig. 2. VSWR

From Fig. 2, it can be seen that the VSWR of the antenna is between 1700-2650 MHz so it can be concluded that the working frequency of the antenna is good if used in the frequency 1700-2650 MHz, so this antenna has bandwidth of 950 MHz which is the antenna ultra wideband (bandwidth> 500MHz) [4] and include a working frequency of 1800MHz GSM, Wifi CCTV, and 2.4 GHz.

Fig. 3. is the return loss to be represented, due to return loss shows of how much power lost in the load and not come back as a reflection, where the value of the corresponding standard of Return Loss is 9:54> RL. So that has a working frequency in 9:54> RL is 1700-2650 MHz [5].

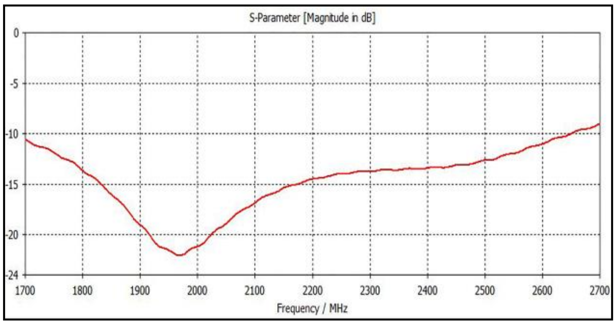

Fig. 3. Return loss

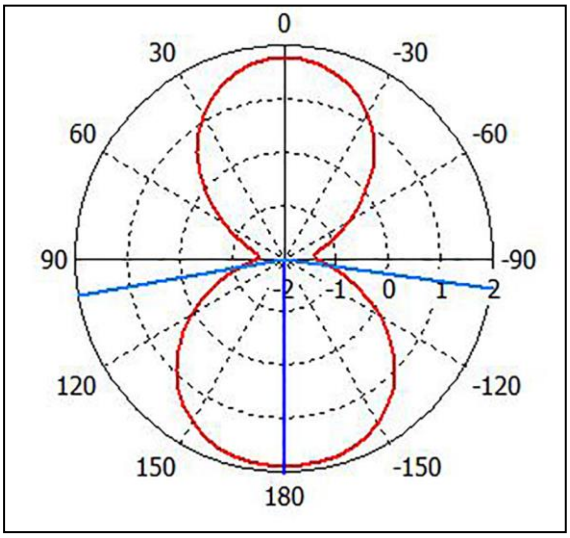

Fig. 4. Radiation pattern

Fig. 4. is a chart of Radiation pattern.

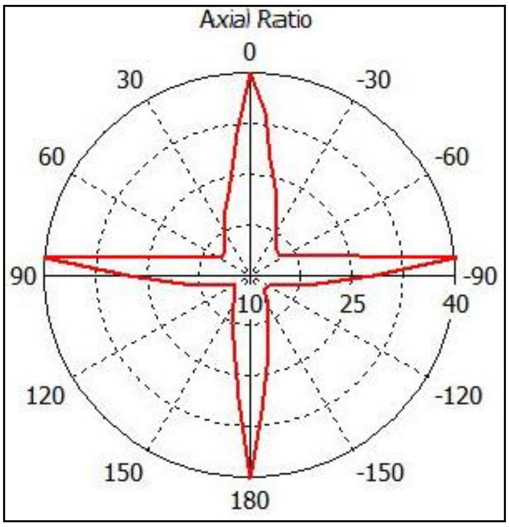

Fig. 5. Polarization of hat patch microstrip antenna

Fig. 5. is a chart of antenna polarization. The antenna selecting linear polarization so the propagation of electromagnetic waves radiated and received well in linear conditions [6], [7].

Fig. 6. determines the gain value is expressed power intensity of each unit of space where the value of the gain has been shown with a layer of color in the space dimension transmitting an antenna the highest in red color with a value of 3.4 dB of gain [8]. With the value of a positive gain then the antenna is good and effective for use [9].

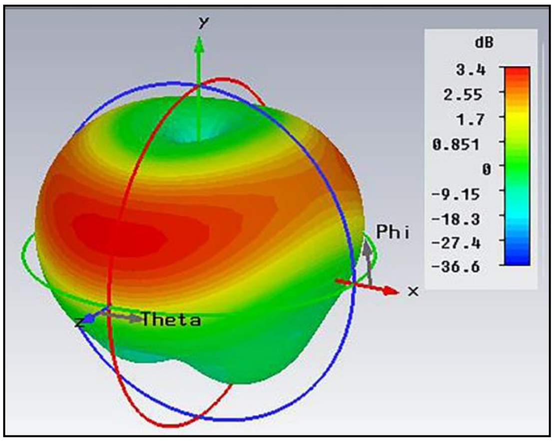

Fig. 6. The radiating intensity (gain) distribution

III. Rectifier Design and Fabrication

Rectifier has to be created for this research is a rectifier that can work in accordance with the frequency of the antenna, and has the ability to double the small AC voltage from the antenna to be larger DC voltage that is by rectifier Using voltage multiplier circuit.

The design process rectifier is begun to determining the various components according to the type of circuit and the input frequency circuit from the antenna, then the design is mathematically by adjusting the components and input circuit to be output in accordance with the expected, after simulates using the design software of the circuit, then in fabrication to use the PCB and carefully put the components used, because the components are in use very susceptible to heat and electromagnetic waves [10]. (Fig. 7).

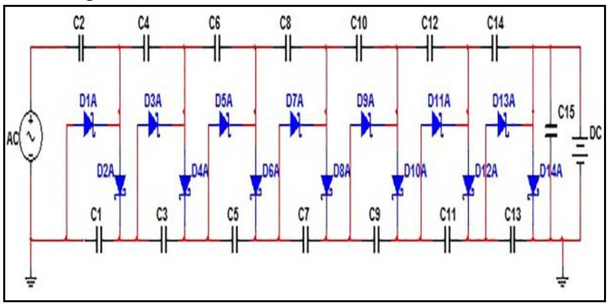

Fig. 7. Rectifier circuit circuit scheme

TABLE II: CIRCUIT COMPONENT

Component name	Labels	Value
Capasitors	C1, C3, C5,C7, C9, C11, C13, C15	100uF
Capasitors	C2, C4, C6,C8, C10, C12, C14	10nF
Diodas	D1A-D14A	HSMS 2850

AC symbol is a source of voltage that comes from an antenna that is AC wave and DC symbol is an output of the rectifier which has a DC voltage as a result of the multiplication process and rectification voltage of the rectifier.

Components are chosen because in addition to follow the literature on the previous journal we also did some research on some components that are most appropriate as a voltage multiplier so that large voltage produced and loss in the circuit due to looping on each segment is getting smaller. As the use of diode HSMS 2850, this diode has a smaller forward voltage compared to another diode that is 150mV, so the voltage and current will more quickly move to the next loop and resulting in more voltage on each capacitor segment.

In the process of taking the measurements after the antenna joins with rectifier then in need of a certain space, which space has been in an aluminum blanket tightly to avoid entry of electromagnetic waves from outside the circuit. So that the electromagnetic waves just past the antenna and the rectifier section altogether. This aluminum enclosed space in addition to functioning as a protection from electromagnetic waves on the circuit (so pure wave from the antenna) as well as the protector that the components of the rectifier circuit last longer because if the incoming electromagnetic waves then the circuit will actively work continuously and will damage the rectifier components. so space is tight and narrow cover the rectifier circuit needs to be made well and effectively.

IV. Measurement

The antenna will be combined with a rectifier so it will be a rectenna is capable of converting AC into DC voltage and is able to multiply the voltage by 7 segment rectifier. antenna and rectifier also have the capability to work with three different frequencies without changing the antenna and rectifier if the transmitting device is GSM, CCTV, and Wifi with having a different frequency and power.

The device transmitter of GSM is using Nokia X-2 with a frequency on 1800MHz in a power 10MW, transmitter device of CCTV is using CCTV SW-5000-24 (5W) with work frequency on 2400MHz in power 5W and the device transmitter Wifi is using wifi EAP9550 in work frequency on 2400MHz in power 20-60 mW.

Fig. 8. shows the output of each device by an equal distance with different the type and power of devices. The output of the CCTV is 395 mV at a distance of 1 m and the smallest on the CCTV output is 128 mV at a distance of 6 m. The output of the Wi-Fi is 104.2 mV at a distance of 1 m and the smallest output Wi-Fi is 80.1 mV at a distance of 6 m. GSM is the largest output at 85.4 mV with a distance of 1 m and the smallest in the GSM output is 58.8 mV at a distance of 6 m. from the three devices that have the greatest output voltage if the

transmitter is CCTV devices with the greatest power and the closest distance that is 1 m.

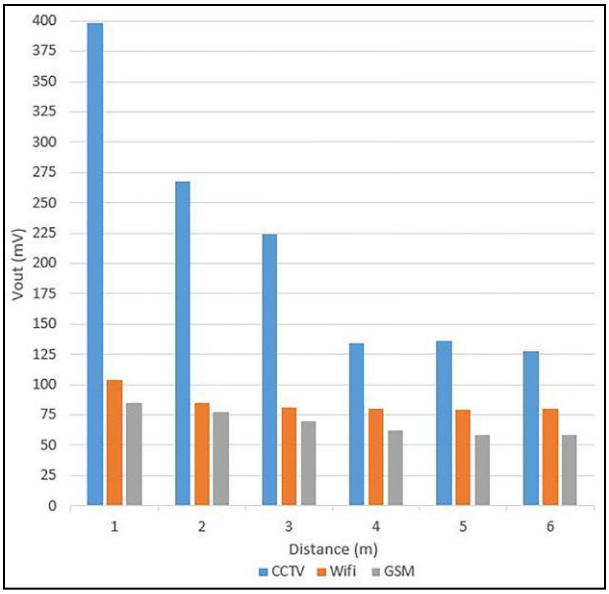

Fig. 8. Rectenna output at a distance of 1 m to 6 m from the transmitter

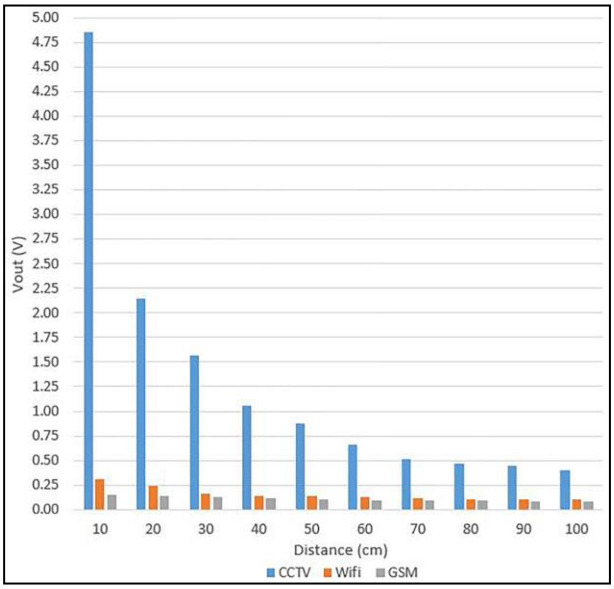

Fig. 9. Rectenna output at a distance of 10 cm to 100 cm from the transmitter

Fig. 9 shows the output of each device by an equal distance to the type and power of different devices. On CCTV is the largest output of 4.8 V with a distance of 10 cm and the smallest on the CCTV output is 0.395 V at a distance of 100 cm. on Wi-Fi is the largest output in 0.313 mV with a distance of 10 cm and the smallest on the Wi-Fi output is 0.104 V at a distance of 100 cm. on GSM is the largest output of 0.155 V with a distance of 10 cm and the smallest output in GSM is 0.085 V at a distance of 100 cm. from the three devices that have the greatest output voltage if the transmitter is CCTV devices with the greatest power and the closest distance of 10 cm.

From the two graphs has shown the Identical conclusion of each rectenna experiment usage that is in use on three telecommunications devices that are often used in the market. Where a device which has the greatest power and the closest distance that have the greatest rectena output.

V. Conclusions

Based on research in this paper it can be concluded that the antenna that has been created that a microstrip antenna with the main material FR4 has a patch with hat shape which has a working frequency Ultra wideband (UWB) that is 950MHz with a range between 1700 MHz to 2650 MHz. antenna fabrication specification has bi-directional radiation pattern, polarization is linear and has a gain: 3.4. therefore, the antenna is able to work for the transmitter with the circuit among other is 1800MHz GSM devices, CCTV and Wi-Fi transmitter.

Rectifier made have been adapted to the antenna and the ability to receive the voltage and have the frequency from 1700 MHz to 2650 MHz. This rectifier has a 7 segment as AC into DC voltage converter and an effective voltage multiplier with the main component is capacitor and diode HSMS 2850 generates multiple outputs higher than the input antenna that is very low. The device used in this research is the most widely and frequently used in the market so that we easily find the devices are all around us and the power radiated also abundant (this is better [1], [2], [5] because previous research has not tried directly on the device that is often in found in the market). The greatest power that was obtained rectenna that on CCTV devices, that is approximately 4 volts at a distance of 10 cm and 395 mV at a distance of 100 cm from the transmitter CCTV. And the conclusion increasingly radiated power is great and near so greater the power generated.

The Future work will be investigation of matching impedance between the antenna and rectifier device for improving the output voltage of Rectenna

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