# RANCANG BANGUN RECTENNA UNTUK ENERGY HARVESTING PADA FREKUENSI WIFI 2,4 GHZ

***Abstract*—The development of IoT devices and sensors in the future will be very broad. In the future it is expected not to rely on batteries. Utilization of electromagnetic waves in the environment to be converted into energy is one way to eliminate dependence on batteries. In urban environments, the availability of WiFi networks is very abundant. The WiFi network emits electromagnetic waves at a frequency of 2.4 GHz. These electromagnetic waves can be used to turn on low-power IoT devices. In its development, this effort is referred to as the RF Energy Harvesting technique. To realize the RF Energy Harvesting technique a hardware device called a rectenna is required. For this reason, in this final project a rectenna design is carried out for Energy Harvesting at the 2.4 GHz WiFi frequency. The results of the built rectenna succeeded in converting electromagnetic energy into DC electricity with a voltage of 470 mV at a distance of 10 cm and a voltage of 11.7 mV at a distance of 1000 cm from an RF source with a power of 5 Watt.**

**Keywords— RF Energy Harvesting, Rectenna and WiFi**

## I. INTRODUCTION

Autonomously powered sensor devices using non-hazardous alternative sources and sustainable energy supply have attracted research and development (R&D) attention in industry and academia. Until recently, batteries supplied limited power to conventional devices. Batteries store chemical energy and convert it directly into electrical energy when needed. The released battery chemicals can be toxic and harmful to human life and the environment in case of leakage, either by accident or spontaneously. For this problem, many researchers recommend developing new sources of long-lasting and reformative power to fulfill the desired energy of these devices. One of the most attractive solutions to replace nodes and devices without batteries and automatic power is the environmental energy harvesting method [1]. Telecommunication technologies that use wireless media as information signal carriers can be a source of electromagnetic waves, resulting in an abundance of these electromagnetic waves in the human environment. Many other unknown radio frequency (RF) signals come from the military, police, government and radio amateurs. As a result, the amount of small-power electrical energy will also increase in the future. This makes it easy to collect electrical energy by using RF harvesting techniques and electromagnetic waves as energy objects [2]. RF Energy Harvesting is an emerging technology used to reduce or eliminate the dependence of most wireless devices and low-power integrated circuits on wired or non-automated power sources. With proper antenna mixing, circuit matching, and improved circuitry and energy storage devices, the available RF energy can be used to power (some or all) wireless devices [3]. Precisely, in rectenna design, the main function of the rectifier circuit is to convert the captured RF energy into Direct Current (DC) with minimum loss and supply DC to wearable electronic devices. In other words, the rectenna will not only be used to transmit and receive RF and microwave signals for communication but also to power and charge low-power electronic devices, such as sensors [4]. The rectenna-type voltage multiplier circuit can be applied at high voltages without the charge pump capacitor function commonly used in conventional multipliers [5]. The advantages of microstrip antennas are light weight, small size, capable of single, dual or multi-band operation, and can produce circular or linear polarization [6]. Rectenna is a combination of two different words: rectifier and antenna. The rectifier is responsible for converting RF energy into DC, and the antenna is responsible for receiving RF energy. Electromagnetic waves emitted by various devices such as Access Points (AC) and WiFi can be the voltage source of other devices without using batteries. The rectenna's DC output can drive electrical loads such as sensors, drones, and LEDs. The rectenna is designed to operate at 2.4 GHz when sensing electromagnetic energy in WiFi networks. For this reason, in this final project, Rectenna Design for Energy Harvesting at 2.4 GHz WiFi Frequency is carried out.

## II. BASIC THEORY

### *A. Rectenna*

A rectenna is basically a device that converts RF energy into DC voltage. It is a compound word of rectifier and antenna. The antenna acts as a receiver of radio frequency energy, which is then converted into electrical energy in the form of an alternating current (AC) signal. The rectifier then converts the RF energy into an AC signal into a DC voltage [7].

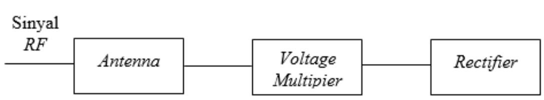



***Figure 1*** *Rectenna System Block Diagram.*

### *B. Power Energy Harvesting*

Power Harvesting adalah metode menangkap gelombang elektromagnetik dan mengubahnya menjadi energi listrik untuk menyalakan perangkat berdaya rendah. Teknologi pemanenan energi terdiri dari dua komponen utama: antena yang menerima gelombang elektromagnetik dan rangkaian penyearah yang mengubah sinyal RF menjadi energi listrik DC. Secara umum, rangkaian antena penerima dan penyearah disebut rectenna atau antena penyearah. Aplikasi teknik pemanenan energi telah dikembangkan untuk beberapa jenis antena penerima [8].

### C. Antenna Dipole

Antenna is one of the important tools used in the world of telecommunications. It has an important role in telecommunication transmission systems, where electromagnetic waves are emitted to and captured from free space.

The characteristics of a dipole antenna include the following:

1. Omnidirectional, which is sending and receiving waves evenly at a certain angle.

2. Low gain. Because the waves are emitted evenly in all directions, causing the power to be evenly distributed, so that the power value is not as great as if the waves were emitted in a certain direction only.

3. Does not require a ground plane.

4. The shape is simple, because it can be made with only two conductor cables. In general, the ends of the two cables that form the dipole antenna are disconnected (open circuit), this causes the current flowing in the dipole to tend to be parasitic capacitance. Parasitic capacitance is capacitance that occurs due to the presence of several electronic components that interlock nearby. the current flowing through this uncontrolled parasitic capacitance causes radiation.

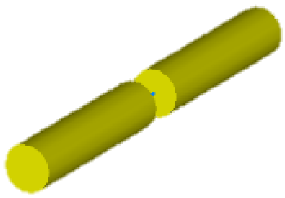


***Figure 2*** *Antenna Dipole*

### D. S-Parameter

S-Parameter is a quantity that describes the relationship of the input and output terminals of a transmission line with respect to the strength of the emitted or reflected signal. The concept of S-Parameter in two terminals can be seen at Figure 2.

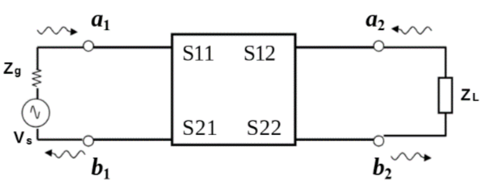



***Figure 3*** *S-Parameter Concept with Two Terminals*

Description:

S11: comparison of power in and out of terminal 1

S12: comparison of power entering from terminal 1 and exiting to

terminal 2

S21: comparison of power entering from terminal 2 and exiting to

terminal 1

S22: comparison of power entering and exiting terminal 2

a1 : incoming power from terminal 1

a2 : power entering from terminal 2

b1 : power coming out to terminal 1

b2 : power out to terminal 2

$$S11 = \frac{\boldsymbol{b1}}{\boldsymbol{a1}} \quad (2.1)$$

$$S12 = \frac{\boldsymbol{b1}}{\boldsymbol{a2}} \quad (2.2)$$

$$S21 = \frac{\boldsymbol{b2}}{\boldsymbol{a1}} \quad (2.3)$$

$$S22 = \frac{\boldsymbol{b2}}{\boldsymbol{a2}} \quad (2.4)$$

### E. Radiation Pattern

A radiation pattern is a graphical representation of the radiation characteristics of an antenna. The radiation pattern of an antenna is called a field pattern if the field strength is depicted. To express the radiation pattern graphically, it can be described in absolute or relative form. Relative form means a normalized radiation pattern, where each value of the radiation pattern is divided by its maximum value. So that the normalized radiation pattern can be expressed by equation 2.5.

$$F(\theta,\Phi) = \frac{\boldsymbol{E}(\boldsymbol{\theta},\boldsymbol{\Phi})}{\boldsymbol{E}(\boldsymbol{\theta},\boldsymbol{\Phi})\mathbf{max}} \quad (2.5)$$

### F. Voltage Doubler

The RF input signal is in the positive part of the cycle input followed by the negative part of the cycle input. The voltage stored on the input signal during half a cycle is transferred to the output signal during the next half cycle of the input signal. Therefore, the voltage at the approximate output is approximately twice the peak voltage of the RF source, reducing the diode turn-on voltage. Below is a picture of the circuit in Figure 4.

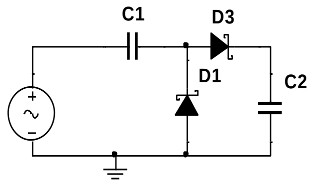



***Figure 4*** *Voltage Doubler [9]*

### G. *Dioda Schottky*

Schottky diodes use metal semiconductors, resulting in fast junctions and high voltage drops. The type of system used by the author in this final project is the HSMS 2822 Schottky system.

***Figure 5*** *Dioda Schottky HSMS 2822 kemasan SOT-23 [10]*

## III. RESEARCH METHODOLOGY

### A. *Workflow*

The stages of this final project based on Figure 3.1 begin with the planning and fabrication of the dipole antenna. This survey will be used as input for the RFEH system design in the original design. Then proceed to match the implementation and design. If there is a mismatch, optimization is performed to unify the calculation and simulation. As a result of implementing the RFEH system, the output voltage and voltage efficiency are measured. Next comes the test run.

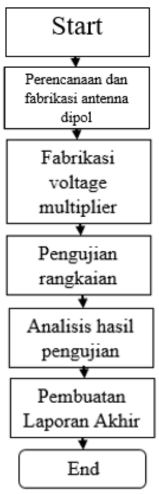



***Figure 7*** *Flow of Final Project*

At this stage, the dimensions of the antenna will affect the characteristics of the antenna to be made. The calculation stages of the dipole antenna dimensions such as determining the wavelength and length of the dipole antenna. Before determining the length of the dipole antenna, the wavelength must first be determined because the length of the dipole antenna is related to the wavelength. To calculate the wavelength can use the equation.

$$\lambda = \frac{c}{f}$$

Dimana $\lambda$ = wavelength (mm)

c = speed of light (m/s)

f = frekuensi kerja (Hz)

This antenna design uses CST Microwave Studio software based on the antenna dimensions obtained from the above calculations. The first design made is a dipole antenna. Antenna design aims to find out how good the antenna performance is and the results of the antenna are in accordance with predetermined specifications or not. Table 3.1 shows the Dipole Antenna Parameters.

| PARAMETER | UKURAN (mm) |
|---|---|
| L | *46* |
| R | *2.5* |
| Gain | 2 |

***Table 1*** *Parameter Antenna Dipole*

### B. *Voltage Multiplier Design*

The design starts with determining the performance of the electronic device. It works using the XPS system source. Multisim software simulation is then used to determine the number of steps, the type of components from the number of inputs until the output voltage expected to be used for the TMP102 temperature sensor is obtained.

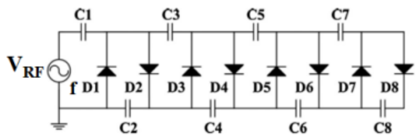



***Figure 6*** *Villard-Dickson Series of Stages*

### C. *Rectenna circuit design*

The rectenna circuit or wave rectifier generally uses a 1N 5711 diode as its main component. Figure 7 shows the rectenna circuit design that will be applied to a dipole antenna in an omnidirectional radiation pattern.

The last stage of this research is the assembly of the rectenna that has been made by adding several components and then connected to the dipole antenna that has been fabricated using a cable. Figure 8 shows the schematic of the rectenna circuit.

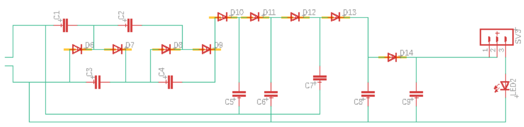


***Figure 8*** *Rectenna circuit design*

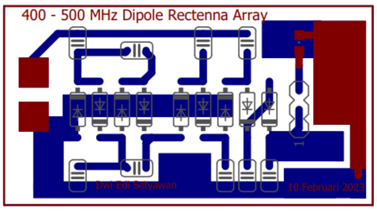



***Figure 9*** *Rectenna circuit schematic*

***Figure 12*** *Antenna Manufacturing Realization*

### *D. Circuit Testing*

This device system has two phases (The test scenario is shown in Figures 9-10):

1. An antenna that captures or receives the electromagnetic system around the system.

2. In power harvesting, the electromagnetic wave system is converted into a direct current electrical system and amplified at the same time. The generated DC electrical energy can be stored or used to charge low-power devices.

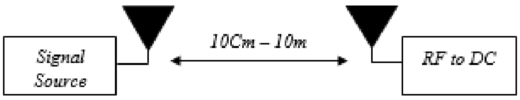



***Figure 10*** *Testing Scenario 1*

In testing the Rectenna system, system testing was carried out using a Signal Source (access point) which was carried out around the ITTelkom Surabaya Campus. Radiation power is measured at the same distance as the Rectenna. The conversion results of the RF rectenna acquisition were then measured using a Spectrum Analyzer. As shown in Figure 9-10.


***Figure 11*** *Testing Scenario 2*

The antenna is like a transmitter that captures the electromagnetic wave system, multiplies it by a voltage and then the rectifier converts it into a DC current. After the system is tested, then analyze and make a report on the results of the system test.

## IV. RESULTS AND DISCUSSION

After following the flowchart described earlier, here are the simulation and measurement results of the $\boldsymbol{\lambda}/2$ Dipole Antenna.

### *A. Antenna Manufacturing Realization*

The circuit used consists of diodes as rectifiers and bypass capacitors. The diode used is Schottky Diode 1N5711, this diode is suitable for high frequency and can detect AC electrical signals with low power. This diode circuit is connected to a low pass filter (LPF) by a 100 pF ceramic capacitor. The voltage multiplier is used to increase the DC voltage generated by the rectifier. In the last circuit, a 100 pF ceramic capacitor is used which is connected in parallel with the RL load. The bypass capacitor serves to pass the remaining ripple signal, so that all DC signals can be maximized to RL.

This RL load will be changed later to see the effect of load changes on the resulting DC voltage.

### *B. Dipole Antenna Design*

The dipole antenna designed in this final project has an arm length of 6.25 cm, a width of 2.5 cm diameter arm and a distance between arms of 2 cm. By using CST Microwave Studio, the dipole antenna design is obtained as shown in Figure 11.

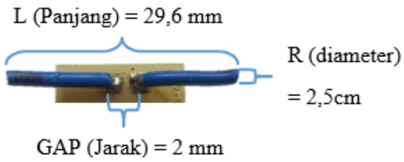



***Figure 13*** *Dipole Antenna Rectenna Dimensions*

Pada penelitian ini, $\lambda = \dfrac{c}{f}$

Dimana $\lambda$ = panjang gelombang (m)

c = kecepatan cahaya (m/s)

f = frekuensi kerja (Hz)

Pada penelitian ini, $\lambda = \dfrac{3x10^8}{2,4x10^9}$ $\lambda = \dfrac{300.000.000}{2.400.000.000}$

$$\lambda = \frac{3}{24}$$

$\lambda = 0,125$ m = 12,5 cm

$$\lambda = \frac{12,5}{2}$$

$\lambda =$ 6,25 cm (Panjang)

### *C. Radiation Pattern*

For simulation results using CST Microwave Studio software with a $\boldsymbol{\lambda}/2$ dipole antenna. Radiation patterns from simulations that have been carried out are obtained as shown in Figure 14.

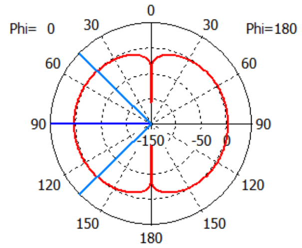


*__Figure 14__ 2.4 Ghz Radiation Pattern Results*

From Figure 4.3, the $\lambda$/2 dipole antenna has radiation that is not only in one direction. The radiation shape of the $\lambda$/2 dipole antenna is donut-shaped, which means that the radiation of the $\lambda$/2 dipole antenna is almost radiated in all directions. So from the simulation data, it can be said that the $\lambda$/2 dipole antenna is an antenna that radiates in all directions (omnidirectional).

### D. *Return Loss*

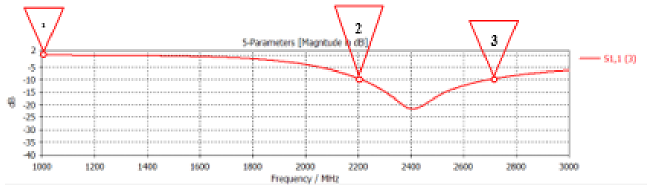


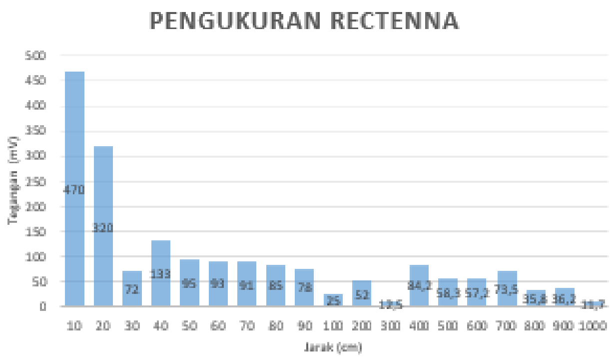
*__Figure 15__ S-Parameter Results Frequency 2.4 Ghz*

From Figure 15, it shows that the bandwidth of the $\lambda$/2 dipole antenna is 2,200 to 2,700 MHz. This is based on the return loss value that meets the requirements for the antenna to work properly, which is for a return loss below -10 dB.

### E. *Measurement of Output Voltage on Rectenna*

In this subchapter, the results of rectenna measurements can be seen in Table 2 showing the results of rectenna measurements at several distance variations with RF sources.

*__Table 2__ Rectenna Measurement Results at Cm distance variation*




| Jarak (cm) | Tegangan (mV) |
|---|---|
| 10 cm | 470 mV |
| 20 cm | 320 mV |
| 30 cm | 72 mV |
| 40 cm | 133 mV |
| 50 cm | 95 mV |
| 60 cm | 93 mV |
| 70 cm | 91 mV |
| 80 cm | 85 mV |
| 90 cm | 78 mV |
| 100 cm | 25 mV |
| 200 cm | 52 mV |
| 300 cm | 125 mV |
| 400 cm | 84,2 mV |
| 500 cm | 58,3 mV |
| 600 cm | 57,2 mV |
| 700 cm | 73,5 mV |
| 800 cm | 35,8 mV |
| 900 cm | 36,2 mV |
| 1000 cm | 11,7 mV |

The results of this measurement are carried out with the need for a distance between the rectenna and the RF source of 10 cm to 1000 cm. Ideally, the voltage at the rectenna output has a smaller value with each increase in distance. But during the test, there were some anomalies in the voltage value. These anomalies are due to the fact that the test was conducted in a non-ideal environment. There are many objects and materials made of metal around the test location. The dipole antenna can be seen in Tables 4.1-4.2. It can be seen that the working frequency of the antenna is 2.4 GHz, with a return loss value of below -10 dB. The minimum and maximum frequencies at 2200 to 2700 MHz.

### F. *Data Analysis*

Based on the results of the analysis and detailed discussion of the data processing results on the measurement results, it is found that the rectenna frequency of 2.4 GHz can work well. But in the measurement process it was found that the distance affects the amount of voltage produced.

## V. Conclusion

From the data that has been obtained and the analysis that has been done, it can be concluded that:

To obtain the characteristic parameters of the $\lambda$/2 dipole antenna can also use an alternative way by using CST Microwave Studio. Measurements from a distance of 10 cm to 1000 cm. From the measurement results obtained, it shows that the distance between the source antenna in the rectifier circuit and the voltmeter greatly affects the DC voltage output. The resulting radiation pattern is omnidirectional radiation pattern. In the research that has been done, the design and realization of rectenna for frequency 2.4 GHz simulation results using CST Microwave Studio show that rectenna works at frequency 2.4 GHz, with bandwidth of 500 MHz from 2200 MHz to 2700 MHz with return loss below -10 dB.

The voltage measurement test results show that the rectenna is able to convert electromagnetic waves into DC electricity.

## ACKNOWLEDGMENT

In this final project, measurements were not taken in an ideal environment. For this reason, in the next final project research, measurements need to be made in an ideal environment (Chamber).

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