

Design of Rectifier Antenna (RECTENNA) for Electromagnetic Energy Harvesting at Frequency of 3500 MHz

(Perancangan Antena Penyearah (Rectenna) untuk pemanen energi Elektromagnetik
pada Frekuensi 3500 MHz)

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Abstract — This research purposed the design of rectenna that it can convert the electromagnetic field source into the DC voltage output. The research is conducted in two steps, simulation and fabrication of antennas, and rectifier circuit. This research applies CST Studio Suite software to simulate the antenna and NI Multisim 14.0 to simulate the rectifier. The antenna has been designed and fabricated by utilizing the array antenna of the circular patch microstrip with adding of the insertion feeder with 7 mm of length and 1 mm of width to reach of the matching antenna. The rectifier has been created by using BAT 85 DO-35 Schottky diode where it can work at high frequency. The measurement result of the antenna is minimum with the return loss amount of 33.783686 dB, bandwidth is 100 MHz, and VSWR (Voltage Standing Wave Ratio) is 1.021669. The rectenna can receive a maximum voltage of 11 mV at a range of 1cm.

Keywords — Circular Patch, Rectenna, Array, Schottky Diode, BAT 85.

Abstrak— Artikel ini membahas perancangan antenna yang dapat mengubah sumber medan elektromagnetik menjadi tegangan keluaran DC. Penelitian dilakukan dalam dua tahap, simulasi dan fabrikasi antenna serta rangkaian penyearah. Riset ini menggunakan perangkat lunak CST Studio untuk simulasi antenna dan NI Multisim 14.0 untuk simulasi rangkaian penyearah. Antena dirancang dan difabrikasi menggunakan antenna mikrostrip susun patch melingkar dengan penambahan sisipan pengumpan yang mempunyai dimensi panjang sebesar 7 mm dan lebar sebesar 1 mm untuk mencapai keadaan antenna “Match”. Penyearah telah dibentuk menggunakan BAT85 DO-35 Diode Schottky dimana diode tersebut dapat bekerja pada frekuensi yang lebih tinggi. Hasil pengukuran antenna bernilai minimum dengan rugi – rugi balik sebesar 33.783686 dB, bandwidth sebesar 100 MHz, VSWR (Voltage Standing Wave

Ratio) sebesar 1.021669. Rectenna dapat menerima tegangan maksimum sebesar 11 mV pada sebuah rentang sepanjang 1 cm.

Kata Kunci — Patch Melingkar, Rectenna, Array, Dioda Schottky, BAT 85.

I. INTRODUCTION

The wireless technology is widely used and investigated by many scientists and engineers and the most important thing to conduct wireless communication is an antenna. The antenna is a device that can transmit the important electromagnetic wave through the air media[1]. The microstrip is a thin layer of an electrical conductor and grounding layer that is separated by the electrical isolator layer and well known as the substrate[2]. The patch part from the microstrip is the radiation element that can be radiated the electromagnetic.

The frequency is the amount of repetition cycle in a second and Hertz unit. In the telecommunication worlds, it represents the number of waves that propagates in a second. The frequency is an important resource because the electromagnetic wave transmitted by the antenna will propagate into the air and the existence of particular frequency. Currently, the frequency of 3.5 GHz in Indonesia is applied by the satellite communication. In the future, this frequency is planned for the 5G cellular communication that can give internet services with low latency[3].

By the existence of energy resources that will not run out, it requires to be an utilization of energy emitted from the BTS (Base Transceiver Station) other than communication purposes. One of technique that can be used is the energy harvesting technique. The energy harvesting is a technique

that uses an approach by taking the energy from various sources to improve the battery function. In this technique, it is explained how to send the power supply through the wireless media [4]. There are various kinds of energy harvesting techniques that have been developed are the utilization of solar energy or more familiarly called solar cells [5], waste vibration energy that utilizes vibration as a energy resource then it is converted into the electrical voltage using piezoelectric material [6] and the energy produced from radiation electromagnetic waves for sending information using a rectenna (rectifier antenna). Rectenna is an antenna that it's integrated with a rectifier circuit to convert an electromagnetic source into a DC output voltage [4].

The previous research, it has been design the rectenna at the frequency of 1800 MHz and produce the average of voltage amount of 0.4 mV[4], and the frequency of 2400 MHz creates the average of voltage amount of 4.02 mV[7]. This paper explains the design of rectenna as a changer of the electromagnetic wave into the DC Voltage by utilizing the frequency of 3500 MHz as the working frequency of 5G in Indonesia[3].

II. RESEARCH METHODOLOGY

A. Research Method

The research process divided into the few stages that is conducted base on the research procedures;

- The problem identification by concluding the background until the aims of this research.
- Literature studies by collecting the data from reference books and journals as suitable as the research topics of rectenna, circular patch of micro-strip antenna, micro-strip array antenna, and diode rectifier circuits.
- Simulation by conducting the simulation of antenna and rectifier circuits to get the model from the expected devices.

Fabrication by realizing the result from the expected model from the simulation process into the physical shapes based on the material size, design, and components.

B. Research Flow Chart

This research creates an antenna to convert the energy from the electromagnetic wave that it is emitted by the particular transmitter then accepted by the rectenna, afterward the received energy is converted from the AC voltage into the DC voltage by using the rectifier circuit. The design of rectenna can be implemented by following the design flow as shown in figure 1.

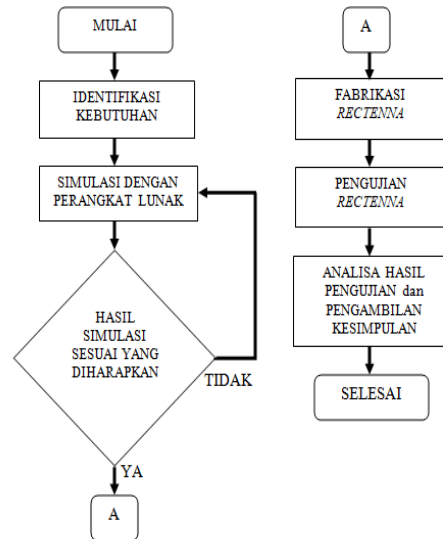


Figure 1. The research flowchart.

C. Determination of Antenna Characteristics.

The working frequency or operating frequency is expected from 3.45 GHz until 3.55 GHz with the center frequency amount of 3.5 GHz. The bandwidth is 100 MHz at the return loss = 10 dB with the lowest return loss point at 3.5 GHz, and also the VSWR is less than 2. These values will be the basic parameter of antenna for determination of the antenna dimension, the width of the supply path and any others.

D. Determination of substrate

After getting the antenna characteristic then choosing the substrate to be used. In this experiment, the substrate chosen Determination of substrate was Rogers Duroid RT5880 with the specifications in Table 1.

Table 1. Substrate specification of Rogers Duroid RT5880[8]

Parameters	Value
Dielectric Constant	2.2
Thickness	1.575 mm
Material Conductivity	$2 \times 10^7 S/m$
Loss Tangent Dielectric	0.0009
Relative Permeability	1
Constant	

E. Calculation of Antenna Dimension.

After determining antenna characteristics and choosing the substrate that to be used, afterward, calculate the patch antenna dimension. Before computing of the value of the patch antenna dimension, first, calculate the logarithmic function value of the radiating element F using [9];

$$F = \frac{8.791 \times 10^9}{f_r \sqrt{\epsilon_r}} \quad (1)$$

$$F = \frac{8.791 \times 10^9}{3.5 \times 10^9 \sqrt{2.2}} = 1.693$$

After getting the F value, then it can be count the radius of patch antenna (a) by utilizing equation[9];

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi \epsilon_r F} \left(\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right)\right\}^{1/2}} \quad (2)$$

$$a = \frac{1.693}{\left\{1 + \frac{2 \times 0.1575}{\pi \times 2.2 \times 1.693} \left(\ln\left(\frac{\pi \times 1.693}{2 \times 0.1575}\right) + 1.7726\right)\right\}^{1/2}}$$

$$a = 1.597 \text{ cm} = 15.97 \text{ mm}$$

Because the antenna to be made is the array antenna, each antenna must be separated between the midpoints of patch. The distance of two patch antenna (d) can be written by using the equation[9],

$$d = \frac{c}{2f_r} \quad (3)$$

$$d = \frac{3 \times 10^8}{2 \times 3.5 \times 10^9} = 42.85$$

After getting the length of the patch radius, then determine the dimension of the substrate. Length and Width of the substrate will be adjusted by the radius of the patch, the distance between the center points of the patch, and Length and Width of the supply channel. Therefore, the length and width of the substrate to be used are 90 x 60 mm.

F. Determination of the power supply channel dimension.

Each antenna must have a channel that connects the power supply channel or the feed channel to the antenna load. The feed channel to be used is a microstrip channel type and it has an impedance characteristic (Z_K) amount of 50 Ω . For getting the feed channel on the matching conditions of the array antenna is two patches, it will use the impedance transformer (Z_T) for connecting the input of line impedance (Z_0) = 50 Ω and the load channel impedance (Z_L) = 100 Ω . The impedance of the transformer is obtained by using the formula [10],

$$Z_T = \sqrt{n} \times Z_K \quad (4)$$

$$Z_T = \sqrt{2} \times 50 \Omega = 70.71 \Omega$$

To get the width of the feed channel, it can use the menu on CST application by following the command *Macros* → *Calculate* → *Calculate Analytical Line Impedance*.

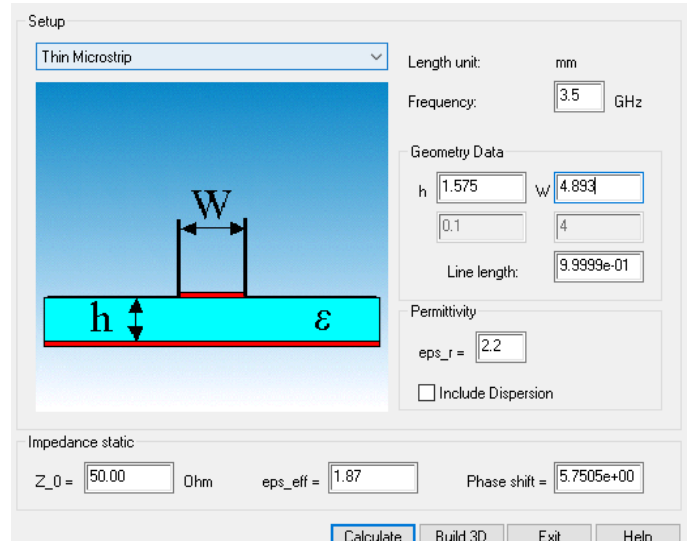


Figure 2. The width calculation of the power supply channel using CST application.

Figure 2 shows the substrate thickness amount of 1.575 mm, the dielectric coefficient is 2.2 and the input of line impedances are 50 Ω , 70.71 Ω and 100 Ω where it requires the width of the power supply channel amount of 4,893 mm, 2,807 mm and 1,417 mm respectively.

G. Determination of the rectifier circuit and diode

This research report uses the full-wave rectifier circuit because the expected voltage is DC. For getting the result, a full-wave rectifier is chosen because of the wave release by the AC voltage. Afterward, the AC voltage will enter into the two diodes for changing with the same voltage and the difference phase[11]. The elective diode is adjusted to the technology requirements because each diode has the difference characteristic. In this study, BAT85 schottky diodes were chosen because they are needed for the low current with the high-frequency operation[12].

III. RESULT AND DISCUSSION

The expected research result are the data from simulation, antenna fabrication, and rectifier circuit.

A. Antenna simulation result.

The modeling and simulation result of the antenna is obtained from the calculation result to get the initial dimension values of the antenna by utilizing the equation (1), (2), (3), (4) and (5). The antenna dimension result is shown at table 2 below.

Table 2. The calculation result of the antenna dimension.

Antenna Dimension	Value (in mm)
Radius	15.97
Length of Substrate	90
Width of Substrate	60
Thickness of Substrate	1.575

Distance between patches	42.85
Width of channel 50 Ω	4.893
Width of channel 70.71 Ω	2.807
Width of channel 100 Ω	1.417

Simulation of the antenna is achieved by entering the values mentioned in table 2. The results of the manual calculation and the CST program are all values in the table.

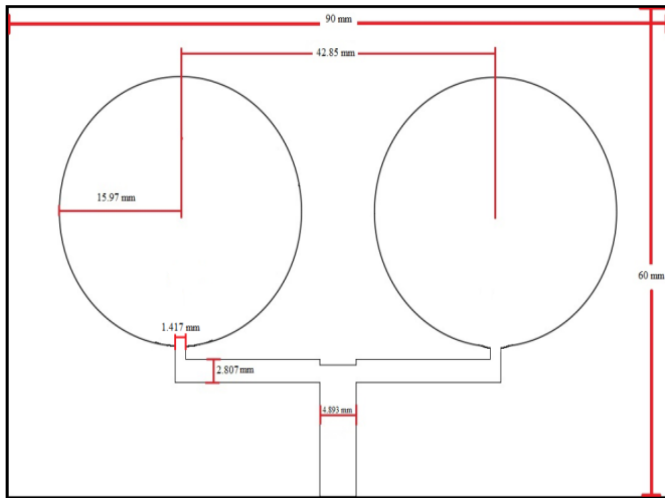


Figure 3. Simulation product of dimension of the antenna array

In Figure 3 shows the initial simulation results of antenna array dimensions. The antenna has the results of S11 Parameters in the form of return loss and VSWR shown in Figure 4

Figure 4 indicates the effect of the return loss at a frequency of 3.5 GHz equal to 8.1128298 dB, while VSWR at a frequency of 3.5 GHz equals 2.2947. The above tests have not met the expected value where the estimated return loss is less than 10 dB and VSWR is less than 2 so it is important to refine the antenna to get the expected value.

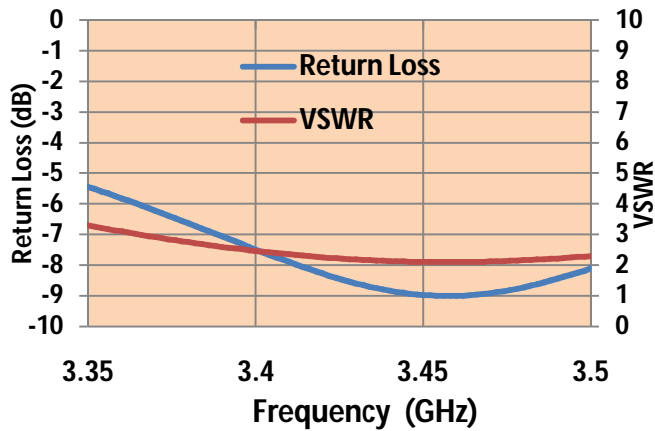


Figure 2. Simulation result of S11-Parameter before optimization process

The optimization is conducted by changing the antenna dimension and using the insertion feed technique, which is by

adding a gap on the side of the supply channel with a gap length of 7 mm and a gap width of 1 mm. The antenna picture of the simulation result after optimization process is shown in Figure 5.

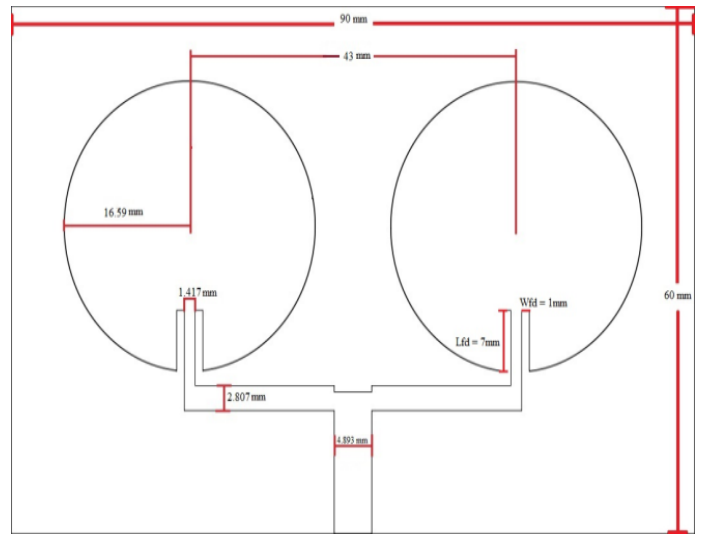


Figure 5. The antenna dimension after the optimization process

From figure 5 to get the optimal parameters, the optimization process is done by changing the radius to 16.59 mm, the distance between patches to 43 mm, and adding the insertion feed with a gap length of 7 mm and a gap width of 1 mm. The S-parameter results of the antenna after optimization are seen in figure 6.

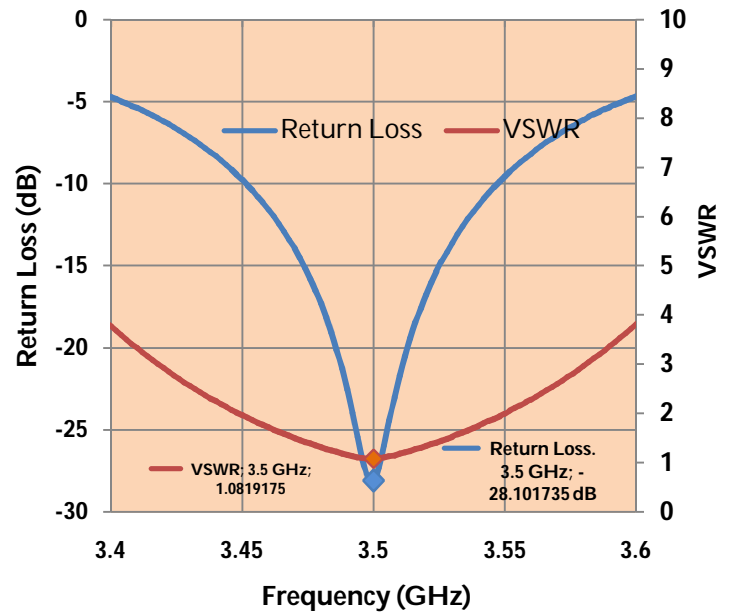


Figure 3. The simulation result of S11-Parameter after optimization

From Figure 6 shows the simulation result after optimization of the S11-Parameter, it's getting the lowest of return loss result at the frequency of 3.5 GHz is equal to 28.1017 dB, and also obtained bandwidth at a return loss of 10 dB in the range of 3.4519 MHz to 3.5459 MHz so that the antenna bandwidth of 94 MHz is obtained. Figure 6, the VSWR value at a frequency of 3.5 GHz is 1.0819. Furthermore, knowing the antenna gain simulation results after optimization will be shown in Figure 7.

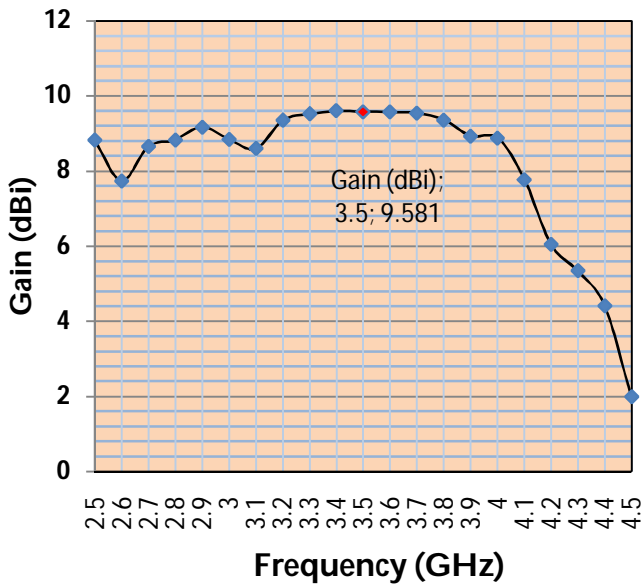


Figure 4. The gain of simulation antenna after the optimization

The frequency graph of the array antenna is shown in Figure 7. From the results a 3.5 GHz frequency antenna gain is obtained at 9581 dBi.

B. Simulation result of Rectifier Circuit

The simulation is started by preparing the components that stored at Library Menu then choose the diodes amount of 4 parts, the capacitor is 1 part, LED is 1 part, the AC current source, millimeter and Oscilloscope. Afterward, the components are assembled to look like Figure 8. Determination of the capacitor value influences the amount of voltage that can be produced, the value of the condenser used must have a low capacitance value for the use of high frequencies, and therefore a capacitor with a capacitance value of 1nF is selected.

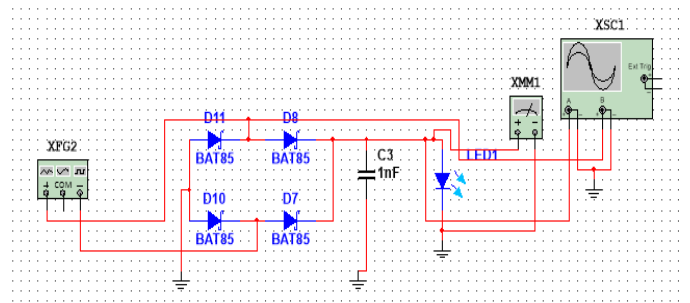


Figure 5. Simulation of rectifier circuit using NI Multisim

The circuit's function in the simulation is demonstrated in Figure 8 after simulating the rectifier circuit to be studied. The rectifier circuit simulation findings can be seen in Figure 9 as well as Figure 10.



Figure 9. Simulation result of rectifier circuit using Oscilloscope

Figure 9 indicates the oscilloscope settled on results. The voltage generated on channel A is a signal originating at a frequency of 3.5 GHz from an AC current source and the signal is also in the form of an AC signal. The resulting signal is then redirected from the rectifier circuit in channel B, the signal begins to increase and then becomes stable at ± 3.6 V.

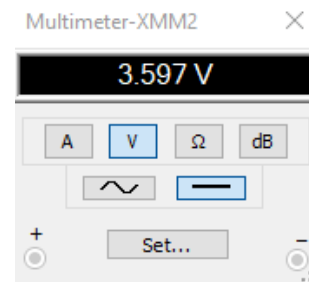


Figure 6. The voltage result at the multimeter.

The measurements are made using a multi meter to determine the voltage produced by a rectifier circuit. In Figure 10, the voltage value on the LED is also on the load; at the source function generator, the voltage value on the LED is 3.597 V DC.

C. Antenna Fabrication and Rectifier Circuit

After the antenna and rectifier circuit model is obtained that will be made. Then both can be produced to have the antenna and rectifier circuit physical condition. Figure 11 displays a circular array of microstrip antennas on the Rogers Duroid RT-5880 substrate with a patch radius of 16.59 mm. Figure 12 shows the results of the rectifier circuit using a schottky BAT 85 DO-35 diode after the fabrication phase.

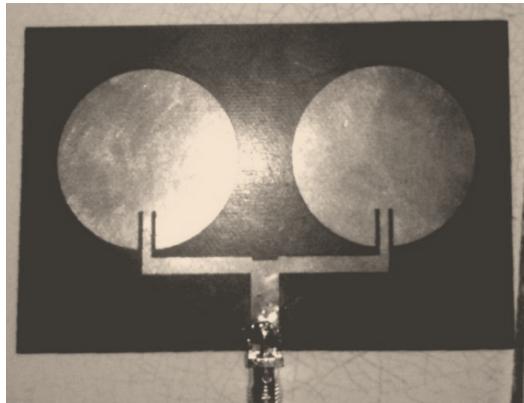


Figure 7. Fabrication result of antenna



Figure 8. Fabrication result of rectifier circuit

D. Antenna Measurement Result

After the antenna has been produced using measurements, the antenna performance is measured. The observable parameters are return loss, VSWR, and antenna gain. Return loss calculation and VSWR is achieved by linking the antenna that was manufactured with a network analyzer. Figure 13 displays effects of return loss antenna and VSWR measurements.

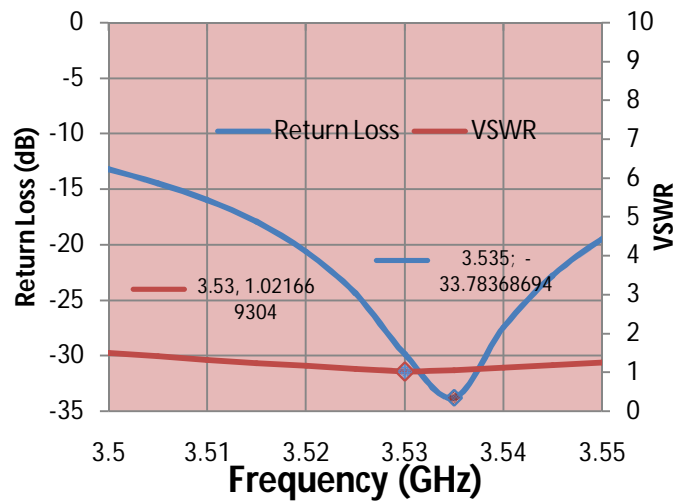


Figure 9. Measurement result of S11 parameter with return loss and VSWR

In Figure 13, the Return Loss chart shows the effects of antenna measurements showing that the antenna's lowest return loss value is 33,7836 dB at a frequency of 3,535 GHz, and the antenna bandwidth obtained at a return loss of 10 dB is 100 MHz (3,485 GHz-3,585 GHz).

From Figure 13 the results of the VSWR antenna measurement obtained the lowest point at a frequency of 3.53 GHz with a VSWR value of 1.02166 these findings are included in this study's estimated value. The gain calculation is carried out using the two antenna system, where identical antennas are used as transmitter and receiver. Measurement results for the antenna gain are shown in table 3.

Table 3 The parameters of gain measurement.

Parameters	Value
Frequency of Generator	3500 MHz
Power of Generator	0 dBm
Distance of Antena	90 cm
Receiving Power Level	-32.52 dBm

In table 3, the power level obtained in the spectrum analyzer is -32.52 dBm or 5.59×10^{-7} W, λ is 0,0857 m, the gap between antennas (R) is 0,9 m and the transmitting power is 0 dBm or 0,001 W, respectively. Use the gain measurement on an antenna similar to formula (6)[2] can be translated from these data into gain parameters. Where R and λ in meter (m), P_r and P_t in Watt (W).

$$\begin{aligned}
 (G_{ot})_{dB} &= \frac{1}{2} \left[20 \log_{10} \left(\frac{4\pi R}{\lambda} \right) + 10 \log_{10} \left(\frac{P_r}{P_t} \right) \right] \quad (6) \\
 &= \frac{1}{2} \left[20 \log_{10} \left(\frac{4 \times 3.14 \times 0.9}{0.0857} \right) + 10 \log_{10} \left(\frac{5.59 \times 10^{-7}}{0.001} \right) \right] \\
 &= \frac{1}{2} [43.9 + (-32.52)] = 5.69 \text{ dB}
 \end{aligned}$$

From the calculation formula (6), it can be found the gain antenna amount of 5.69 dB at the frequency of 3500 MHz.

E. Measurement Result of Rectifier Circuit

Measurement of the rectifier circuit is performed by connecting the rectifier circuit and signal generator as show in Figure 14, and then the oscilloscope connects the output result of the rectifier circuit to show the output signal and the voltage.



Figure 10. The rectifier circuit test.

The measurement result of the rectifier circuit is shown in Figure 15 below.



Figure 11. The rectifier circuit test using Oscilloscope.

In Figure 15, the result of tests conducted by the oscilloscope. It can be seen the signal that is made successfully converts the AC input signal into the DC. The DC voltage is 3.2 V then decrease to 2.4 V, this is due to the ability of the capacitor used in the fabrication process is different from the capacitor in the simulation software.

F. Measurement Result of Rectenna

The rectenna calculation is conducted using the two antennas, where the first antenna is connected to the signal generator and the second is connected to the rectenna. Both antennas are made face-to-face and the distance between the two antennas is held away to see the difference in distance from the power the rectenna gets. The results of the measurement resolution for rectenna shown in Figure 16.

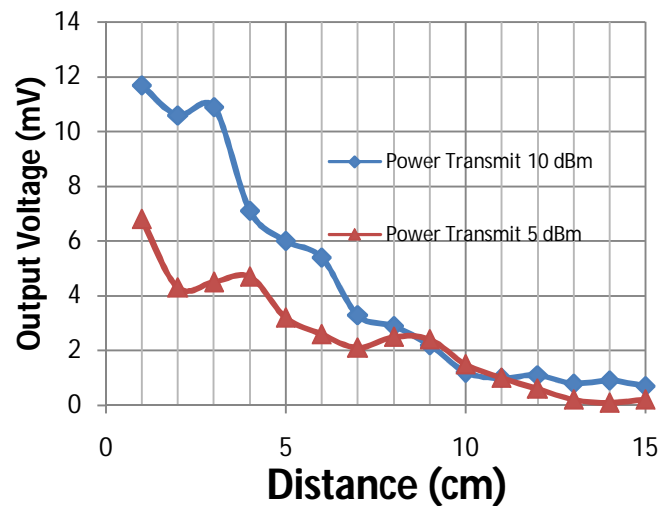


Figure 12. Output Voltage from Rectenna

Figure 16 shows the voltage graph that could be produced from the rectenna. The blue line represents the voltage created from a 10 dBm transmitter, and the most received voltage at a distance of 1 cm from Figure 16 is 11.7 mV. Although the red line indicates the transmitter generates a voltage of 5 dBm, the average voltage produced at a distance of 1 cm is 6.8 mV.

IV. CONCLUSION

From the above study, there are three variations from the results of antenna simulation with the results of antenna testing provided on the parameter S11, where the results of the measurement have a higher frequency of 0.857 percent, a greater bandwidth of 6 MHz and a lower return loss of 5.6813 dB than the results of the simulation. The antenna results also increase when the fabricating results are smaller than the results of the simulation which is equal to 5.69dB. The effect of the distance between the rectenna and the reference antenna reduces the voltage and the losses that occur when the process of transmitting power in the air.

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