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Analysis of Energy Harvesting Systems from RF to Dc Power

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Abstract
Harvesting energy system from RF signals has great potential as an alternative energy source. This research focuses on the performance of an energy harvesting system that converts RF signals into DC Power using components such as Schottky BAT-17 diodes and MKM 100V 1nF capacitors. The main components used in this matching network are a 100 Ohm resistor, 100nH inductor, and 0.33pF capacitor. The 100 Ohm resistor was selected based on impedance analysis to achieve good matching, reduce signal reflections, and increase power transfer efficiency. A 100nH inductor is used to match impedance and filter out unwanted frequencies, chosen because this value provides appropriate inductance at the target frequency. Tests were carried out at distances of 1m, 3m and 5m with Vpp results of 30.4 mV at distances of 1m and 3m, and 45.6 mV at a distance of 5m. The obtained voltage decreases with increasing distance: 3.35 V at 1m, 3.19 V at 3m, and 2.85 V at 5m. Energy conversion efficiency also decreases with increasing distance. In the long term, performance shows good stability even though there is a decrease in voltage and efficiency. Technical obstacles such as signal degradation and efficiency can be overcome by network matching optimization.

Keywords: harvesting energy; rf signal; dc power; diode schottky.

Introduction

Currently, energy harvesting technology from radio frequency (RF) signals has become an interesting research topic in the development of renewable energy systems. New Energy and Renewable Energy (EBT) are an alternative source of energy supply, because apart from having a low impact on environmental damage, it also guarantees energy sustainability into the future. The availability of clean and affordable energy has become one of the 2030 sustainable development goals, where energy sustainability has become a global issue and requires the commitment of the central and local governments to participate in implementing this goal. In 2018, national use of new energy and renewable energy only reached 11.68% and was still far from the target (Setyono et al., 2019).

By utilizing RF signals that already exist around us, this technology has the potential to reduce energy needs that currently most people expect only from fossil fuels. However, over time, fossil sources will be used up. One solution to overcome this is by harvesting energy at radio frequencies. Suppose we imagine a city full of wireless communication devices, such as radio stations, cellular networks, and Wi-Fi devices. RF signals from these devices travel through the air at varying frequencies, forming a dense electromagnetic landscape, imagine an office building with special antennas that pick up RF signals in the surroundings. Even distribution of RF signals in a building or city creates opportunities to place more energy harvesting antennas, increasing the total potential energy that can be generated.

Although the concept of harvesting energy from RF signals is promising, technical challenges still need to be overcome. So far, previous research has focused on increasing energy conversion efficiency and optimizing antenna design to improve signal capture. However, further research is needed to explore its full potential and overcome technical barriers that may limit practical implementation. Therefore, this research aims to investigate and analyze the energy harvesting system from RF signals to DC power, with the hope of making a contribution to overcoming technical challenges and encouraging progress in renewable energy technology.

This research is relevant in the context of the application of renewable energy technologies in urban environments, where RF signals are widespread. By utilizing energy sources that already exist around us, we can open the door to more distributed and environmentally friendly energy solutions. This energy harvesting produces small amounts of power to supply low-power devices. Regarding this energy harvesting, a tool is needed in the form of an antenna to capture electromagnetic waves from radio frequency transmitting sources and a rectifier to convert electromagnetic waves into DC voltage (Aditama et al., 2019). This research is also relevant because it uses a pan bolic antenna because it has a parabolic reflector which allows it to collect and focus RF signals to a focal point, so this can increase the receiving power and performance of the antenna.

Economically, the application of this technology can reduce operational and maintenance costs for wireless devices, as well as help overcome battery power limitations. Therefore, this research has the potential to become a foundation for the development of economical and sustainable renewable energy solutions. By exploring the potential of energy harvesting technology from RF signals, this research is expected to provide new insights and positive contributions to the development of renewable energy technology in the future. With the energy harvesting system from RF signals, it is hoped that it can also make a significant contribution to the development of smart cities and smart devices that require efficient energy sources.

Literature Review

Energy is an entity that we always feel and need in our daily lives. There are various forms of energy that are often encountered, such as motion energy, heat energy, light energy, electrical energy, electromagnetic energy and others. Technological developments are currently increasingly rapid, many technologies are becoming more advanced and modern, one of which is the development of telecommunications technology. The increasing number of communication and data transmission tools or devices currently contain radio frequency (RF) transmitting sources, such as radio transmitters, cellular base stations, television stations, wireless transmitters, and other RF-based devices. The transmitter causes many electromagnetic waves in the surrounding environment. From this, various research has emerged which has now been developed to be able to utilize the energy contained in electromagnetic waves in the surroundings as an alternative energy source, also known as Energy Harvesting (Novian Rahmatur Rajab et al., 2019).

Harvesting energy or taking energy from the surrounding environment has become the main focus in renewable energy research. Utilization of nearby energy sources, including RF, has attracted attention because it can overcome the limitations of conventional resources. Analysis of RF signal characteristics, such as frequency, strength, and modulation, is a primary focus in understanding the potential energy that can be extracted from the surrounding environment. Energy harvesting is a process where energy comes from external sources such as solar energy, heat, radio frequency (RF) waves and other electromagnetic waves that emit signals. One device that can be used to harvest electromagnetic waves is a rectifier that is integrated with an antenna. A receiving antenna integrated with a full wave rectifier circuit converts electromagnetic wave radiation energy into DC voltage (Aditama et al., 2019).

In the energy harvesting system, the significance of Radio Frequency (RF) signals is a key element in energy harvesting technology. Widespread RF signals in our environment create great potential as an alternative energy resource that can be utilized efficiently. Energy harvesting is a process where energy comes from external sources such as solar energy, heat, radio frequency (RF) waves, and other electromagnetic waves that emit signals. One device that can be used to harvest electromagnetic waves is a rectifier that is integrated with an antenna.

Converting energy from RF signals into DC power requires an efficient system. Various technologies and conversion methods have been developed, such as rectenna (rectifying antenna) which converts electromagnetic energy into DC electrical energy. Rectenna is a combination of a rectifier and antenna, namely a device whose function is to convert electromagnetic waves into electrical power (Novian Rahmatur Rajab et al., 2019). Several factors that influence the rectenna output include antenna topology, rectifier circuit, and a combination of both. The antenna topology and arrangement, for example arranged in an array, is expected to be able to capture RF signals optimally, so as to improve RF power harvesting. A deep understanding of this conversion mechanism is important for designing an effective Energy Harvesting system.

A number of studies have been carried out in the domain of Harvesting Energy from RF signals, such as those carried out by Hamka Ikhlasul Amal NZ, Arfianto Fahmi and Yuyu Wahyu (2016). In his research, it was stated that energy harvesting is a process where energy comes from external sources such as solar energy, heat, RF (radio frequency) waves and other electromagnetic waves that emit signals. The test results show that the rectifier successfully converts AC signals into DC electrical voltage. Output measurements using a double quad antenna produce 0.954 Volts (indoor), 1.206 Volts (outdoor), and 2.604 Volts (UHF TV working frequency) (Ikhlasul et al., 2016).

Based on the research above, a more in-depth analysis will be carried out regarding the Energy Harvesting System from RF Signals to DC Power. The main focus of this research is analyzing the performance of the energy harvesting system, identifying technical obstacles that arise and examining how the Wajan Bolic antenna can capture radio frequency signals into DC power so that harvesting energy or energy harvesting from RF signals is maximized.

Methods

To understand the characteristics and performance of a wok bolic antenna, the methods and techniques used in calculating key parameters relating to work bolic antennas whose value must be calculated are the fedder (fw) Pan focus. The figure is shown in the following bellow.

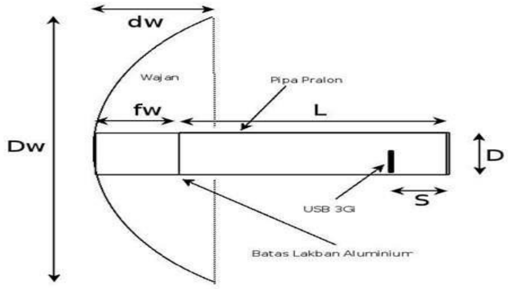

Figure 1. Bolic pan calculation diagram

Distance of the antenna focal point :

$$Fw = \frac{w^2}{dw \ x \ 16} \quad (1)$$

Meanwhile, calculating the length of the paralon pipe covered with aluminum foil duct tape (L) requires a longer step. So the calculation must be done first, namely the radio wave length is 900 Mhz. Using the following equation

$$\lambda \frac{c}{f} \quad (2)$$

In practice, the development of RF energy harvesting circuits faces major challenges related to the nonlinear behavior of the diode and the low amplitude of the input signal. As a result of the nonlinearity of the diode, the impedance of the rectifier varies depending on the input power, frequency, and load resistance, which ultimately limits the performance of the circuit at a limited frequency, and hinders maximum power transfer. However, practically, this issue is not a major concern here because the available power does not reach that level. In fact, a major concern in designing a harvesting circuit is the availability of adequate RF power levels. The RF signal received by the antenna cannot activate the rectifier diode, thereby reducing the efficiency of the circuit. In situations like this, the use of a matching network can effectively overcome this problem by ensuring maximum power transfer from source to load. The use of matching networks can be implemented using either concentrated elements, such as resistors, inductors, and capacitors, or dispersed elements.

The main components used in this matching network are a 100 Ohm resistor, 100nH inductor, and 0.33pF capacitor. The 100 Ohm resistor was selected based on impedance analysis to achieve good matching, reduce signal reflections, and increase power transfer efficiency. A 100nH inductor is used to match impedance and filter out unwanted frequencies, chosen because this value provides appropriate inductance at the target frequency, helping to maximize power transfer efficiency. The 0.33pF capacitor works with the inductor to form an LC circuit that regulates resonance and ensures good impedance matching.

If the input peak voltage exceeds the diode voltage threshold (Vth), diode D1 will flow current in the forward bias phase or become open. As a result, capacitor C1 will store charge so that Vc1 = A - Vth. D2 will become open due to reverse bias. In the negative cycle of a sinusoidal wave, current flows through capacitor C2 and diode D1, making D1 reverse biased or open, while D2 becomes open. The output on capacitor C2 will be charged equal to the input voltage plus the voltage stored on C1. From this process, it can be concluded that the output voltage of C2 is twice the input peak voltage minus the diode threshold voltage.

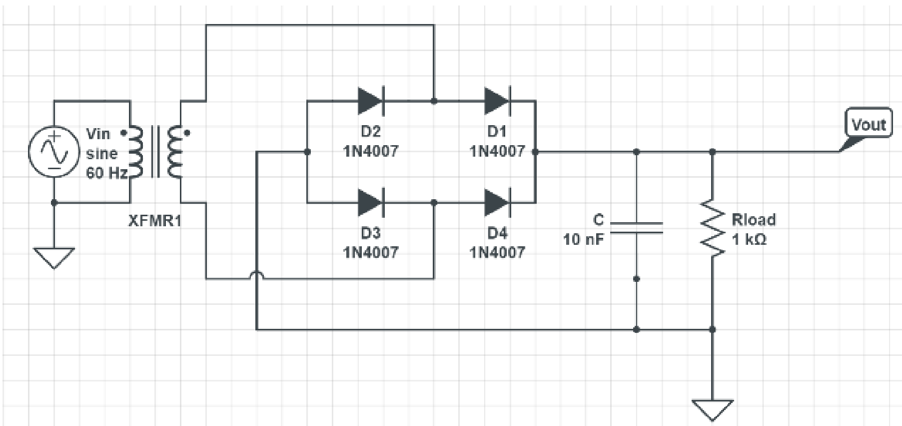

Figure 2. Full Wave Voltage Doubler Circuit

From the overall circuit, the input of a radio frequency signal in the form of 400 MHz will enter and then flow through the 7 stage Dickson model Rectifier circuit, after which it will go straight into the Filter before flowing out to the energy saving area, where the use of the filter here can also reduce the amount noise resulting from energy harvesting. The simulation results can be seen using an oscilloscope and multimeter to see the output of the energy harvesting circuit.

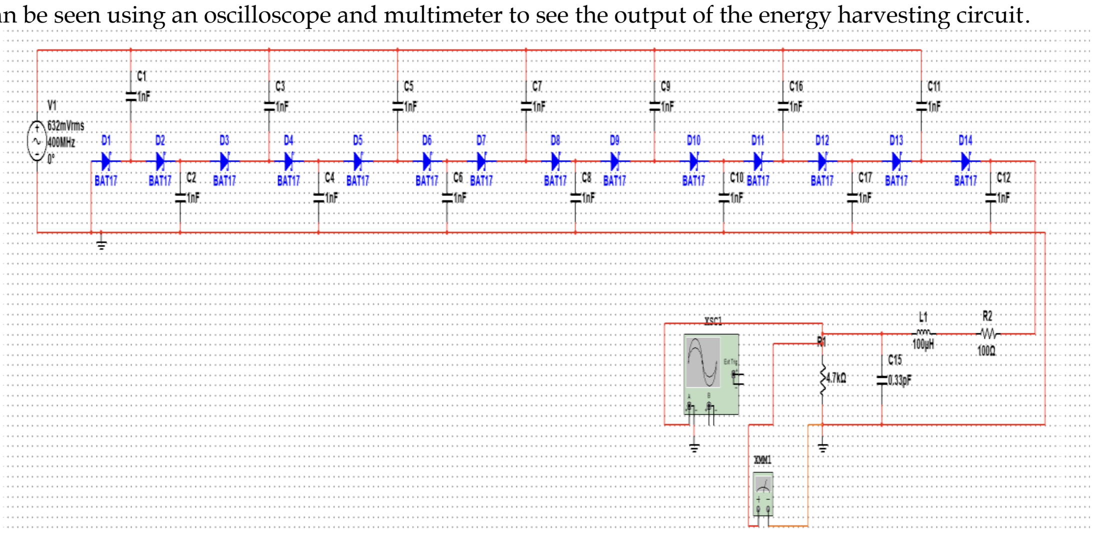

Figure 3. Overall circuit of the RF Energy harvesting system

Results and Discussion.

The RF input measurement process is carried out by producing measurement values as shown in Figure 4. 1 This measurement was carried out in three experiments with varying distances: 1 meter, 3 meters and 5 meters. Each experiment aims to evaluate how effective the system is in capturing RF signals at different distances. An oscilloscope is used to display and analyze the waveform of the received RF signal, while a frequency counter is used to measure the signal's frequency precisely

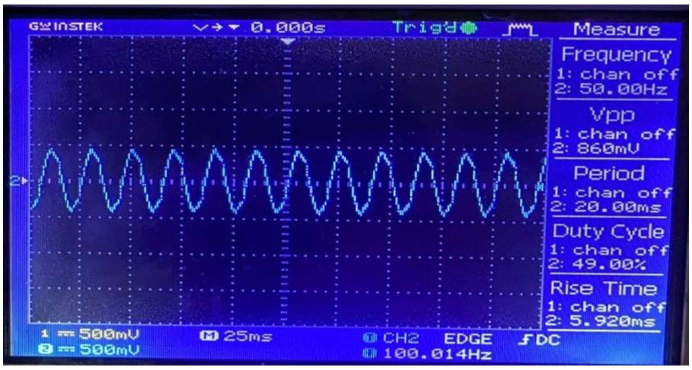

Figure 4. Rf Input Signal

The measurement results from each experiment are recorded and arranged in Table 1, making it easier to analyze system performance at various distances. This analysis will provide a deeper understanding of how distance affects the efficiency and effectiveness of the designed energy harvesting system.

Table 1. Measurements of frequency

Parameter	Pengukuran 1	Pengukuran 2	Pengukuran 3
Frekuensi (Frequency)	56,121 Hz	67,380 Hz	99,950 Hz
Tegangan Puncak-ke-Puncak (Vpp)	860 mV	820 mV	780 mV
Periode (Period)	19.80 ms	20.00 ms	19.80 ms
Duty Cycle (Siklus Kerja)	52.53%	50.00%	51.52%
Waktu Naik (Rise Time)	4.880 ms	5.145 ms	5.187 ms

Frekuensi counter(Hz)	462,125 MHz	462,825 MHz	469,951 MHz

The test results of RF signal measurements, as shown in the graph, show that the level of movement of the wave frequency shows significant changes as the distance increases. From the measurement results, it can be seen that the farther the signal distance, the signal will experience greater interference with the peak-to-peak (Vpp) value and the period displayed. This interference is usually caused by several factors, such as higher signal attenuation, interference from external sources, and signal quality degradation. At a distance of 1 meter, the RF signal is relatively stable with consistent Vpp and period. However, at a distance of 3 meters and even further at 5 meters, the interference starts to become more obvious. Vpp experiences larger fluctuations, and the signal period becomes less stable. This analysis shows that distance is a crucial factor in the efficiency of the system for harvesting energy from RF signals. The greater the distance between the signal source and receiver, the greater the interference that occurs, which can ultimately affect the energy conversion efficiency.

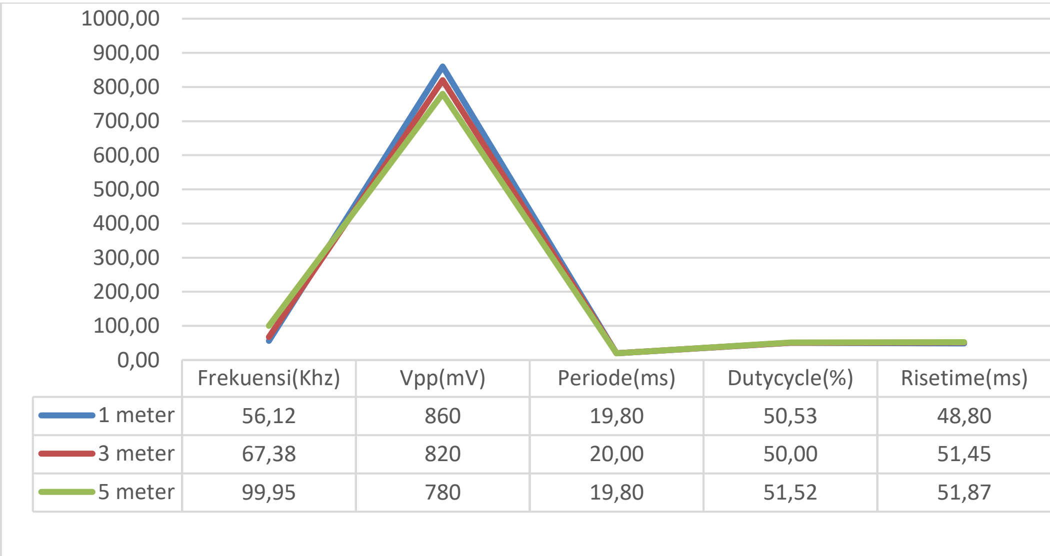

Figure 5. The energy harvesting system shows stable performance

Overall, the test results show that the energy harvesting system from RF signals has satisfactory performance in the aspects of frequency stability, conversion efficiency and duty cycle. With continued development and optimization, this system can play an important role in supporting low-power electronic devices and encouraging the use of alternative energy that is more environmentally friendly and sustainable. This opens up opportunities for further innovation in the field of renewable energy and green technology, which is much needed in this modern era.

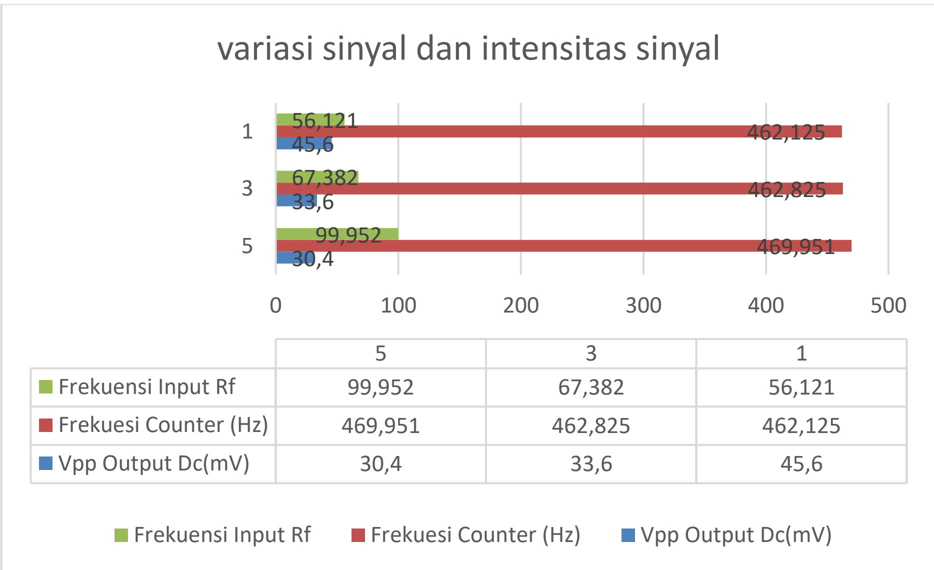

Figure 6. Signal Variation and Intensity

Conclusions

The energy harvesting system shows quite good performance in converting RF signals into DC electric current. The output voltage obtained at a distance of 1 meter is 3.35 v, at a distance of 3 meters is 3.19 v, and at a distance of 5 meters is 2.85 v. Long-term testing shows that the system has good stability. In the first 1 minute of power measurement, the system produced 327.46 mW of power. After 15 minutes, the power generated was 322.54 mW, and at the 30 minute reading, the power returned to 330.22 mW. These results indicate that the system is not only stable but also has the ability to maintain nearly consistent performance over long periods of time. This research identified several technical obstacles that affect system performance, such as a decrease in RF signals due to distance, loss of power in components and the resulting DC signal still contains ripples which can disrupt output stability. These factors cause variations in output voltage and energy conversion efficiency. The research results show that the Wajan Bolic antenna is effective in capturing radio frequency signals and directing them to the receiving system, where the signals are then converted via a 7-stage Dickson rectifier circuit into a usable DC voltage, with multitester measurements showing a voltage of 2.62V . This voltage proves that the designed system is capable of harvesting energy from radio frequency signals in the surrounding area and converting it into DC electrical voltage, thus demonstrating the antenna's ability not only to capture RF signals but also optimize the use of these signals to produce stable electrical energy.

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