Prototype Design of Radio Frequency Energy Harvesting for Lighting Applications

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Article Info	ABSTRACT (10 PT)

The prototype resonant frequency is designed to work at 150 MHz. The signal source prototype is the signal that comes from handy talky (HT). There are two subsystems, which are Matching Impedance and Voltage Multiplier. The resonant frequency of the matching impedance subsystem at 143 MHz from 0.053 mH inductor and 0.0233 pF capacitor. The output of the matching impedance subsystem is then amplified by the multiplier voltage subsystem using parallel PH4148 diodes with the 6-stage multiplier. Load prototype is a CR-151 LED that works at 12 volts 1 watt. When the HT battery has a voltage of 7.3 volts, the prototype can turn on the lamp with the distance between the TX antenna and the antenna on the prototype less than 36 cm. The maximum voltage on the load is 6.8 volts with a length of 5 cm between the antenna and the lamp 774 lumen.

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1. INTRODUCTION

Electrical energy is one of the primary roles in daily life [1], [2]. One of the needs for artificial lighting, which generally comes from electrical energy in the transportation sector, is lighting on public roads. Lighting consumption only from the public roads sector took up 1.83% of the total electricity consumption in Indonesia in 2015, which was 104.49 GWh per year [3]. The largest source of electrical energy used in Indonesia comes from fossil energy sources that come from petroleum [4]. Petroleum is a non-renewable energy source whose yields will fall over time [5], [6]. Thus, there are three efforts needed to overcome the problem of energy shortages in Indonesia, including (1) looking for new oil fields [7], (2) developing renewable energy [5], [8]–[10], and (3) using energy efficiently [11].

The concept of energy harvesting was finally developed to do 2 (two) efforts simultaneously, namely developing renewable energy and using energy efficiently. An energy harvesting system is an energy collected from the environment using a transducer that converts the surrounding energy into electrical energy to supply autarchic electronic devices. One type of energy that can be collected is Radio Frequency (RF) energy [12]. RF energy harvesting is also called ambient (collection) RF energy. Ambient RF energy comes from the many emitters of various radio transmitters, including cell phones, mobile base stations, Wi-Fi access points, broadcast television, broadcast radio stations, and more. Apart from being free and green energy, collecting this type of ambient RF energy has advantages concerning the design of portable devices. Which can be battery-free or at least extend battery life, which can be done without connectors and cables, and have freedom for mobility during charging and use [13]. If lighting technologies use the harvesting energy, it will have many advantages such as (1) renewable energy, (2) efficient energy use, (3) freedom from complicated cable

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installation, and (4) flexibility of device position cause of transfer energy occur wirelessly. The future of this prototype can be applied in many systems such as live performance lighting, photography lighting, garden lighting, and lighting for the fair event.

Radiofrequency is a source that has been harvested in this prototype. As a light source of prototype load, CR−151 LED was chosen that works at 12 Volts, 1 Watt. The load impedance must match the source impedance to transfer the optimum amount of power from the start to the load. Common problems of source and load mismatching can be corrected by connecting devices matching impedance between source and load. Device matching impedance can be components, circuits, or equipment [14]. One of the devices matching impedance is a parallel LC resonance circuit. The parallel resonant circuit is shown in Figure 1 (left). The inductor and capacitor are connected in parallel, then connected to the supply source. The resistance R represents the coil resistance. The value of R is usually minimal and is generally negligible compared to other impedances. Capacitor C is assumed to be lossless. The source frequency VS may vary. Inductor, capacitor, and frequency relationship resonance (fr) are indicated by equation (1) [15]. In other words, the resonance circuit selects the frequency range over which the response will be close to or equal to the value maximum, as shown in Figure 1 [16].
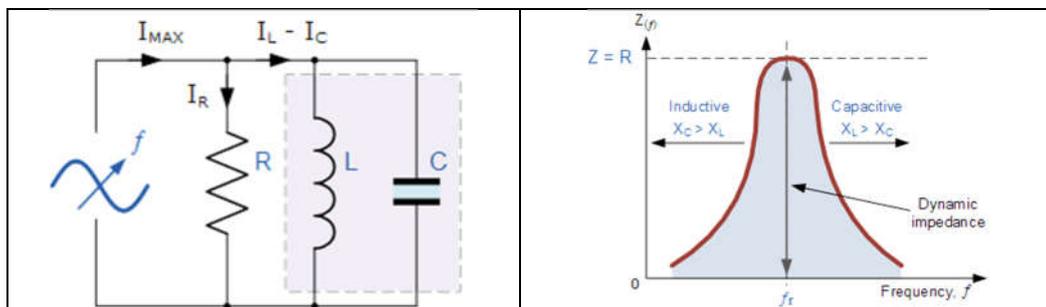

Figure 1. (left) Parallel resonance circuit; (right) Amount of power in resonance state (Yahdi et al. [16]).

A voltage multiplier is a circuit configuration consisting of two or more peak rectifiers designed to produce a direct current (DC) voltage that is a multiple of the peak input voltage (e.g., 2Vp, 3Vp, 4Vp, etc.). The unique aspect of this circuit lies in its ability to be connected in series, much like batteries, to achieve a significantly higher output voltage by stacking multiple stages. This feature allows for substantial voltage amplification without requiring an increase in the input voltage. The schematic representation of a voltage doubler, which is a basic form of a voltage multiplier, is illustrated in Figure 2.
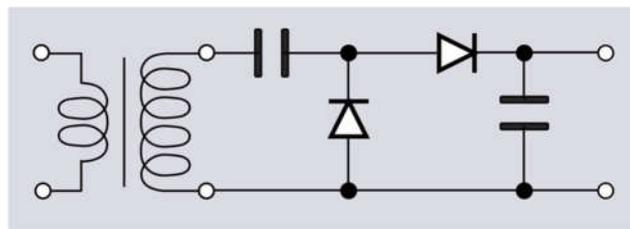

Figure 2. Schematic of the voltage doubler.

To get accurate data in the study, the researcher must determine the frequency used. The HT is the transmitter with a large enough power that is easy to find by researchers. This paper briefly designed and measured the prototype's performance by observing the voltages depending on the distance. So, researchers will develop a prototype that uses one of the frequencies that HT, namely 150 MHz, can emit. So, we made the prototype for energy harvesting using the radiofrequency energy converter technique for lighting applications.

2. METHOD

This research was conducted with engineering writing and the Borg & Gall model [18]. There are ten steps in the Borg & Gall model; we only use four stages, including: (1) analysis, (2) design, (3) development, and (4) testing.

a. Analysis

This step includes a review of the theoretical literature and observations (field studies) to analyze the needs of the specifications or performance of the prototype. In the field study, we decided that the transmitter uses HT, which has 150 MHz. Thus, we used the HT Diamond BNC HT antenna on the prototype and HT

Lupax VEV−V18 as a transmitter. We conducted a field study and looked for less power but more significant than ordinary light-emitting diodes (LED) lamps. Thus, we determined to use the CR−151 light, optimally active with 12V 1W. Then, we looked for capacitors available in the market which matched perfectly with oscilloscope specifications, multimeter specifications, and LCR meter specifications.

b.   Design
        This phase consists of designing subsystems and systems. We designed subsystems making, including (1) matching impedance and (2) voltage multipliers.
    i.   Impedance Matching Subsystem Design
        The matching impedance circuit consists of capacitor and inductor components. The capacitor component uses a capacitor made of MLCC (Multilayer Ceramic Capacitor) and has no polarity. For inductor components, use a toroid transformer. The inductor component uses a toroid transformer. The toroid transformer uses a toroid core. The toroid core used is *W157081A*. The dimensions of the toroid core can be seen in Table 1 [19].

Table 1. W157081A toroid core dimension specifications.

Outer diameter 40	40.72 mm
Inner diameter	23.30 mm
Height	15.37 mm
Cross-sectional area	133.8727 mm^2
Volume	10.500 cm^2
Material Permeability	60 μ
AL	81 nH/N^2
Toroid color code	Bluish Green
Material	Fe-Si Alloy Powder
Winding wires	0.50 mm

Source: Dongbu Electronics Material [19].

        The LC meter measures inductors at a minimum of 0.02 mH. Thus, we consider designing an appropriate inductor value of 0.05 mH. Using the calculations listed on the toroid core datasheet, the number of turns is 29. The value of the capacitor in the matching impedance circuit can be known by analyses using the following equation (1) and (2). Then we measured the inductance value of the inductor and got a weight of 0.053 mH. To find out the value of the capacitor, we cannot use an LCR meter because the minimum capacitor measurement is 0.02 nF. Thus, we measure the resonant frequency of the matching impedance circuit so that the capacitor value can be found using the resonance frequency calculation formula (based on equations (1) and (2)).

$$150 \times 10^6 \, Hz = \frac{1}{2\pi\sqrt{(0.05 \times 10^{-3} \, H) \times C}} \tag{1}$$

$$C = 2.12 \times 10^{-14} \, F = 0.0212 \, pF \tag{2}$$

Based on equations (1) and (2), the capacitor in the market whose value is the smallest that we can obtain is 0.1 pF. So, we arranged a series of 5 capacitors with 0.1 pF to make them 0.02 pF.

    ii.   Voltage Multiplier Subsystem Design
        The matching impedance output is planned to be equal to 1 Volt. Hopefully, it became an input of the voltage multiplier subsystem. To have 12 Volts in production with a current of 84 mA, the design of the prototype of the voltage multiplier subsystem made a series of 6 levels (12Vp) voltage multiplier.

c.   Development
        In this phase, we build subsystems matching impedance and voltage multiplier based on the design stage. Then we tested each subsystem to find out the actual value of the components made to determine the difference between the component design value and the availability value of the fundamental element.

    i.   Matching Impedance Subsystem Development
        We test the resonance frequency in the matching impedance subsystem. But, first, we try to push the resonance frequency in the matching impedance circuit. The matching impedance circuit is tested by sending

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an RF signal via HT. Then the output voltage is measured by being given a distance of 5 cm between the transmitter (HT) and the antenna prototype (Figure 4). HT battery has a voltage of 8 Volts when testing. The test is carried out at each frequency that HT can transmit, namely 136−172 MHz. The measurement results are shown in Figure 3, indicating that the resonant frequency is 143 MHz and can produce 1660 mV. After testing the resonant frequency, the capacitor value of the matching impedance subsystem can be seen and is known to be 0.0233 pF. The output voltage results from the test at the resonant frequency are shown in Figure 3.
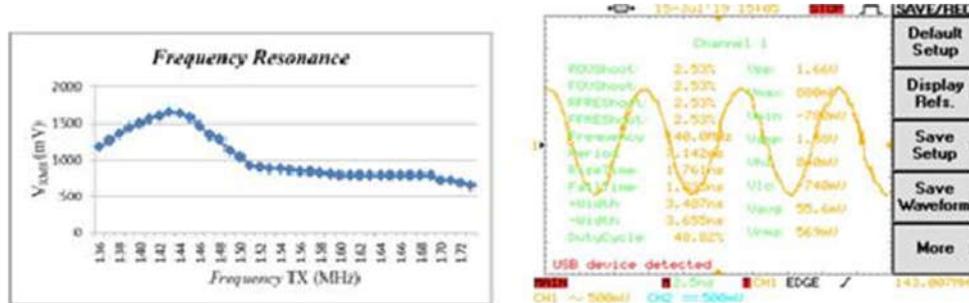

Figure 3. (left) resonance frequency graph when the range of TX antenna is 5 cm from RX Antenna; (right) matching impedance measurement results with an oscilloscope at the resonance frequency.

ii.   Voltage Multiplier Subsystem Development

We test the voltage multiplier circuit. The input voltage comes from the CT transformer. Given that the minimum voltage that the prototype can amplify is equal to the forward bias voltage of the diode. The forward bias voltage of the germanium diode is 0.2−0.3 Volts. So, the examiner decided to test the circuit Voltage multiplier at a voltage of 300 mV. The input voltage is measured to have 312 mV, and the output from the subsystem voltage multiplier with the 6-stage produces a voltage at Capacitor 0th of 1.4VDC. Measurement documentation is shown in Figure 4, and the test results are shown in Figure 5.
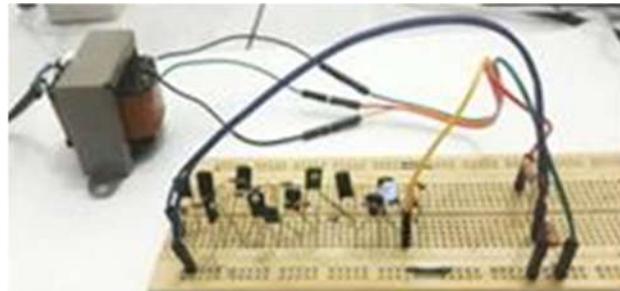

Figure 4. Building the voltage multiplier for testing before implementation.

Based on Figure 4, after all the circuit has been tested, the subsystems (matching impedance and voltage multiplier subsystem) will try to experiment to find out the previous assembly's results in Figure 5.
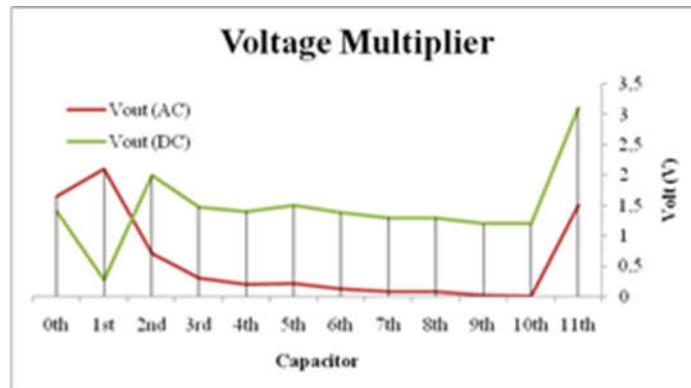

Figure 5. Result of the testing of matching impedance subsystem.

d.   Testing

In this phase, we test the specifications of the actual prototype to find out that the prototype can generate how much voltage and can turn on the load to produce how much light. The research can be complete if the system can turn on a 1W 12VDC LED lamp at the output by utilizing the RF power conversion by a matching impedance circuit and a voltage multiplier.

3.   RESULTS AND DISCUSSIONS

First, test the matching impedance subsystem using PTX common HT type at resonant frequency prototype. The test was carried out repeatedly with differences in the distance between HT and prototype, and the test results are shown in Figure 6.
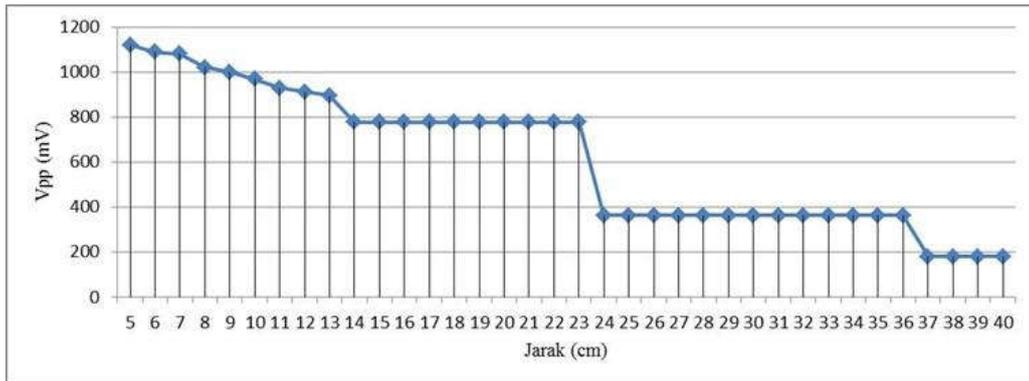

Figure 6. Result of the testing of matching impedance subsystem.

Based on Figure 6, the matching impedance subsystem decreased by increased distance (in cm). The circuit input voltage multiplier comes from the matching impedance subsystem. Testing by sending a low signal from HT at the resonant frequency. The test results, when with load, can be seen in Figure 7 (above) and without a limitation below. Documentation of voltage multiplier testing with loads when RX and TX antennas have a distance of 7 cm can be seen in Figure 8.
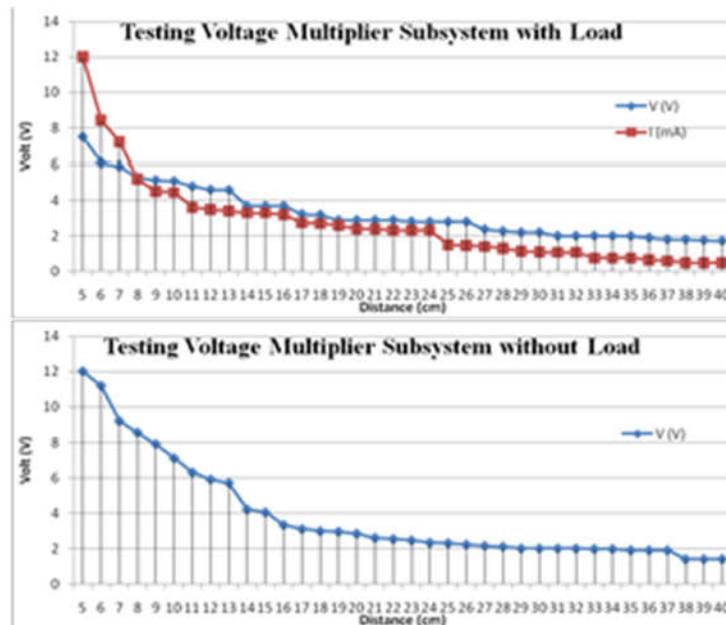

Figure 7. Result of the testing of matching impedance subsystem with load (above) and without limitation (below).
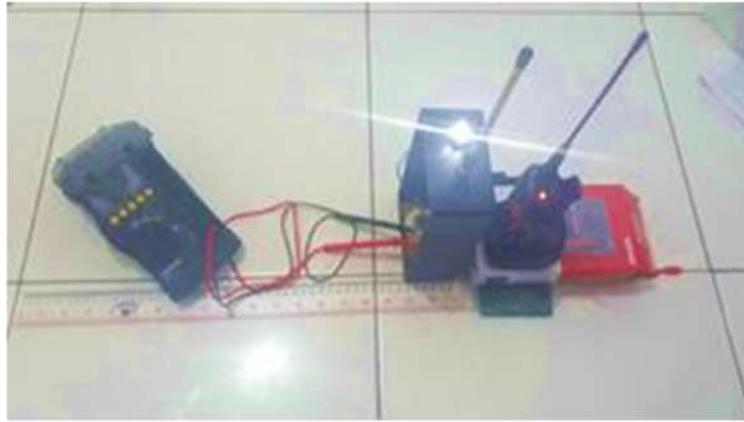
Figure 8. Prototype building.

After building the prototype, we tried load testing to determine how the light was produced at varying distances. The test is carried out when HT has a battery voltage of 7.3 Volts. The load test is carried out in 2 ways, in conjunction with the stress measurement. The results are shown in Figure 9.
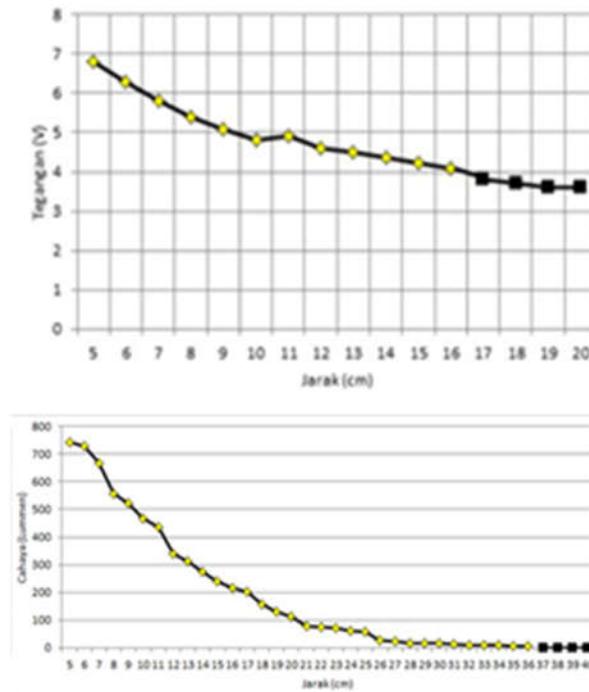

Figure 9. Loads testing occurs when a voltage measurement occurs (above) and does not (below).

Measurement of light at load when not in conjunction with other measurements (only light measurement) in Figure 9 shows that prototype can produce 744 lumens when the antenna distance is HT and the prototype by 5 cm. The yellow color indicates that the load in the form of a lamp has a light and the black color indicates that the load in the form of a lamp does not produce light.

4.   CONCLUSION

When the prototype is not connected to a load, a prototype could have 12 Volts at the output. The moment a prototype has a load, a prototype can produce a DC voltage of 6.8 Volts when the distance between the RX antennas (prototype) and TX (HT) at 5 cm has a 744 lumen of light. A prototype can turn on the load light when the distance between the RX (prototype) and TX (HT) antennas is less than 36 cm, and the space can shorten to 15 cm in length when the measurement occurs. The prototype successfully produced 12VDC as a goal of this prototype based on lamp specifications. When the load was connected (lamp), the voltage was

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decreased, which is the limitation of this paper to find the effect of resistance on load. The impact of this load is possible for a decrease in performance if the system receives more than one receiver. We suggest further research to improve performance for systems with multi receivers. The prototype was made from non-SMD components that are usually used in industry. So, the concept of this prototype could be better.

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