Harvesting Wasted Energy (Low Voltage Electricity) From Electromagnetic Waves Emmited By Electronic Ballast Lamp (Tube Lights)

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ABSTRACT

This paper presents a concept of harvesting and transferring wasted energy (low electricity energy) generated from electromagnetic waves to a low powered electrical appliances using wireless technology that, does not necessitate interconnecting wires between the antenna and the source of electromagnetic waves referred to in this project as electronic ballast lamp. This study is a ground work for the future alternative energy, especially to areas where supplying normal direct energy is a challenge such as in deep sea exploration and remote areas like in mines, as well as to area where power interruption is a problem. This paper shows how the waste signal and energy in lighting nodes (energy saver lamps) could be collected and converted into useful energy that can later be used to supply power to low voltage electrical appliances.

The design work started by simulation using Circuit marker 2000, and then ISIS 7 professional, which was used to develop the design and later used as guidelines in the development of the prototype. The Electromagnetic waves (signal) that is regarded as energy loss available in air is harvested by using an Electromagnetic energy harvesting circuit. This circuit is capable of harvesting the energy and converts it into low voltage electricity. Energy conversion was accomplished by using a wire mesh as an antenna to capture the RF energy and an electronic device that doubles the voltage or the frequency of an input signal called a voltage doublers circuit to convert and magnify the alternating current (AC) input signal to larger direct current (DC) output. The circuit managed to capture 6V (dc voltage) which was stored in a rechargeable battery and developed a power output of about 0.447W. The stored energy in the rechargeable battery was then utilized to power up low-powered electrical appliances such as White LED. General purpose Silicon diodes and capacitors have been used to harvest and amplify the voltage so that a better and higher output can be achieved. This design can further be improved for more stable and larger rechargeable batteries of up to 12Vdc, by the use of combined Germanium diode, Schottky diodes and ceramic capacitors.

Keywords: Low voltage electricity, emission, lost energy, electromagnetic waves, electronic ballast lamp

INTRODUCTION

Portable devices such as cellular phones, personal digital assistants, laptop computers and broadcasting devices such as television and radios has become pervasive over the past decades. Not only that, the successful development of the solid-state devices has brought more techniques of saving energy usage in power systems, for example the development of energy saver lamps. As the technology for these devices improves, the need and desire to use them have also increased exponentially (Grzywacz, 2002) over the years with tremendous increase in the number of users. For example in 1995 the number of telephone users in

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Tanzania was 90,198 people but increased to 8,488,774 people in 2007. Also up to June, 2012 the number of telephone users increased to 28,024,611 people. Figure 1.1 shows the growth pattern and Teledensity (population coverage) from 1995 to 2007. While the population of Tanzania is growing at the rate of 3.3% annually, the annual number of Tanzanian subscribing for a telephone lines grows at an average rate of 48%. (*www.tcra.go.tz*). The growth in users had a corresponding growth of band-width and broadband applica1tions, especially recently.

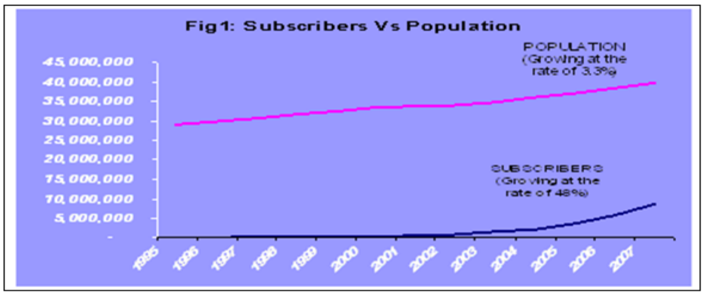

Figure 1.1 Growth Pattern & Teledensity (Population Coverage

When the use of portable devices first started, there were huge in size and massive in weight as compared to what is being used today. However, as the technology for these devices improves over the years, there is also a reduction in the size of these communication devices (Sabate et al., 2002) and hence a reduction in sizes of the batteries to power them. The source of energy to power these devices is not inexhaustible and thus calls for the need to either replace the batteries or recharge them with time by plugging the phone into the wall outlet in order to recharge the battery. This makes it very inconvenient sometimes to stop in the middle of a conversation only to recharge or replace the used-up battery. It is even more disturbing in situations where there is no power available to recharge the phone raising the questions of its “wirelessness” (Harrist, 2004b). The problem of charging and recharging of cellular phones can be solved by making good use of energy from electromagnetic radiation sources such as radio frequencies (RF) (Parker, 2005); a source of free and inexhaustible energy. Sources of this energy include; satellites orbiting around the earth, radio and television towers, as well as cell phone antennas (Harrist, 2004b). The energy from RF frequency can be harvested by means of an effective antenna connected in a circuit, using variable capacitors with diodes to convert the alternating-current (AC) captured from RF frequencies by the antenna to direct-current (DC) (Parker, 2005). The harvested energy can either be used to power remote personal applications like charging mobile phones and cameras. In addition the industrial applications like stand-alone devices such as wireless sensor nodes located in hardly accessible places can now work on their own without having human intervention to replace or recharge battery or store for future use (Parker, 2005).

Rural Electrification in Tanzania

Development of rural areas in Tanzania is very important if efforts to alleviate poverty are to succeed. It should be understood however the supply of energy in these area is very crucial for such development to take place. The supply to rural areas would create opportunities for better health care, education, and income generating activities which are important for rural development. The Country’s Development Vision 2025 stipulates the need to improve energy supply in rural areas and improvement of the welfare and standard of living of the rural population. Rural electrification has been a long time national interest as a prerequisite for socio-economic development.

However, high cost have hindered grid electricity distribution in rural areas. Some projects on transformation of the solar photovoltaic (PV) market in rural Tanzania are now ongoing, in cooperation with donor agencies. The ongoing government effort to promote renewable energy in rural areas can stipulate socio-economic development.(Ministry of Energy and Minerals, 2003).

The number studies to analyze the feasibility to adopt renewable energy technologies in rural Tanzania which can supplement grid electricity when long term plans for rural electrification through grid electricity by government are underway. Studies has shown that rural areas grid electrification problems could be solved with decentralized long term renewable energy sources which may play a crucial role in providing energy services in such areas and also would be environmentally friendly(Karekezi et al, 2002).People living in rural areas have installed solar panels for many applications such as lighting, charging of cell phones, running TVs and radios. Due to high initial cost of buying solar systems some uses small generators which steel have high running cost as the fuel prices is raising every day.

Although the running cost of solar system is low this source of energy is not continuous as it depends on the presence of sun- light. Therefore, challenge here is how to have a sustainable energy. This project focuses on recycling the electromagnetic radiation from energy saver lamps to recharge the battery system. This will pro-long the use of energy since the battery will have be full of charge for some hours during the shortage of sun light. So the expensive solar equipment will be useful as in night remains useless due to lack sun shine.

PROBLEM STATEMENT

This is the modern era, a time period ruled by electronic machines and appliances. As our exposure to electronic objects grows, concerns about radiation have also increased. Although most radiation from everyday devices is harmless(except in extreme cases) energy of ambient electromagnetic waves remains unutilized. Because there is no way to reduce power loss through radiation, a device must be constructed to recycle this energy. With numerous devices like Laptops, Televisions, Radios and Cellular phones being used at a regular basis, one such device would be extremely useful and beneficial. Therefore this project aims to build a device capable of harvesting energy from ambient electromagnetic waves.

METHODOLOGY

Methodology refers to the methods used in collecting, interpreting data ,critically analyzing step by step to be taken during undergoing the project from the beginning to the end and evaluating the possible result or outcome that would be brought by the user of the data collected. This chapter present the ways in which information are gathered from various data sources. The purpose of conducting data collection was to compare amount of electromagnetic waves that can be harvested from fluorescent lamp using electronic ballast and that using electromagnetic ballast one.

Different sizes of antennas were tested to obtain a suitable size of antenna to be used for the proposed electromagnetic waves harvesting circuit. The data for this project were collected through reading different literature reviews and internet surfing.

(i) Primary data were collected through field visiting to get the suitable material to be used as antenna which is cheap compared to the commercial antennas available in the market and also can be easily mounted with fluorescent lamp fitting.

(ii) Secondary data were collected through different books, internet surfing and documents to obtain the relationship between operating range of frequency for electronic ballast lamps and that of the radio waves.

Data Collection Methods

Various data were collected in different area by using primary and secondary methods.

Primary Data

These are technical information that may be collected or obtained from the site through visual or direct measurement. Below are the primary data which were collected in the market on the type of antenna to be mounted with fluorescent lamps in order to harvest the electromagnetic radiation from the lighting sources.

Table 3.1 Sizes of Antenna used to collect EM Radiations from Ballast Lamps

S/No	*Material/Antenna*	*Quantity*	*Dimensions (cm)*
1	Wire mesh	1	120x100
2	Wire mesh	1	100x4
3	Wire mesh	1	120x42

Table 3.2: Different Size of Fluorescent Lamps as Source of EM Radiations

S/No	*Item*	*Size (ft)*	*Power(w)*	*Quantity*	*Voltage (v)*
1	Fluorescent lamp with Electronic ballast	4	40	2	220
2	Fluorescent lamp with Electronic Ballast	2	20	1	220
3	Fluorescent lamp with electromagnetic Ballast	4	40	1	220

Secondary Data

These are information obtained from different sources like stored documents, internet and books. The Table below shows the range of Radio frequency as shown in Figure 2.4 and the range of operating frequency of Fluorescent lamp with electronic ballast as shown in Figure 2.8.

Table 3.3: Different Operating Frequency Ranges

S/No	*Item*	*Frequency rage*
1	Fluorescent lamp with Electronic Ballast	20KHZ - 60KHZ
2	Radio frequency	3KHZ - 300GHZ
3	Fluorescent lamp with Electromagnetic ballast	50HZ - 60HZ

DATA ANALYSIS, DESIGN AND DISCUSSION OF RESULTS

This part indicates how obtained data were compared, analyzed, simulated and design calculations of all necessary components that are to be employed in realization of this project were done. The overall outcome was to have a circuit capable of achieving the main objectives (i.e power harvesting circuit from electromagnetic waves due to use of electronic appliances).

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Determination of the Surface Area of the Antenna

The proposed antenna has different dimensions as shown in Table 3.1. Here the received AC signal is compared so as to see contribution of surface area of antenna to the input AC signal. The antenna material selected is made up of galvanized metal wire mesh. Wire mesh is simple to use and has less weight. Due its shape can be fixed together with the fluorescent lamp easily.

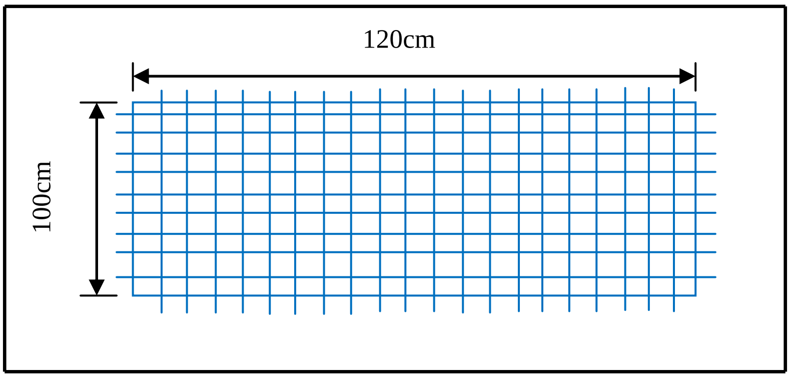

Figure 4.1 Proposed Antenna Configurations

Area calculation: *Area = Length x Width*

Antenna one: *Dimensions 120cm x 100 cm; Area = 120cm x 100cm = 12000cm²*

Antenna two: *Dimensions 100cm x 4cm; Area = 100cm x 4cm = 400cm²*

Antenna three: *Dimensions 120cm x 42cm; Area = 120cm x 42cm = 5040cm²*

After calculation of the antenna surface area the test were conducted to compare the input signals obtained when connected to electronic ballast lamps. The results were obtained by measuring the potential from the antenna with respect to ground. The antenna is attached to the lighting fluorescent lamp. The input voltages obtained from the experiment were shown in Table 4.1.

Table 4.1 Different Antenna Size and Corresponding Distance From RF Source

Distance (Cm)	*Antenna area (cm^2)*	*AC Component (V)*	*DC Component (V)*	*Signal Frequency(KHz)*
	400	4.25	0.22	60
0	5040	5.00	0.25	60
	12000	7.00	0.55	60
	400	2.32	0.21	60
50	5040	3.12	0.22	60
	12000	5.13	0.43	60
	400	0.51	0.08	60
100	5040	1.53	0.19	60
	12000	2.42	0.25	60

From the data obtained in Table 4.1 it shows that the output voltage obtained from the antenna depends on the distance between the antenna and fluorescent lamp. As the distance from the antenna to the RF source increases the output voltage decreases. Therefore to obtain maximum output voltage the distance in between must be kept as small as possible. This can be achieved by attaching the antenna with the fluorescent lamp.

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Comparison of Input Voltage from EM Sources

The proposed sources of electromagnetic waves shown in Table 3.2 were tested by attaching an antenna with different lamps. The aim of the experiment was to compare input signals obtained. The input voltages obtained were tabulated in Table 4.2. The antenna used in this experiment was the with 12000 cm^2 area.

Table 4.2 Signals (input voltages) From Different EM Sources

EM Source	*Power (w)*	*Source voltage (Vac)*	*AC component (v)*	*DC component (v)*
Electronic ballast lamp	40	220	6	0.25
Electronic ballast lamp	20	220	2.5	0.22
Electromagnetic ballast lamp	40	220	0.9	0.44

The data summarized in Table 4.2 shows that electronic ballast lamp rated 40 watts give a promising output voltage as compared to other categories of the lamps. In this project the fluorescent lamp operated by electronic ballast is selected as the source of electromagnetic waves to the proposed electricity harvesting circuit from electromagnetic waves.

RF Detector Circuit Analysis

This part is an analysis of the function of the diode used in the detection part of directional RF detectors. It is the assertion of this section that the diode can act as a square law detector and not as a “rectifier” for low input signals. For small signals, the output of the Low Pass Filter (LPF) in Figure 4.2 is a DC voltage directly proportional to the Power dissipated in R_S. (The LPF can simply be a capacitor placed across R_L). So this will show how the AC component is converted by the detector circuit to get pure DC with the help of filtering capacitor. Consider the following circuit and the typical diode curve in the forward bias region. This looks like a half-wave rectifier circuit, but it’s not always so.

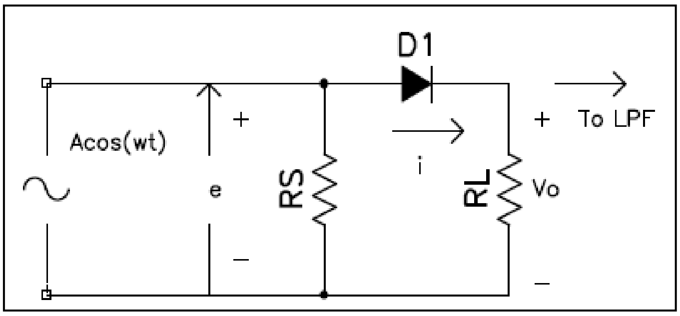

Figure 4.2 Representation of RF detector circuit

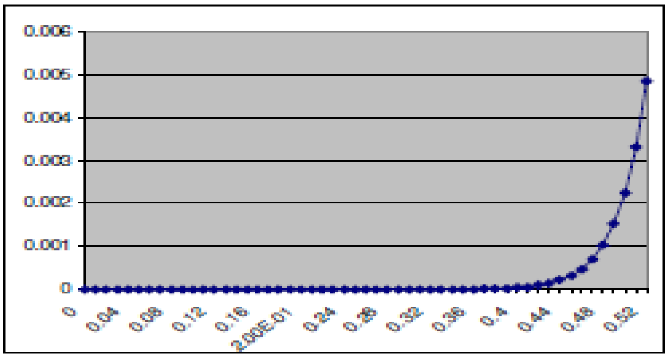

Figure 4.3 Typical diode V-I curve

The following assumptions are made for the sake of simplicity of analysis:

(i) The diode need not have any forward bias to function, but for now, assume that a very small signal is operating in the knee of the curve by adding a small bias current.

(ii) Acos (wt) <<V_{diode} Note that under these conditions, the signal is not rectified

(iii) The V-I curve of the series combination of D_1 and R_L can be represented by a power series of the form;

$$i_d = ae_1 + be_2 + ce_3 + ... \quad (4.1)$$

(i) $R_{diode} + R_L >> R_S$

Analysis of the First Assumption (small signal)

Since, e = Acos (wt), id, may be represented by the polynomial equations as follows,

$$i_d = a\,Acos\,(wt) + bA^2 cos^2 (wt) + cA^3 cos^3 (wt) + ... \quad (4.2)$$

(The Rs term is absorbed in the constants a, b, c, etc.)

In trigonometry ratios, there are identities that are useful. Here are two of them,

$$Cos^2 (wt) = (1/2) [1+ cos (2wt)] \quad (4.3)$$

And

$$Cos^3 (wt) = (1/4) [cos (3wt) + 3cos (wt)] \quad (4.4)$$

Substituting Equations (4.3) and (4.4) (and the continuing infinite list of identities) into Equation (4.2) gives us the following result;

$$i_d = aAcos\,(wt)+(b/2)A^2 [1 + cos\,(2wt\,)\,]+(c/4)A^3 [cos\,(3wt\,)+3cos(wt)\,] +.. \quad (4.5)$$

$$i_d = (b/2)A^2+[aA+(3/4)\,cA^3\,]cos(wt)+(b/2)A^2 (2wt)+(c/4)A^3 cos(3wt) …….. \quad (4.6)$$

Again, simplifying the constants gives an equation of the form

$$i_d = \beta_1 A^2 + \beta_2\,cos\,(wt) + \beta_3 cos\,(2wt) + \beta_4 cos\,(3wt) + ... \quad (4.7)$$

(Where β_n are constants)

Note that a DC term β_1A^2 has appeared. Since the voltage across R_L (V_0) is what is of interest,

$$V_0 = id\,R_L \quad (4.8)$$

$$V_0 = R_L\,\beta_1 A^2 + R_L\,\beta_2 cos\,(wt) + R_L\,\beta_3 cos\,(2wt) + R_L\,\beta_4 cos\,(3wt) + ... \quad (4.9)$$

This represents a DC term plus all the harmonics of cos (wt). By passing Vo through a low pass filter (a simple output capacitor) we can output only the DC output voltage

$$V_o = R_L\beta_1 A^2 \quad (4.10)$$

This is a DC voltage proportional to the Square of the amplitude of the input RF signal. Remembering that A is the amplitude of that RF signal, and that Power

P = (V^2/R), the peak power dissipated in R_S is

$$P=A^2 / R_s \quad (4.11)$$

Solving equation (4.10) for A^2, Equation (4.11) becomes

$$P= V_O / (R_L R_S \beta_1) \quad (4.12)$$

This is of the form,

$$P = \alpha V_O \quad (4.13)$$

Where, 'a' is a constant and V_O is the DC term at the output of the LPF.

In other words, Vo is directly proportional to the power dissipated by RS.

Analysis of Different Assumption (large signal)

The above analysis is based on the assumption that Acos (wt) << V_{diode} and that the signal is not being rectified by the diode. Let's now look at this detector using the opposite assumption. That is to say that the diode acts as a rectifier and that

$$A \cos (wt) >> V_{diode} \quad (4.14)$$

With the addition of the LPF (capacitor) at the output, and again making the assumption that there is no detector circuit loading ($R_{diode} + R_L >> R_S$), then

$$V_O = A \quad (4.15)$$

Where, A is the amplitude of the input sinusoid. The circuit becomes a simple voltage peak detector (again assuming that V_{diode} is small) and the power dissipated in R_S is related to the square of V_O rather than being a linear function of V_O as concluded previously. That is to say that;

For the peak (large signal) detector

$$P=\alpha(V_o)^2 \quad (4.16)$$

And for the square law (small signal) detector.

$$P = \alpha V_0 \quad (4.17)$$

So, for very small signal levels, the voltage varies Linearly with the power input (as a square law detector) but at large signal levels, the Square Root of the voltage varies with the input power (as a peak detector).

Well, the small signal model must be amplified in order to be properly displayed. It also requires a small DC bias for best "linearity". Both require a power supply to be connected to the circuit. However the large signal model can potentially introduce distortion in the signal being measured and will likely generate harmonics and/or inter modulation products. It will likely also suffer temperature-related errors due to changes in the peak voltage (the indicated peak will be the actual peak voltage minus the diode forward voltage).

Determination of Capacitor Size

In order to raise the voltage value obtained by the antenna to a desirable value in (DC) a voltage doublers circuit will be used. Different capacitor sizes were simulated to obtain a reasonable value of capacitor to be used in the design of the electricity harvesting circuit. Design analysis and circuit design were conducted using circuit marker 2000. Voltage doublers circuit was constructed with the single stage and different capacitor size were tested to see if properties of voltage doublers will uphold every time when size of capacitor is changed.

The antenna was replaced by AC source because the output of the antenna was also in AC form. Input voltage was set at 5V. Figure 4.4 shows the single stage voltage doublers circuit. Figure 4.5 shows the output of the single stage voltage doublers circuit with 10nF capacitor. With an input of 5V supply an output of 8.6V is obtained. The Figures (4.6, 4.7, and 4.8) shows the waveforms of the voltage doublers with different capacitor values as indicated in each Figure.

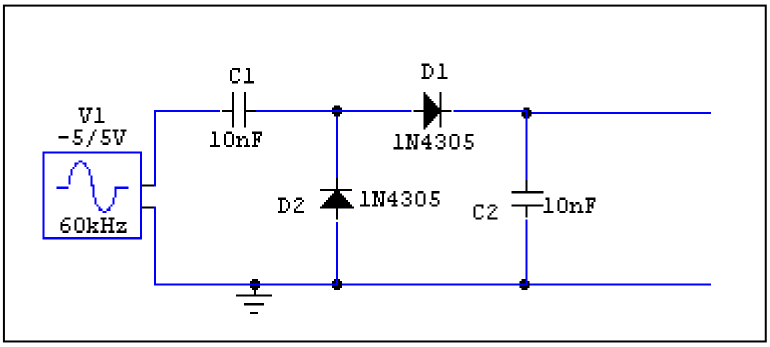

Figure 4.4: Single Stage Voltage Doublers

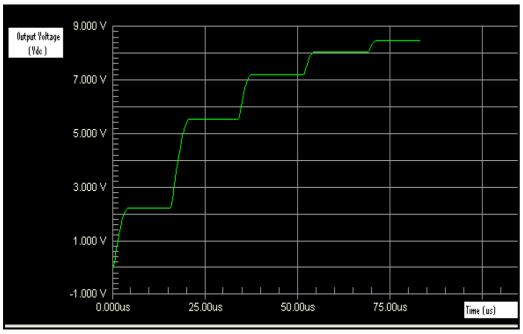

Figure 4.5 Output of Single Stage Voltage Doublers with 1nF Capacitor

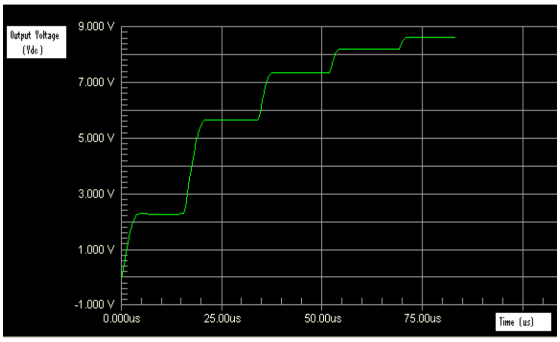

Figure 4.6 Output of Single Stage Voltage Doublers with 10nF Capacitor

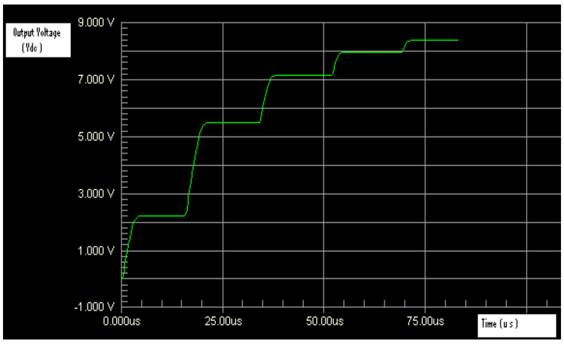

Figure 4.7 Output of Single Stage Voltage Doublers with 22nF Capacitor

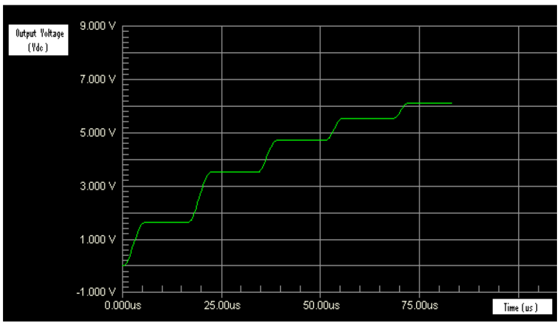

Figure 4.8 Output of Single Stage Voltage with 1uF Capacitor

The output of voltage doublers as shown by the waveforms above concludes that the output decreases as the capacitor size increases. Two tests were done to obtain the best capacitor values to be used as stage capacitor and output capacitor. The tests were done by changing capacitor size of one of the stage capacitor. At the end of these tests it was found that for stage capacitor, same capacitor value is to be used for each and every stage because they have the same charging time. Different capacitors values will have various charging times which some of them are slower than the others. For the output capacitor, it is recommended to have a lower value of capacitor which will give better output response in term of the rise time. From the simulation results, the project objectives are met and these results were used as guidelines to build the prototype.

Prototype Development

The development of the prototype was conducted by attaching a monopole antenna chosen, that is, a wire mesh with dimensions 120cm by 42cm with an energized fluorescent lamp with electronic ballast choke. The voltage doubler circuit was developed using a Silicon Diode (1N4007), 1000uF, 470uF and 100µF capacitors. Unfortunately the Schottky diodes as preferred in the previous chapter are not available in the market. Also the capacitor sizes ranging in nano-Farads did not produce a promising output when used with Silicon diodes. When Silicon diode was used with capacitor rated at mirco-Farads the outputs produced was better. The developed prototype is shown in Figure 4.9.

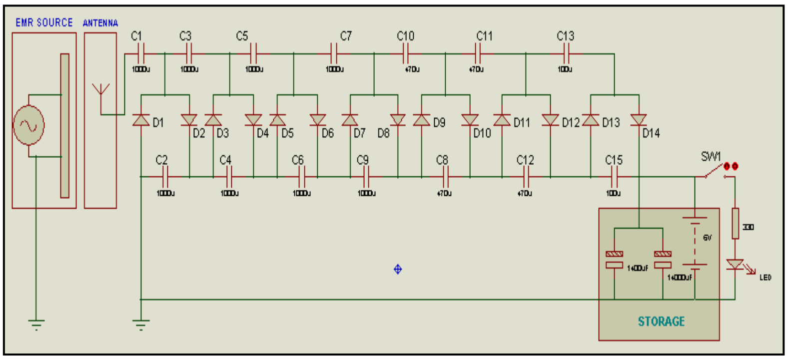

Figure 4.9 Electricity Harvesting Circuit from Electromagnetic Waves

Energy Harvesting Circuit Testing

The test was conducted by connecting a monopole antenna to the receiver (voltage doublers circuit) to replace AC power supply. The harvested energy is the ambient electromagnetic energy and it is obtained from the transmitter (electronic ballast lamp). The output was connected to a voltmeter to measure the possible output voltage. After the antenna and the circuit were properly grounded, the result was very promising. In order to store the harvested energy, two storage capacitor rated 16Vdc/14000uF were used. The circuit managed to charge the two capacitors within 3hours up to full charge but still when the capacitors are not disconnected the circuit over exceed the rating of the capacitors. This indicated that the circuit was powerful enough to produce more power. The output power of the system was calculated by taking White LED lamp as a load. White LEDs are mostly used in energy saver lamps nowadays.

Analysis of the Load

Output voltage from the circuit, $V_s = 16Vdc$,

Load parameter from data sheet for White LED: Voltage, $V_d = 5Vdc$,; *Current,* $I_d = 30mA$,

Determination of limiting resistor to be connected in series with LED can be obtained by the following relation; $R = \frac{V_S - V_d}{I_d} = \frac{16-5}{30*10^{-3}} = 366.67\Omega$

Determination of power output of the system;

$$p_o = v_d * I_d + {I_d}^2 * R_S \qquad = 5 * (30 * 10^{-3}) + (30 * 10^{-3})^2 * 330 = 0.447W$$

The LED was then connected in series with a limiting resistor of 330Ω as obtained in analysis. The resistor of 330Ω is selected because according standard ratings of resistors, 366.67Ω lies between 330Ω and 390Ω. The minimum value was chosen to avoid under voltage to the load. From these parameters the circuit was able to capture power of 0.447watt. The rechargeable battery of 6Vdc/4Ah was finally used as storage device. Rechargeable

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battery is well-known as a promising medium of storing energy with the least amount of self-discharging problem.

The stored energy in this rechargeable battery may be retrieved and used whenever needed. The energy from this battery may be connected to any low power electrical appliances such as toys, table lamps, table clock and etc as a source of power. So the project objective has been achieved as the prototype gives result as expected.

CONCLUSION AND RECOMMENDATIONS

Conclusion

In this project, a wireless electric concept to supply power to electrical appliances for a living room is presented. The harvesting of the energy from ambient electromagnetic energy or transmitter is the key for supplying the AC supply to the voltage doublers circuit. The Silicon diodes were used in voltage doublers circuit that amplifies the input in AC to a higher output voltage in DC. Moderate size of capacitor is also chosen to maintain the performance and to minimize the overall circuit size. The output of the circuit is stored in the rechargeable battery which later can be used to power any low power electrical appliances.

Hopefully if more effort is made to improve the prototype by trying to harvest larger EM energy in the coming years the energy harvesting circuit will be very beneficial to our daily life. This can be achieved by finding ways to combine the Germanium and Schottky diodes. Germanium diodes are better used for capturing the signal whereas Schottky diodes are rectifier diodes which are good for amplifying the input.

Applications, Future Work and Recommendation

This project has great potential in the future because the use of electronic devices will only increase. In addition to the tested appliance, the device could be modified to encompass a wider array of devices. This will greatly increase its versatility. The technology from this project could also be applied to other fields such wireless energy transmission and green energy. The techniques and circuits from this project could also be used in developing wireless energy transfer devices. As demonstrated, this device has many practical applications. For example, this device can be used to charge batteries, and possibly iPods, and cell phones; in addition, this technology could also be integrated into devices like wireless mice so that they would not need to be powered with a battery. Although the current prototype managed to harvest electricity, it could be made more user friendly and aesthetically appealing.

The next step in the process of designing this device would be to make the output voltage more stable for further uses such as charging of larger rechargeable batteries up to 12Vdc. In addition, the device can also be made bigger in order to produce more power.

In the future, the efficiency and other applications of the technology can be explored. For example, the feasibility of inserting the device inside electronic appliances to collect more radiation can be examined.

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