# ENERGY HARVESTING - ELECTRICAL CONVERSION OF GSM SIGNAL FOR BATTERY CHARGING APPLICATION

By

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Submitted to the Department of Electrical & Electronic Engineering
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical and Electronics Engineering)

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# CERTIFICATION OF APPROVAL

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Approved:

______________________

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JANUARY 2014

## CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Siti Nor Ainu Bt Mohd Shakri

# ABSTRACT

This project is about harvesting GSM energy to provide alternative sources for battery charging application. Global System for Mobile (GSM) band is one of the signal that are widely available in RF range with the frequency between 890 MHz – 960 MHz. As the energy levels harvested in the environment are very low and not enough to charge mobile phone, voltage multiplier rectifier circuit and current amplifier are designed to increase the output voltage and current respectively. The aim is to prove that low energy could be increased to achieve charging load voltage and current requirement of 3.7 V and 1.5 A respectively. The multi-stage rectifier (AC-DC) voltage multiplier and low-dropout micro power regulator (LDO) is simulated using Multisim software and presented. Different type of Schottky diodes performance is also studied and simulated in this work. The steps taken to accomplish the projectare discussed in detail.

***Keywords****-energy harvesting; GSM; Schottky diode; voltage multiplier; voltage regulator*

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| AC | : Alternating Current |
| BSS | : Base Station Subsystem |
| DC | : Direct Current |
| GSM | : Global System for Mobile |
| Hz | : Hertz |
| IC | : Integrated Circuit |
| LAN | : Local Area Network |
| LDO | : Low Drop Out |
| mAh | : milliamp hours |
| NSS | :Network and Switching Subsystem |
| OSS | : Operation Support Subsystem |
| RF | : Radio Frequency |
| W | : Watt |
| WiMAX | : Worldwide Interoperability for Microwave |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of study

Nowadays mobile communication is one of the fast growing market tools and widely used by people in all over the world. Throughout the year, cellular phone technology is shrinking not only the ICs size but also the batteries. The need for automatic charging technique is required instead of wired charging via USB or AC socket. Recently there are lots of studies conducted about supplying power to electronics devices using wireless power transmission technology. It is expected that by eliminating the need for power cables, charging batteries can be done anywhere without the need of power supply. Hence, most users do not have to worry that their handheld devices to run out of battery anymore.

Energy harvesting is a conversion of ambient energy present in the environment into electrical energy. There is an abundance of energy propagates all around us at all times. There are some applications such as radio and television towers, satellites orbiting earth and even the cellular phone antennas are constantly transmitting energy. Energy can be harvested from sources such as vibrations, thermal and RF (radio frequency) sources. RF is a general term used to encompass the frequency within the electromagnetic spectrum in the range of about 3 kHz to 300 GHz [1], which corresponds to the frequency of radio waves and the alternating currents to carry radio signal. The advent of wireless broadcasting and communication has increased the availability of free RF energy. Harvesting ambient energy would offer an alternate energy source for low power applications [2]. Global system for mobile (GSM) is one example of energy present in RF range.

GSM is the second-generation cellular system standard or known as 2G. GSM was developed to work out the fragmentation problems of the first cellular systems. Recently, GSM system is the most popular digital cellular telecommunications system and widely used in the world. The range of GSM system utilizes within 25 MHz, 890-915 MHz and 935-960 MHz for transmitting and receiving bands of the mobile system respectively [3].

## 1.2 Problem statement

The fast growing of wireless device and products in market has become the most popular demand among the consumers. Unfortunately the wireless devices are constrained in terms of their batteries due to the inability to operate independently of centralized power sources for an unlimited duration. Nowadays, there have been studies that discovered new method for wired battery charging problem such as power bank and also by shrinking the charger in order to make it easier to carry along with chargeable electronic devices. Although the charger becomes smaller, but it still needs to be plugged into wall outlet.

As the wired charging method was inconvenient method, the better way to transfer power is by wireless power transfer using energy harvesting method instead of traditional methods using power cables. By eliminating the need for power cables, most users do not have to worry in carrying along the charger during travel and also in case of no power supply.

The project is addressed to implement wireless technique for battery charging module. By having such development, mobile or tablet users do not have to worry about finding AC outlet or USB port because the charging is done automatically through novel energy harvesting technique. The aim is to use the harvested GSM energy in order to supply electrical power in places where electrical energy sources cannot be found. Therefore, users are able to get their handheld items powered up wirelessly anywhere.

The availability of the GSM energy is the limitation of the project. The energy levels that can be harvested in the environment are very low that no electronic device can use them. Therefore the output voltage must be boosted before it can be used to power up an electronics devices.

## 1.3 Objectives and scope of study

The main objective of this work is to improve the current wired battery charging by developing new alternative technique using energy harvesting method. In particular, this study aims:

a) to understand the basic principle of RF, GSM and operation of mobile communication.
b) to design and simulate the converter to produce 3.7 V output voltage and 1.5 A output current for specific mobile or tablet load application.
c) to design and simulate the current amplifier circuit to increase the output current.
d) to develop the voltage multiplier circuit and test the design.

## 1.4 Significance of the project

The project is significant in term of applying new method for battery charging module. By using energy harvesting method, the charging can be done automatically without need for power cable. At the same time the electricity consumption can be reduced. Consequently, it provide an alternative source of the energy especially in the current situation where the most of the energy produced depends on non-renewable energy such as oil and gas sources.

# CHAPTER 2

# LITERATURE REVIEW

The idea of harvesting energy from ambient sources has been around since the invention of piezoelectric materials [4]. The usable energy can be obtained from piezoelectric materials by using simple electronic embedded in mobile phone to convert into electrical energy. The recent studies [2, 4] have shown that energy could also be harvested by the RF energy in the environment. The received radio energy can be converted to DC by using rectifier and conversion technique then supplied energy to the battery. Besides, researchers found that not only RF energy could be harvested but also from various energy sources, such as mechanical vibrations, electromagnetic sources, light, acoustic, airflow, heat and temperature variations. In real situation, the energy transmitted by wireless sources is much higher, but only small amount can be harvested in environment as the rest is converted into heat or absorbed by other materials [5]. Table I shows the comparison of the estimated power and challenges of various ambient energy sources in a recent study by [6].

Table I: Comparison of power Density of energy harvesting methods

| **Energy Source** | **Power Density & Performance** |
|---|---|
| Acoustic Noise | 0.003 µW/cm3@75 db<br>0.96 µW/cm3 @ 100 db |
| Temperature Variation | 10 µW/cm3 |
| Ambient Radio Frequency | 1 µW/cm2 |
| Ambient Light | 100 mW/cm2 (direct sun)<br>100 _W/cm2 (illuminated office) |
| Thermoelectric | 60 _W/cm2 |
| Vibration | 4 _W/cm3 (human motion—Hz) |

| | |
|---|---|
| (micro generator) | 800 _W/cm3 (machines—kHz) |
| Vibrations (Piezoelectric) | 200 μW/cm3 |
| Airflow | 1 μW/cm2 |
| Push buttons | 50 _J/N |
| Hand generators | 30 W/kg |
| Heel strike | 7 W/cm2 |

Values in the Table I were derived from a combination of published studies, theory and information from textbooks. Mostly the energy sources as shown in the Table I are highly dependent on the application. Thermal energy for instance is limited because differences on temperature across a chip are typically low [6].

### 2.1 Radio frequency (RF)

Radio frequency is present everywhere in the environment, in the form of signals transmission from mobile phone (GSM), wireless LAN (WiFi, WiMAX), radio, TV, Bluetooth, etc [5]. Study has been done in urban area in order to identify the density of RF energy. From the experiment, it has been reported that RF energy density can be as high as 0.5 $\mu W/cm^2$ in urban area. This value corresponds to an input power level of 16.6 μW (-17.6 dBm) at 1800 MHz [7]. RF can be classified as one of the categories of energy carrying wave which is identified in the electromagnetic spectrum. RF and microwaves are two different types of electromagnetic waves. RF has range of frequencies between 3 kHz to 300 GHz whilst microwaves frequencies are between 300 MHz (0.3 GHz) to 300 GHz [8]. RF energy harvesting can be used as alternate power source for low power applications such as battery charging in mobile communication. Although this method is a good alternative for battery charging, however there are several challenges to implement this method [2] :

a) Required high gain antenna for all frequency bands due to available power varies with distance and gain of the receiver antenna.

b) Broadband impedance matching network is necessary for maximum power transfer due to non linear dependence of the rectifier impedance on the frequency and power.

c) It required higher efficiencies of RF-DC conversion and low power DC-DC converter.

Figure 1 shows the basic block diagram of RF-DC conversion system. A good design of RF energy harvesting system should reduce power dissipation by minimizing the numbers of components [2].

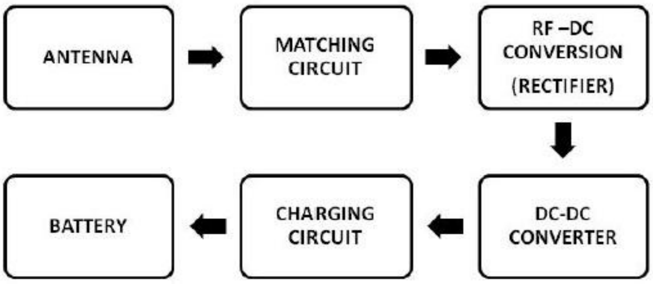


Figure 1  Basic block diagram of RF energy harvesting

RF energy harvesting model is divided into three (3) subsystems. They are receiving antenna subsystem, rectifying subsystem and energy storage subsystem. Figure 2 shows the main step in harvesting method; transducer, energy conditioning stage and energy storage unit [9, 10].

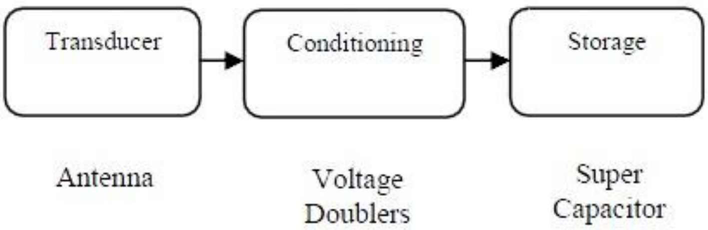


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Figure 2  Step of RF energy harvesting

Transducer consists of antenna for converting RF energy to electrical form. The transducer design should be efficient in order to convert more RF energy into the system. Voltage doublers (charge pump) or voltage multiplier circuit is to amplify the incoming signal in order to increase output voltage. The last component is energy storage unit. As the incoming RF energy is not constant over the time, storage unit is essential to fulfil the demand of the devices.

The amount of energy that could be harvested is required as an input for this project. For this purpose, the actual amount is referred from previous study done by some researchers. The value of energy that could be harvested in environment is mentioned by [11] . A spectrum analyzer is used for this purpose. However the output power of RF is limited by some regulations due to safety and health concern offered by EM radiations. According to [12], the maximum theoretical power available for RF energy harvesting in distance 40 meters is about 7.0 µW and 1.0 µW for 900 MHz and 2.4 GHz respectively. The power available in the environment is estimated around 50 mW to 100 mW. However the energy that could be harvested from environment is about 10 µW to 100 µW [13]. 250 mW energy can be harvested from electro-magnetic noise generated from a fluorescent lamp while 60 µW of RF energy was harvested from TV tower. Figure 3 shows the spectrum of RF signals existing in frequency range of 100 KHz to 3 GHz at a distance of 400 m.

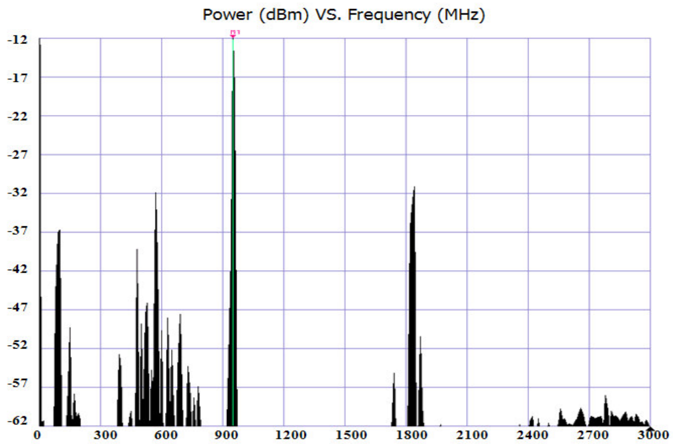


Figure 3: Spectrum of signals in the range from 100 KHz to 3 GHz [14]

As can be observed from Figure 3, there are different values of power at different ranges of frequencies. The signals in frequency within 950 MHz to 960 MHZ experienced more power and less hopping than other frequency range [15]. The amount of received power actually depends on the distance decay, which can be calculated as stated in Eq. (1):

$$W_a = \frac{\lambda^2}{4\pi z} G_{at}\, G_{ar}\, W_t \qquad (1)$$

where $W_a$, λ, $z$, $G_{at}$ , $G_{ar}$ and $W_t$ are received RF power, the wavelength, the distance between the transmitter and receiver, the transmitter antenna gain, the receiver antenna gain, and transmission power respectively.

However, ambient energy sources are usually unstable and cannot be harvested during a certain period of time. For instance, RF energy from TV broadcasts can obtain power all day except during the maintenance period. The actual value of energy harvested from TV broadcasts could not be estimated properly because the RF power attenuated due to the multipath effect, reflection, shielding object, etc. The study done by [11] shows that the amount of harvested power decreases every day at midnight, i.e. from around 1:00 a.m. to 6:00 a.m. due to maintenance factor.

## 2.2 Global system for mobile (GSM)

Early GSM cellular phone has some weaknesses in terms of the battery management which could only allow for less than an hour of talk time [16]. Hence, second generation of GSM cellular system standard purposely developed to improve the limitation of first cellular system. The system was put forward into European since 1991 [3]. According to [3], there are three major subsystems of the GSM network architecture: Base Station Subsystem BSS, Network and Switching Subsystem NSS and operation support Subsystem OSS. There are five parts of GSM services which include internet, mobile fax, secure corporate, LAN access, cell broadcast, and short message. According to [14], the power of air signals can be as high as 30 dBm for GSM frequency which is relatively high and can be used for low power application. For GSM-900 mobile phone, a scavenged power of 1.9 mW is predicted at a distance of 1 m [17].

## 2.3 Antenna

Previous researchers have done the survey to find out the availability of RF signal by using spectrum analyser and antenna. They have found that RF signal are widely available in GSM (global system for mobile communication) band with frequency between 890 MHz – 960 MHz. Hence, antenna is used since the RF energy is available in form of electromagnetic waves [9]. It works as converter which converts energy in to electrical form besides of transmitting and receiving signal. There are 3 types of antenna that commonly used: monopole, dipole and micro strip antenna [18]. Most of antenna in rectenna application uses micro strip patch antenna instead of monopole and dipole antenna because micro strip antenna is most efficient since it has less loss and small in size. "Rectenna" is short name for rectifying antenna that used to capture and convert RF or microwave power to DC power. The efficiency of RF to DC conversion (ηRF to DC) can be calculated according to the following definitions [19] as given by Eq. (2) and Eq. (3) :

$$\eta RF\ to\ DC, rectenna = \frac{P_{OUT,DC}}{S_{RF}A_G} = \left(\frac{V^2{}_{DC}}{R_{LOAD}}\right)\frac{1}{S_{RF}A_G} \qquad (2)$$

$$\eta RF\ to\ DC, Rectifier = \frac{P_{OUT,DC}}{P_{RIC,}R_F} = \left(\frac{V^2{}_{DC}}{R_{LOAD}}\right)\frac{1}{S_{RF}A_{eff}} \qquad (3)$$

where $S_{RF}$ is the power density incident on the antenna, $V_{DC}$ is the DC output voltage, $R_{LOAD}$ is resistive load, $A_G$ is the geometric area of the antenna and $A_{eff}$ is its effective area. The aim of the formula given in Eq. (2) is to emphasize the efficiency of the antenna in collecting the electromagnetic radiation. RF to DC conversion efficiency of rectifier is given in Eq. (3).

Other type of antenna to consider is known as patches. This type of antenna have two major problems analyzed by [20] where it needs to be quite large in size. Second problem is that it is highly directional; meaning that it will receive radiation in one direction. In order to increase the power/area ratio, multiple energy harvesting antennas in one area was proposed and studied by [21, 22]. The studies found that as the area increases, the power generated is also increasing.

## 2.4 Charge pump/ voltage multiplier rectifier circuit

The energy levels that can be harvested in the environment are so low that no electronic device can use them. Output voltage must be boosted before it can be used to power electronics devices [23]. The researcher found that the maximum theoretical power available for energy harvesting is 7.0 µW for 900 MHz frequency and 1.0 µW for 2.4 GHz frequency [5]. In this case, voltage multiplier is the solution to overcome the limitation of the energy. Voltage multiplier (also known as voltage doubler or charge pump) is an electronic circuit using a combined network of diodes and capacitors as energy storage elements to create either a higher or lower voltage. Besides, it is able to convert AC power to DC power, thus eliminating the need of a rectifier in harvesting process.

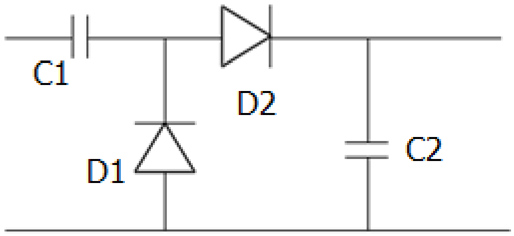


Figure 4 voltage multiplier circuit [9, 24]

Figure 4 shows the basic configuration of voltage multiplier circuit. The circuit can be extended to *n* stages, thus producing theoretical $2nV_{in}$ for the output voltage. Therefore as the number of stages increase, theoretically more voltage is produced at the output [24]. The output of an *n* stage charge pump can be calculated as given by Eq. (4).

$$V_o = nV_{in} - \frac{n-1}{fc} I_{load} \qquad (4)$$

The voltage multiplier increases the voltage not the power. However, power decreases as the number stages of multiplier circuit increase.

## 2.6 Literature review summary table

The summary of literature review is presented in Table II. The references are from different sources such as research papers, journal, articles that are cited in the literature review section (chapter 2).

Table II: Literature review summary table

| No | Authors | Title | Ref | Contents | Issues |
|---|---|---|---|---|---|
| 1 | M. Arrawatia, M. S. Baghini, and G. Kumar (2010) | RF Energy Harvesting System at 2.67 and 5.8GHz | [2] | • several challenges in energy harvesting<br>• basic block diagram of RF-DC conversion system | • requires high gain receiver antenna for all frequency<br>• Higher efficiencies of RF-DC conversion and low power DC-DC converter are required<br>• broadband impedance matching network is essential for maximum power transfer |
| 2 | G. Guifen and P. Guili (2010) | The survey of GSM wireless communication system | [3] | • Second generation of cellular system standard known as GSM. | • improve the limitation of first cellular system |
| 3 | B. G. Karthik, S. Shivaraman, and V. Aditya (2011) | Wi-Pie: Energy Harvesting in Mobile Electronic Devices | [4] | • The idea of harvesting energy from ambient sources<br>• energy could be harvested by the RF energy in the environment | • Specific circuit and conversion technique is required to convert radio energy. |
| 4 | H. Jabbar, Y. S. Song, and T. T. Jeong (2010) | RF energy harvesting system and circuits for charging of mobile devices | [5] | • RF energy transmitted by wireless sources is much higher | • Only small amount of energy can be harvested<br>• The rest of energy is converted into heat or absorb by other materials. |
| 5 | F. Yildiz.,J. Zhu., Pecen., and G. Liping (2007) | Energy scavenging for wireless sensor nodes with A focus on rotation to electricity conversion | [6] | • Comparison of power density of energy harvesting methods for different energy sources. | • Power density for each source is limited and dependent on the application. |

| | | | | | |
|---|---|---|---|---|---|
| 6 | U. Batool, A. Rehman, N. Khalil, M. Islam, M. U. Afzal, and T. Tauqeer (2012) | Energy extraction from RF/ Microwave signal | [8] | • Two different types of electromagnetic waves; RF and microwave. | • RF and microwaves have different frequency; RF within 3 kHz-300 GHz while microwaves between 0.3 GHz-300 GHz. |
| 7 | W. M. D. R. Gunathilaka, G. G. C. M. Gunasekara et al. (2012) | Ambient Radio Frequency energy harvesting | [9] | • Main components and step of energy harvesting | • Consists of transducer, voltage doubler and storage unit.<br>• Voltage doubler circuit |
| 8 | K. Pentikousis (2010) | In search of energy-efficient mobile networking | [16] | • Weaknesses of early GSM cellular phone | • Allow for less than an hour of talk time in a single battery charge. |
| 9 | R. A. Rahim, S. I. S. Hassan, F. Malek, M. N. Junita, and M. F. Jamlos (2012) | An investigation of ambient radio frequency as a candidate for energy harvesting source | [18] | • Availability of RF signal by using spectrum analyzer and antenna<br>• Types of antenna; monopole, dipole and micro strip. | • RF signal available in GSM band<br>• Micro strip antenna is most efficient and commonly used. |
| 10 | D. W. Harrist (2004) | Wireless battery charging system using radio frequency energy harvesting | [20] | • Two major problem in patches type of antenna | • Highly directional<br>• It needs to be quite large in size |

# CHAPTER 3

# METHODOLOGY

## 3.1 Procedures

This project shall include three execution phases as described below. The summary for project activities is summarized in flow chart as shown in Figure 5.

### 3.1.1 Research and literature review

In the early stage of the project, literature review has to be done in order to get an insight and understanding energy harvesting method. The study also emphasizes on the basic concepts of radio frequency propagation, global system for mobile application and mobile network communication. The important point and basic understanding has been established as described in Chapter 2. Review must be done to get as much understanding as possible from research papers, journals, articles, and other sources available on internet. Attention shall be given to two components, which are the conversion circuit and amplifier circuit.

### 3.1.2 Designing and simulation the circuit

Conversion circuit consisting of voltage multiplier rectifier is designed to achieve charging output voltage of 3.7 V. Then amplifier circuit is another important circuit designed to increase the output current for the load to meet the requirement of 1.5 A load. These two circuit models will be analyzed with the use of circuit simulation software such as Multisim 12.0. If the simulation results are incorrect, improvement in the circuit design should be carried out. When required simulation results are obtained, list of components and devices will be identified for fabrication.

### 3.1.3 Testing and Prototyping

The fabrication of voltage multiplier will be done and testing is required to validate the functionality of the prototype. During the testing, the input is fed by signal generator or AC power transformer using generic value of input voltage getting from previous research. It will be used as reference throughout this project. The output is monitored by using multimeter and the result is analysed. If the testing phase meets the requirement, the result analysis will be then carried out. The analysis on how to have better outcome is carried out consequently. Besides, recommendation is made for further improvement in the future design.

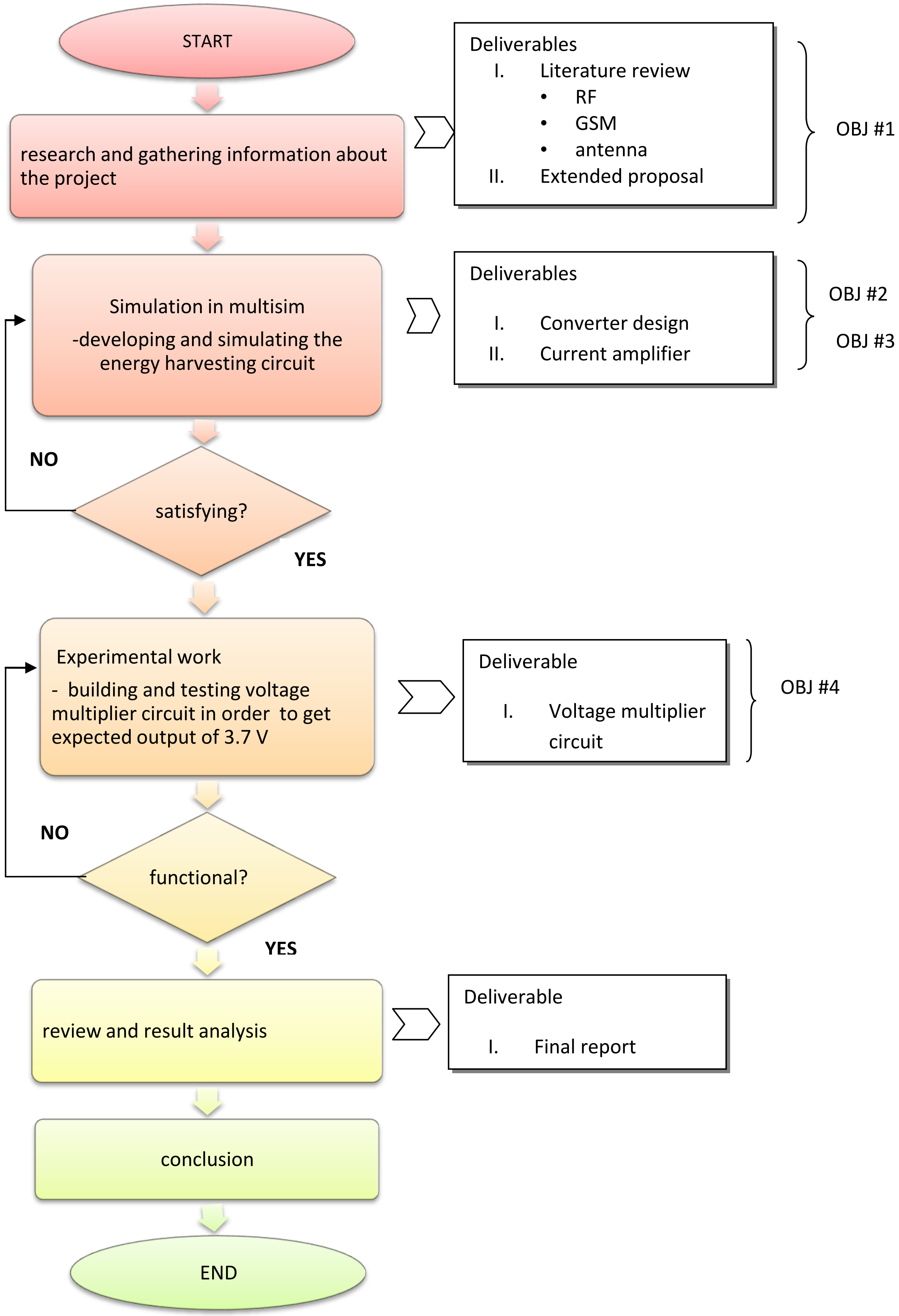


Figure 5 Flow chart

*Gantt Chart is provided as Appendix A & B

## 3.2 Key milestone

There are several key milestones as illustrated in Figure 6 must be accomplished in order to achieve the objectives during FYP 1. Since the project will be proceeding in FYP 2 for final design of the prototype, several milestones need to be completed before the prototyping phase begins such as research, review articles, designing and simulating the design.

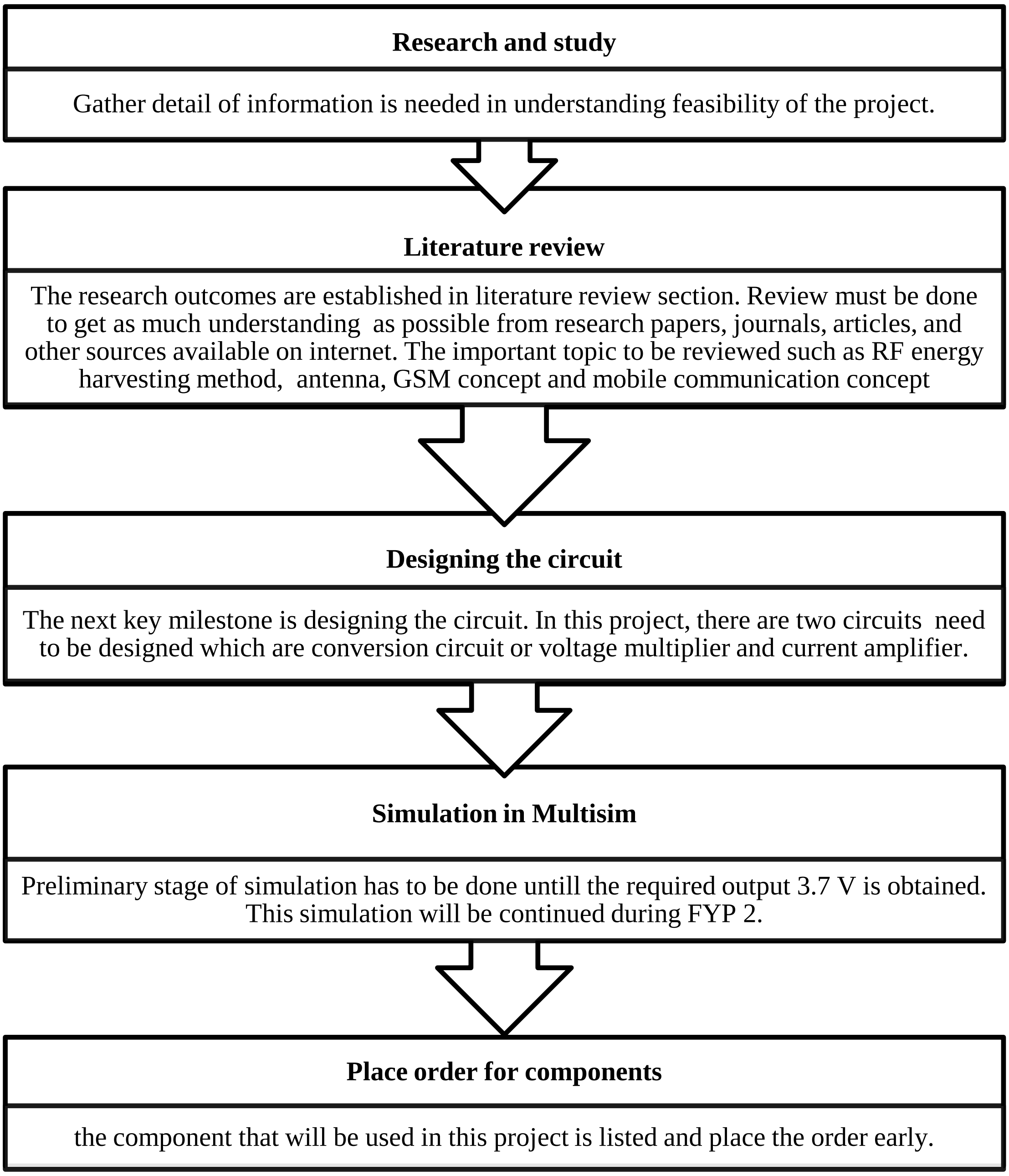


Figure 6 Key milestones for FYP 1

There are 5 key milestones need to be accomplished in FYP 2 as shown in Figure 7. The first milestone which is simulation actually continued from preliminary simulation in FYP 1. Table III summarizes overall milestone need to be achieved for both FYP 1 and FYP 2. The timeline indicates the expected completion period for each milestone.

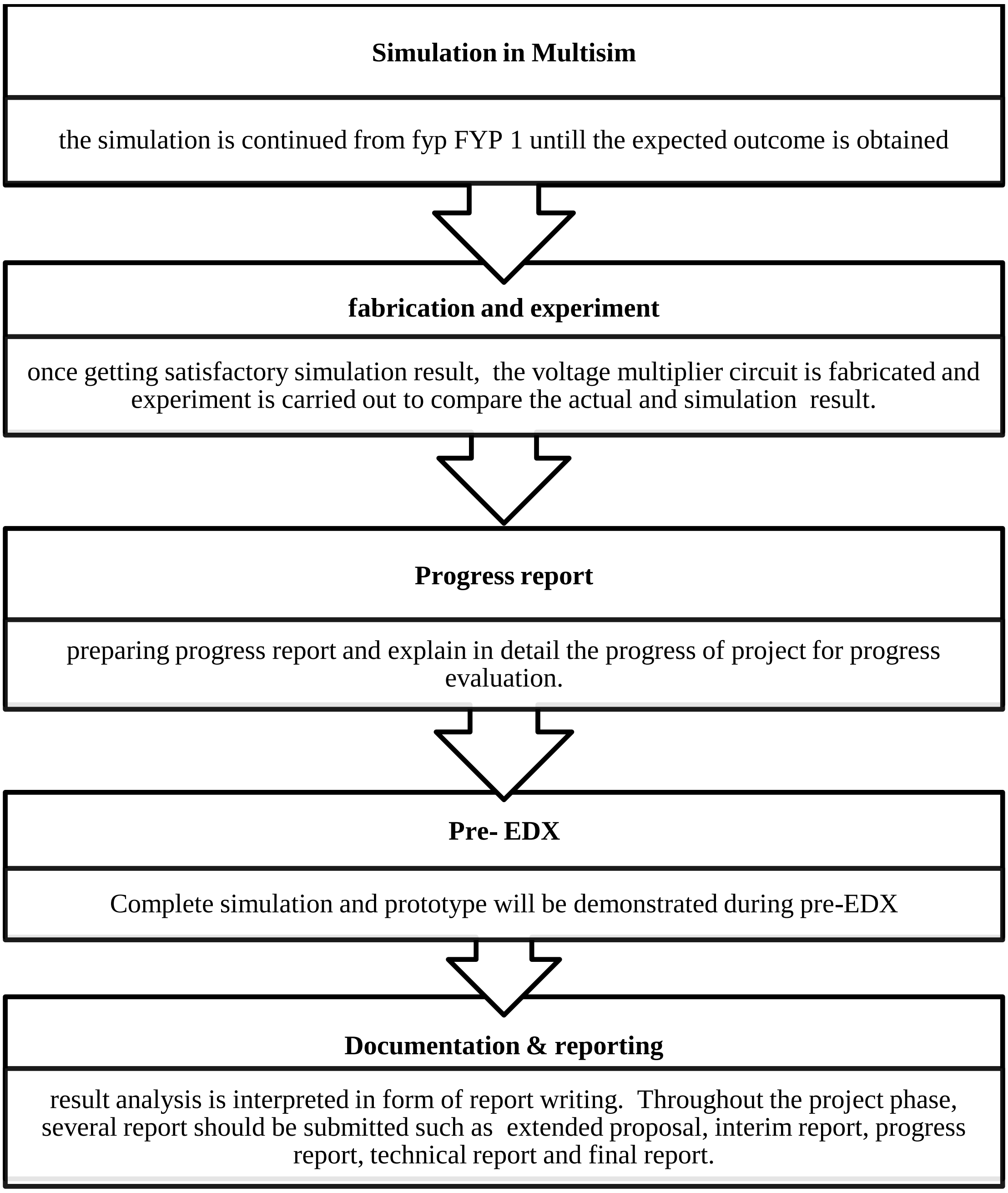


Figure 7 Key milestones for FYP 2

Table III: Summary of Milestone

| MILESTONE | MONTH (2013/2014) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAY '13 | JUNE '13 | JULY '13 | AUG '13 | SEPT '13 | OCT '13 | NOV '13 | DEC '13 | JAN '14 |
| Understanding the project principle | | ↔ | ↔ | | | | | | |
| Design converter and current amplifier circuit | | | | ↔ | ↔ | | | | |
| Preliminary simulation of the circuit design | | | | ↔ | ↔ | | | | |
| Experiments, data collection and analysis | | | | | ↔ | ↔ | ↔ | | |
| Project presentation and evaluation | | | | | | | | ↔ | |
| Final Report writing | | | | | | | | ↔ | |
| Project completion | | | | | | | | | ↔ |

### 3.3 Proposed Topology

Figure 8 illustrates the proposed block diagram of energy harvesting technique in order to power up the load.

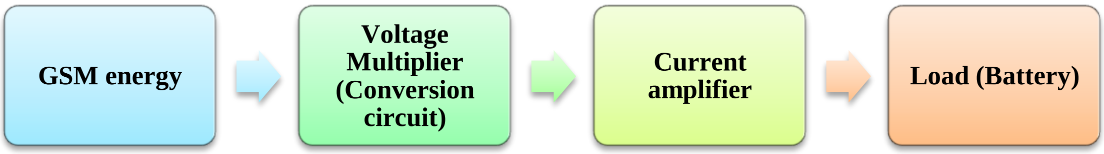


Figure 8: Proposed block diagram of energy harvesting system

The conversion circuit consists of charge pump used to achieve the charging output voltage that is suitable to charge mobile phone. Hence, the specification of battery is required in this project in order to know the battery requirement for charging. The battery specifications are as follow:

i. Battery type: Lithium-ion
ii. Nominal voltage: 3.7 V
iii. Charge current: 0.5 A
iv. Discharge current: 1 A
v. Capacity: 1600 mAh

Since the nominal voltage for battery is 3.7 V, the charge pump shall be designed to increase the output voltage up to 3.7 V.

#### 3.3.1 Charge pump/ voltage multiplier

Figure 9 shows the basic design of charge pump simulated in Multisim. Simulation has been done for better understanding of the voltage multiplier circuits which functions as transformers in order to increase the output voltage. The output of the charge pump is measured by DC multimeter. The simulation for charge pump is focused on determining the most efficient values of the capacitors (number of stages) in the charge pumps and the suitable type of diode to be used as described in section 4.1.

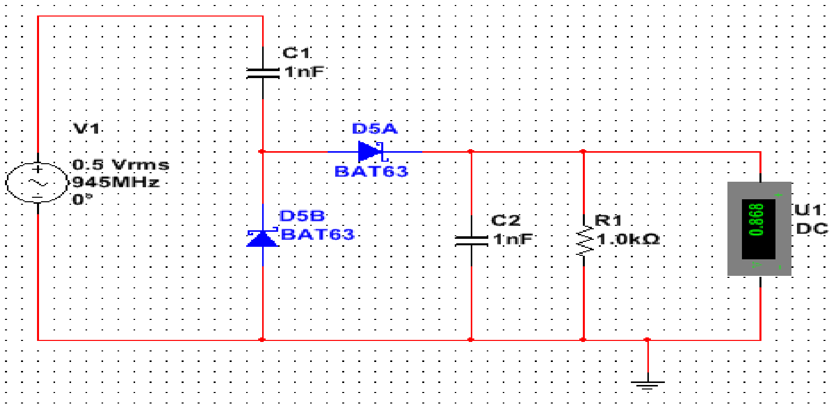


Figure 9: Basic design of charge pump

For circuit simulation, the value of resistor, capacitors C1, C2 and diodes D1, D2 are referred from research paper [25]. The chosen capacitor value can be determined by using the formula shown in Eq.(5) and Eq.(6) [26].

$$C_{MIN} = \frac{I_{out} \times D \times (1 - D) \times 1000}{f_{SW} \times V_{p(max)}} \qquad (5)$$

$$D = \frac{V_{out}}{V_{in} \times \eta} \qquad (6)$$

Where $f_{SW}$ is the switching frequency in kHz, $I_{out}$ is the steady state output load current, $C_{MIN}$ is the minimum required ceramic input capacitance in µF, $V_{p(max)}$ is the maximum allowed peak-peak ripple voltage (the recommended $V_{p(max)}$ is 75 mV) , $D$ is the duty cycle and $\eta$ is the efficiency.

$$C_{MIN} = \frac{|\,1mA \times 8.22 \times (1 - 8.22) \times 1000|}{945\,000 \times 75\,mV} \quad , \quad D = \frac{3.7}{0.5 \times 0.9} = 8.22$$

$$= 0.8\,nF$$

It is recommended to choose the capacitor value equal to or greater than the calculated value because the actual capacitance is less than the stated nominal value at a given dc voltage. Hence the suitable value of capacitors in the voltage multiplier circuit is 1 nF.

From previous research, an AC input voltage to the circuit is 0.5 $V_{rms}$ represents the value for harvested GSM energy and the frequency is fixed at 945

MHz, the performance of the circuit with different number of stages were observed and analysed to choose the maximum output delivered to the load.

The output voltage can be calculated theoretically as shown in Eq.(7). There will be a small difference between theoretical value and simulated output as a result of the parasitic capacitances of the diode and the saturation current.

$$V_{out} = 2N(V_{pk} - V_{th}) \qquad (7)$$

where $V_{pk}$ is $\sqrt{2}\,V_{rms}$, $N$ is number of stage, and $V_{th}$ is threshold voltage for diode.

a) Test 1: The effect of different type of diode

The objective of this simulation is to choose the suitable type of diode which is able to produce maximum output. Schottky diode is known for its low voltage drop which poses to be an advantage over normal silicon diode. The voltage drop for silicon diode usually ranges from 0.6 V to 1.7 V while Schottky diode's voltage drop at forward biases is approximately 0.15 V to 0.5 V. The voltage of the AC sources was set to be 0.5 $V_{rms}$ at 945 MHz. The value of frequency was chosen because it is close to the downlink centre radio frequency of GSM-900 band. Different types of Schottky diodes were used in a single stage charge pump with constant capacitor values as illustrated in Figure 10, Figure 11 and Figure 12 respectively.

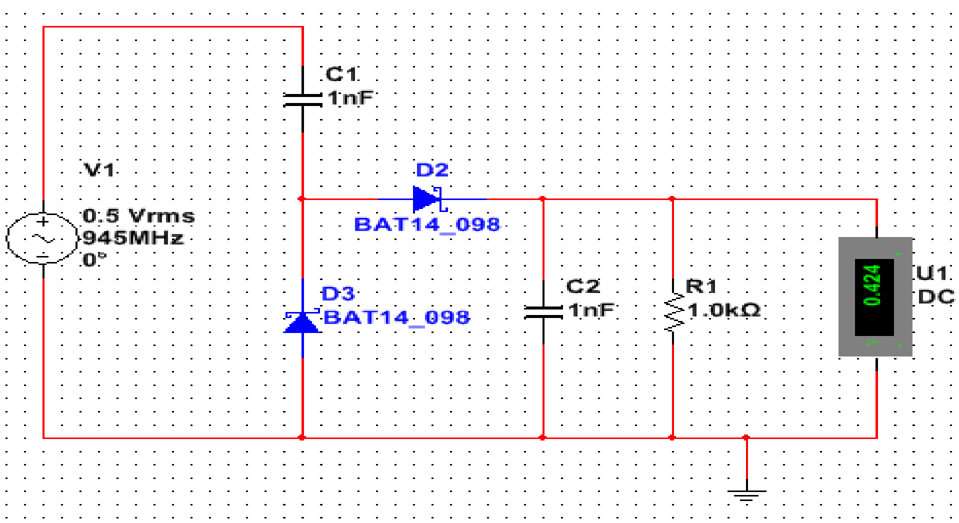


Figure 10 Single stage charge pump with Schottky diode BAT14_098

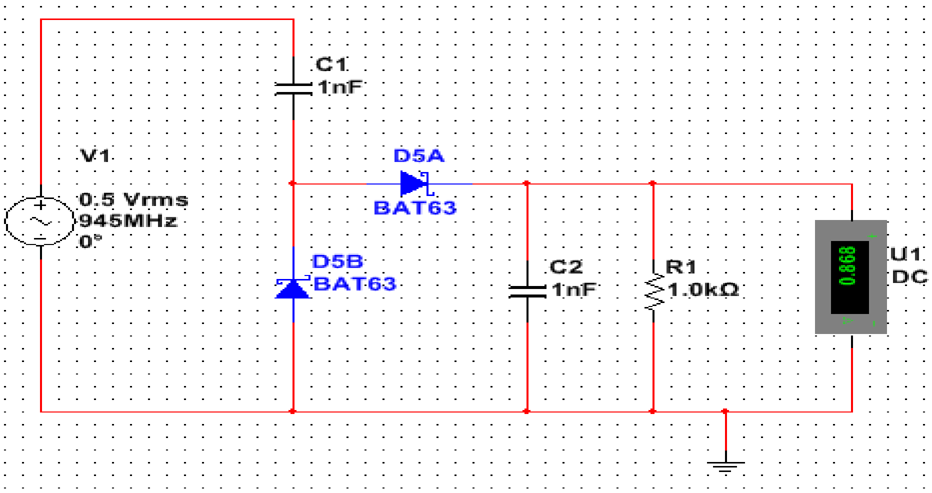


Figure 11 Single stage charge pump with Schottky diode BAT63

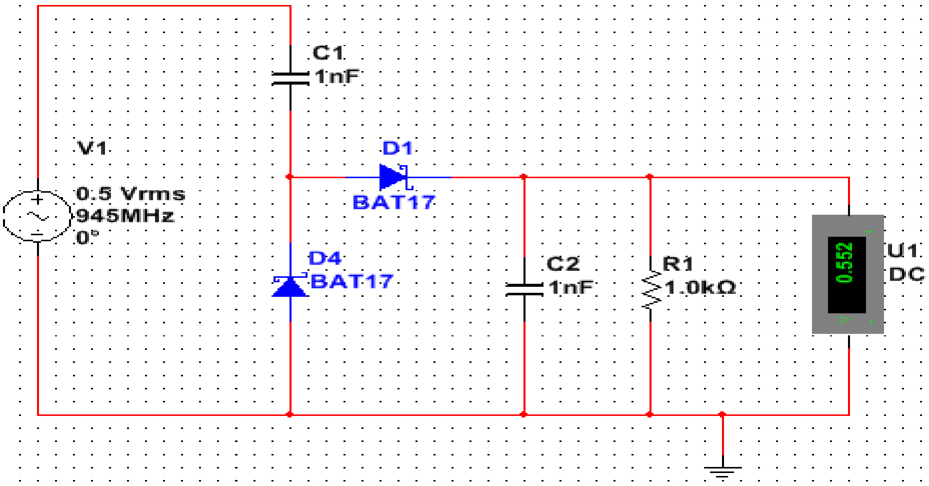


Figure 12 Single stage charge pump with Schottky diode BAT17

b) Test 2: the effect of charge pump stages to the output

The objective of this simulation is to examine the suitable number of stages that produces required output voltage of 3.7 V. Different number of stages were simulated in Multisim software as shown in Figure 13, Figure 14, Figure 15, Figure 16 and Figure 17 respectively. For this simulation, the source is represented by a sinusoidal voltage source at fixed frequency of 945 MHz which is close to the downlink centre radio frequency of GSM band and voltage at 0.5 Vrms.

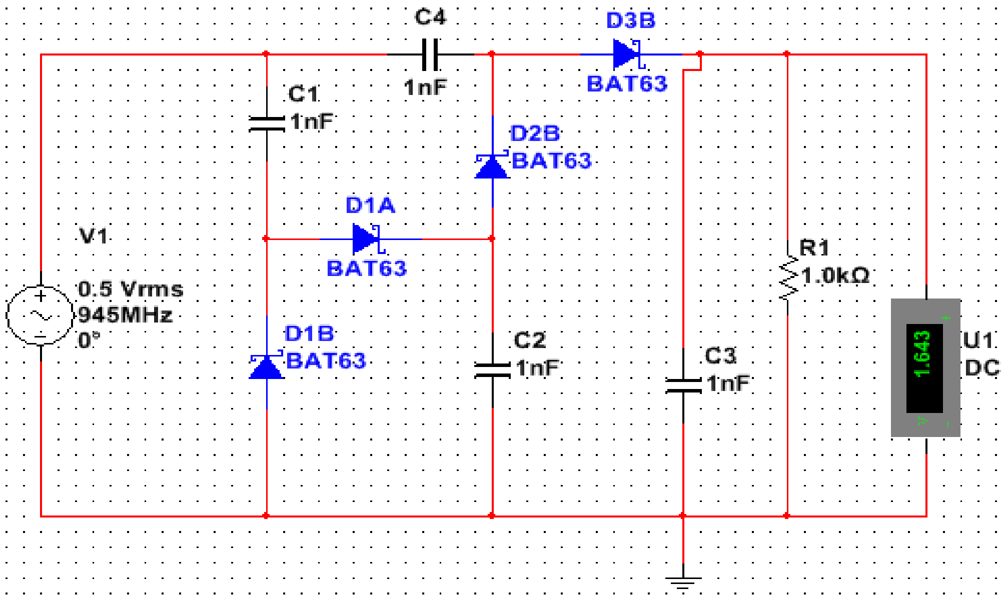


Figure 13 : 3 Stages of charge pump circuit

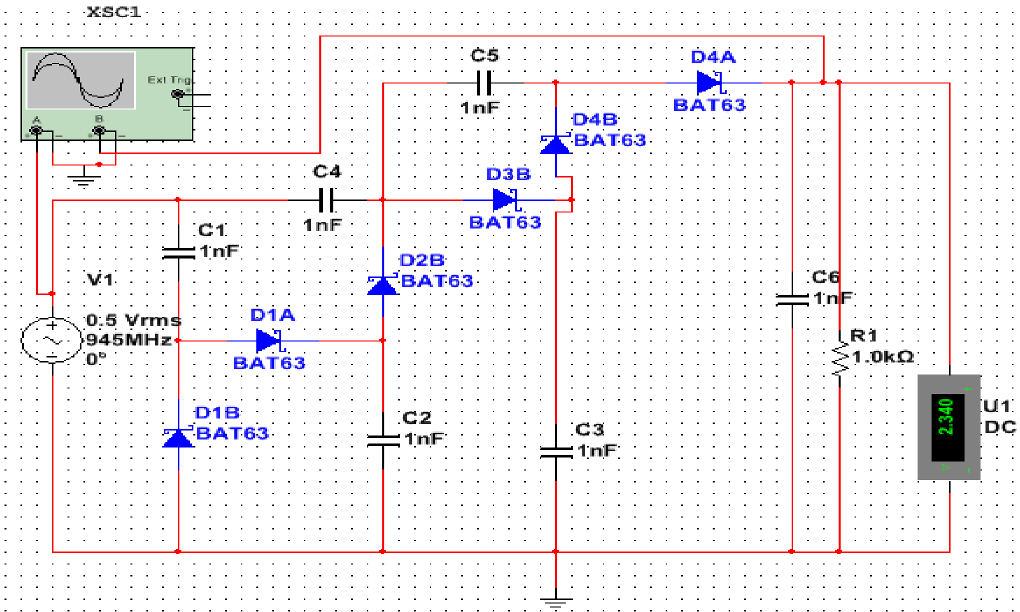


Figure 14 : 5 Stages of charge pump circuit

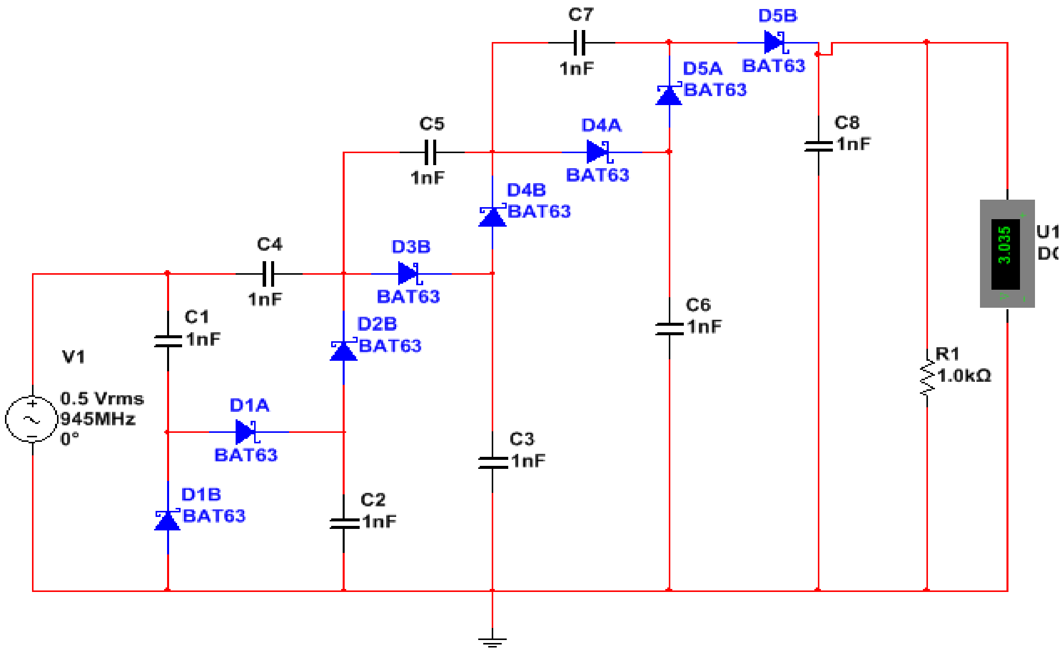


Figure 15 : 7 Stages of charge pump circuit

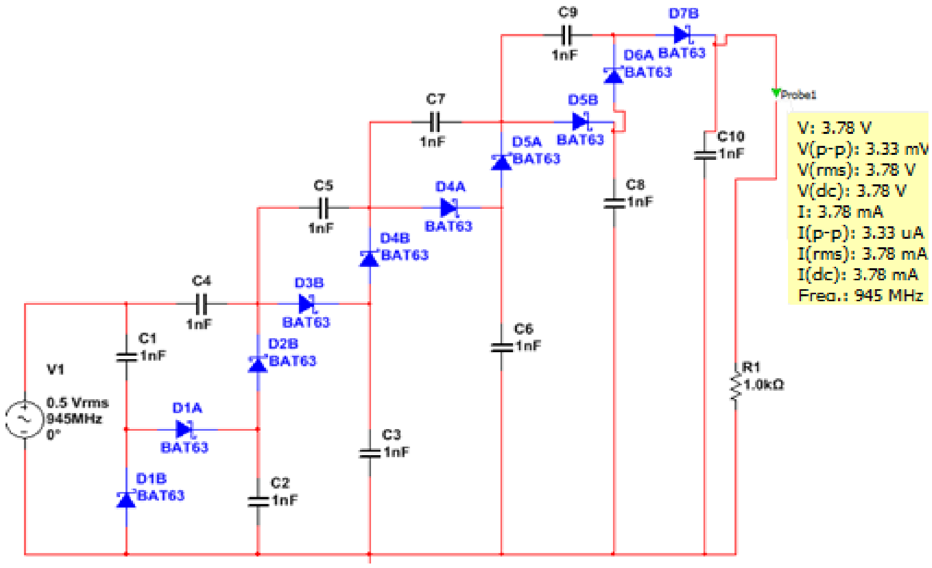


Figure 16 : 9 Stages of charge pump circuit

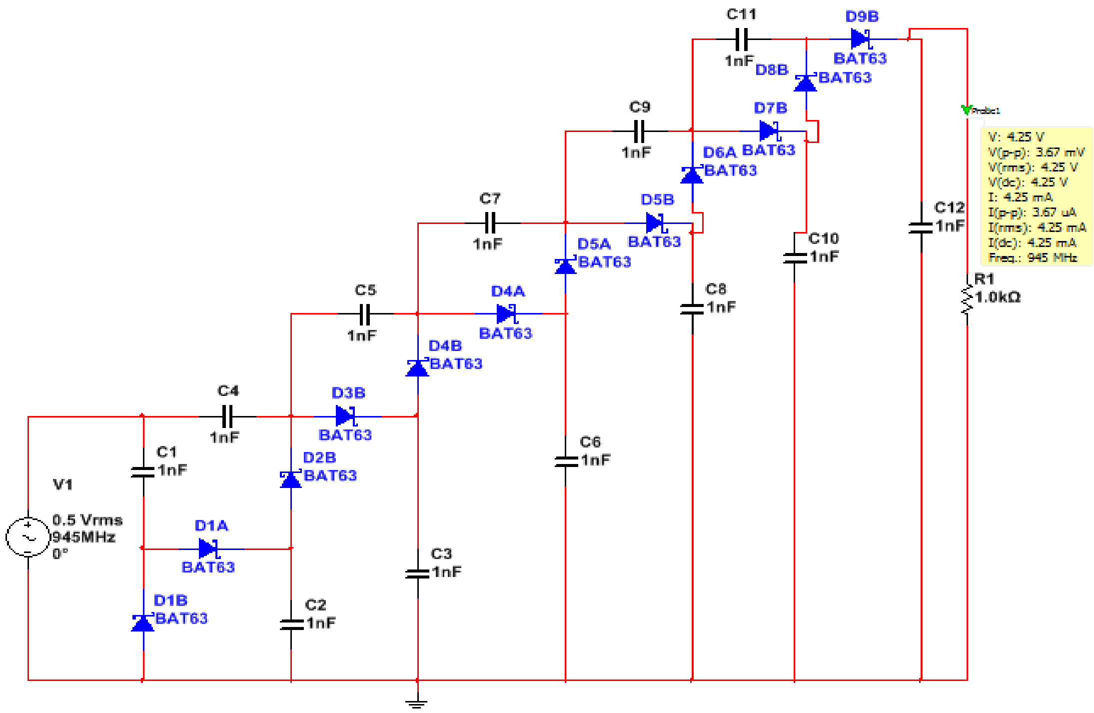


Figure 17: 11 Stages of charge pump circuit

Since the required output voltage is achieved at eleventh stages of charge pump, the current is measured at the output as shown in Figure 17 in order to know the period for battery to fully charge.

### 3.3.2 Current amplifier

The circuit simulation in Figure 17 shows that the output current at eleventh stages of charge pump is too small. Hence the current need to be increased in order to charge the battery for shorter period. The LT1763 series low dropout regulator is used for this purpose.

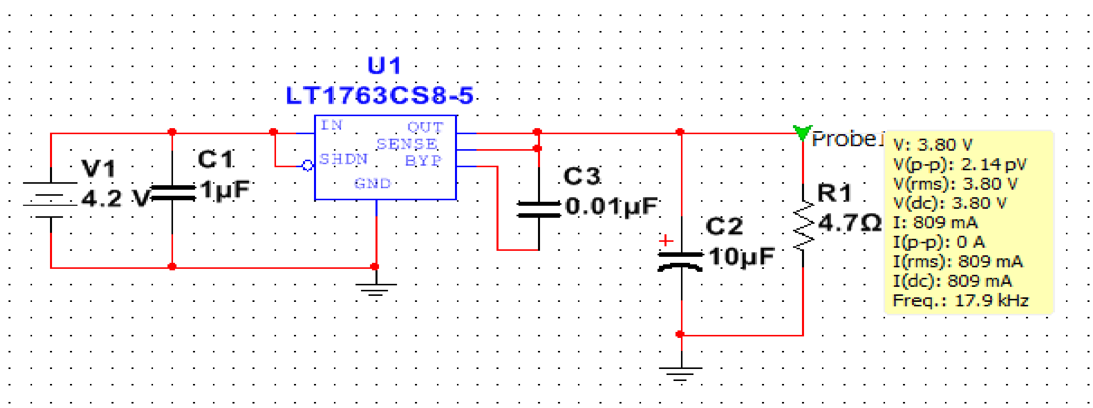


Figure 18: LT1763 micropower regulator circuit

The LT1763 series are micropower, low dropout (LDO) regulator that capable to supply 500mA of output current with a dropout voltage of 300mV. This device can be found in many applications such as cellular phone, battery-powered system and noise-sensitive instrumentation system. Figure 18 shows the pinout configuration for LT 1763 in order to increase the output current. The input voltage V1 is referred to output voltage of 11$^{th}$ stages of voltage multiplier circuit. The value of C1, C2 and C3 are taken from component datasheet that is provided in appendix D while R1 is example of load resistor. The LT1763 series come in fixed output voltages of 1.5 V, 1.8 V, 2.5 V, 3.3 V and 5 V. In this project, LT1763CS8-5 is used in order to get the maximum output voltage of 5 V.

### 3.4 Experimental setup

The experiment was carried out using direct AC input generated from regulated AC power transformer. This part of experiment is to verify that the voltage multiplier circuit works as specified in theory and simulation.

Voltage multiplier circuit was tested on the board as shown in Figure 19. Due to the unavailability of BAT63 Schottky diode, the initial design utilized the germanium diode based on the fact that Germanium diode also has low voltage drop of 0.3 V. The datasheet for OA 90 germanium diode can be found in the appendix C. The circuit consists of OA 90 germanium diode, 1 nF capacitor, 1 kΩ resistor and wire.

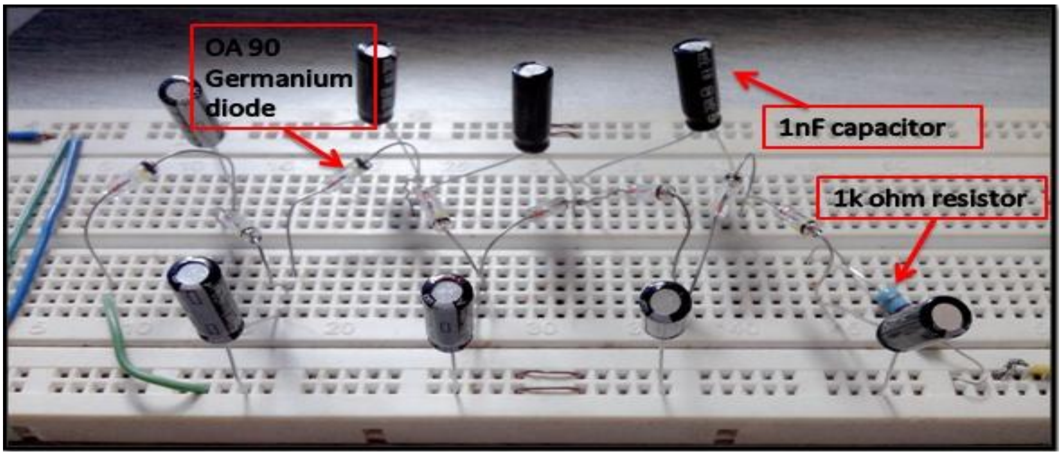


Figure 19: voltage multiplier circuit on testing

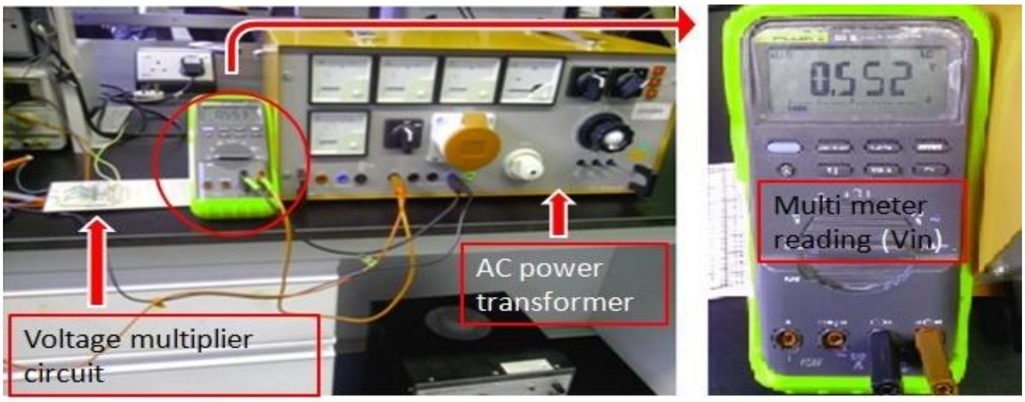


Figure 20: Equipment setup

The equipment setup for the experiment is shown in Figure 20. An Ac power transformer was regulated to 0.5 Vac as input voltage for voltage multiplier circuit. This value is generic representation of an AC signal for GSM energy that is harvested from the surrounding. The multimeter reading of output voltage is tabulated in section 4.3.

## 3.5 List of tools

Several software and hardware equipment were utilized to achieve the project's goal as shown in Table IV.

Table IV: List of tools

| No. | Name of component | Manufacturer/ supplier | Qty | Price/unit (RM) | Total price (RM) |
|---|---|---|---|---|---|
| 1 | Germanium diode (OA 90) | RS Components | 15 | 2.554 | 38.31 |
| 2 | Donut board 20x8.5 cm | Cytron | 1 | 15.00 | 15.00 |
| 3 | Capacitor (1 nF) | EE store | 12 | - | - |
| 4 | Resistor (1 Ω) | EE store | 2 | - | - |
| 6 | NI Multisim 12.0 | Downloaded | N/A | N/A | N/A |
| TOTAL (RM) | | | | | 53.31 |

Lab equipments:

- Function generator, Fluke Multimeter, AC power transformer, and Solder tools.

# CHAPTER 4

# RESULTS AND DISCUSSIONS

## 4.1 Voltage multiplier

a) Test 1: The effect of different type of diode

The result for different type of diode is summarized in Table V. From the simulation, it was observed that Schottky diode BAT 63 gives the best output voltage which is 868 mV. Hence, BAT 63 type of diode will be chosen for the rest of simulation.

Table V: Diode type effect on the output voltage

| **Type of diode** | **Electrical characteristics of diode** | | **Output voltage (V)** |
|---|---|---|---|
| | **Voltage rating** | **Current rating** | |
| BAT14_098 | 3 V | 100 mA | 0.424 |
| BAT63 | 3 V | 100 mA | 0.868 |
| BAT17 | 4 V | 130 mA | 0.552 |

b) Test 2: The effect of charge pump stages to the output

The result of the simulation is summarized inTable VI. The output voltage is theoretically calculated by using Eq. (7) in order to compare the theoretical value and simulation value. The maximum threshold voltage for BAT63 diode is 0.5 V and $V_{pk}$ is set to 0.707 V. From the simulation results obtained, it was observed that the more the stages of charge pump circuits, the higher output voltage is produced. However, as the number of stages increases, the size of the circuit increases.

Table VI : Stages number effect on the output voltage

| Number of stages | Output voltage (V) | | | Output current (mA) | Power loss (mW) |
|---|---|---|---|---|---|
| | Calculation $V_{out} = 2N(V_{pk} - V_{th})$ | Simulation | Percentage differences (%) | Simulation | Calculation $= I^2 \times R$ |
| 3 | 1.242 | 1.643 | 26 | 1.41 | 1.98 |
| 5 | 2.07 | 2.340 | 13 | 2.36 | 5.56 |
| 7 | 2.898 | 3.035 | 4 | 3.04 | 9.24 |
| 9 | 3.726 | 3.670 | 1.5 | 3.78 | 14.29 |
| 11 | 4.554 | 4.25 | 6.7 | 4.25 | 18.06 |

From Table VI, it can be concluded that the simulation tries to achieve the required output voltage for charging the phone. As mentioned in methodology part, the requirement of battery voltage is 3.7 V (minimum) and 5 V (maximum). This requirement can be achieved during the eleventh stage of voltage multiplier since at the eleventh stage gives the output voltage of 4.25 V. It can be observed that the higher number of stages used will increase the DC output voltage as presented in Figure 21. However it may also result in more power loss within the components. Therefore, the simulation is stopped at eleventh stages for better efficiency of the circuit.

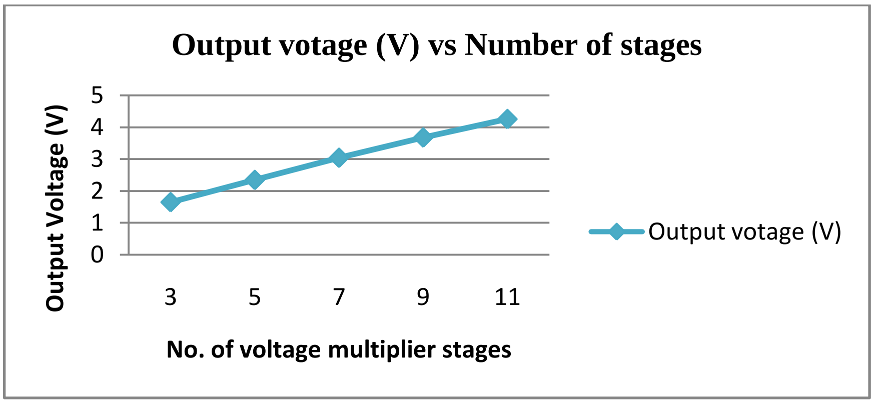


Figure 21 : Graph of output voltage vs number of stages of voltage multiplier

Figure 22, Figure 23, Figure 24, Figure 25 and Figure 26 show the output waveform for 3 stages, 5 stages, 7 stages, 9 stages and 11 stages of voltage multiplier respectively. Channel A represents the waveform of AC signal from the source which is 0.5 $V_{rms}$ while Channel B represents DC output voltages for each stage. The waveform shows that the output voltage has successfully increased up to required output of 3.7 V during eleventh stage of voltage multiplier.

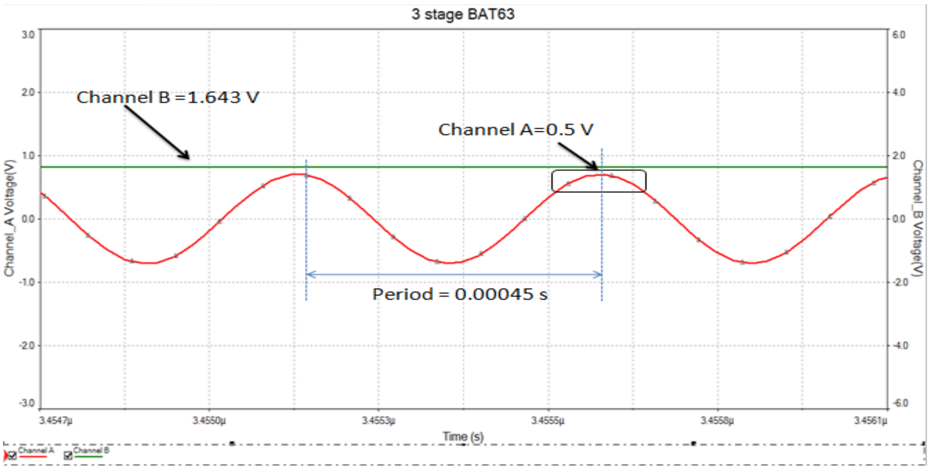


Figure 22: Output waveform of 3 stages voltage multiplier

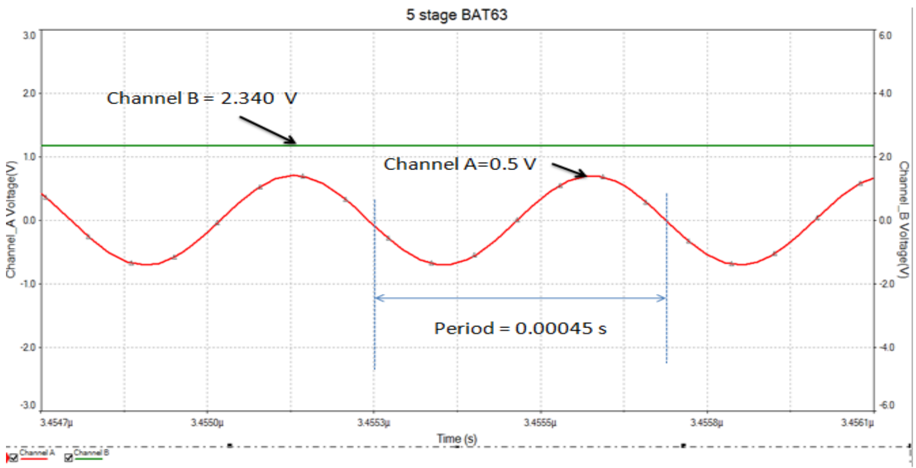


Figure 23: Output waveform of 5 stages voltage multiplier

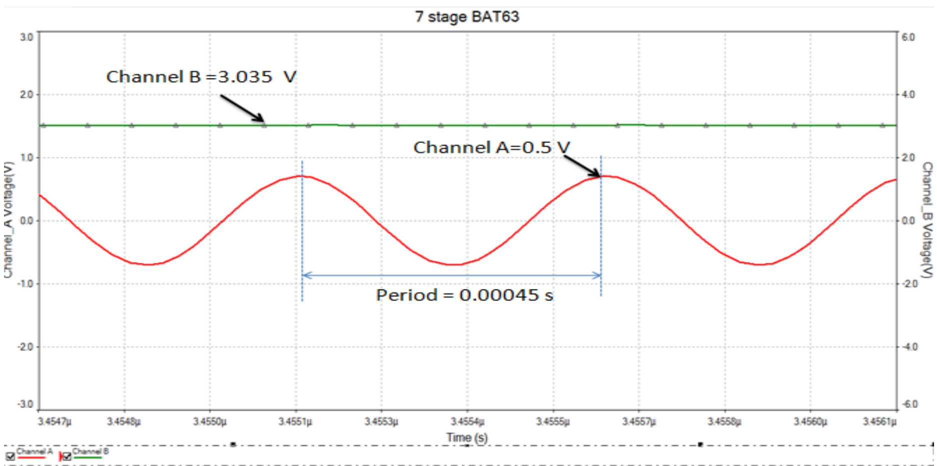


Figure 24: Output waveform of 7 stages voltage multiplier

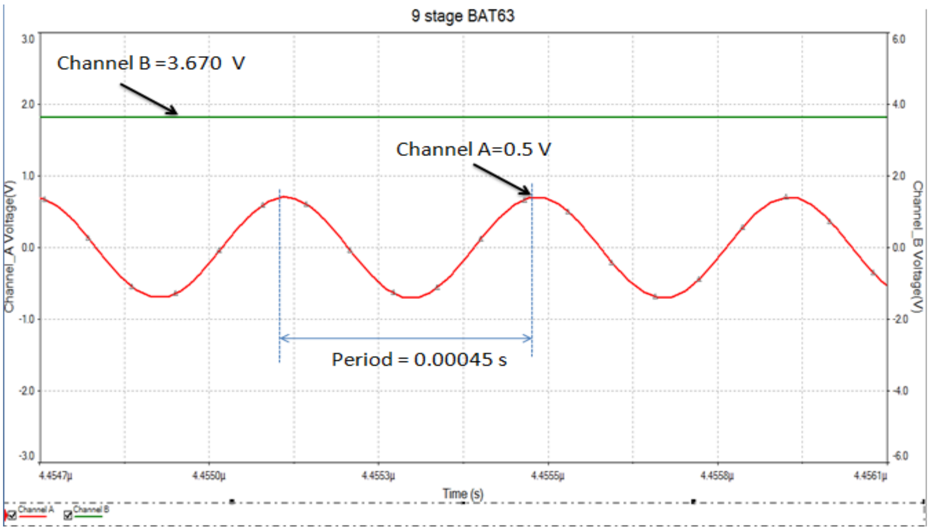


Figure 25: Output waveform of 9 stages voltage multiplier

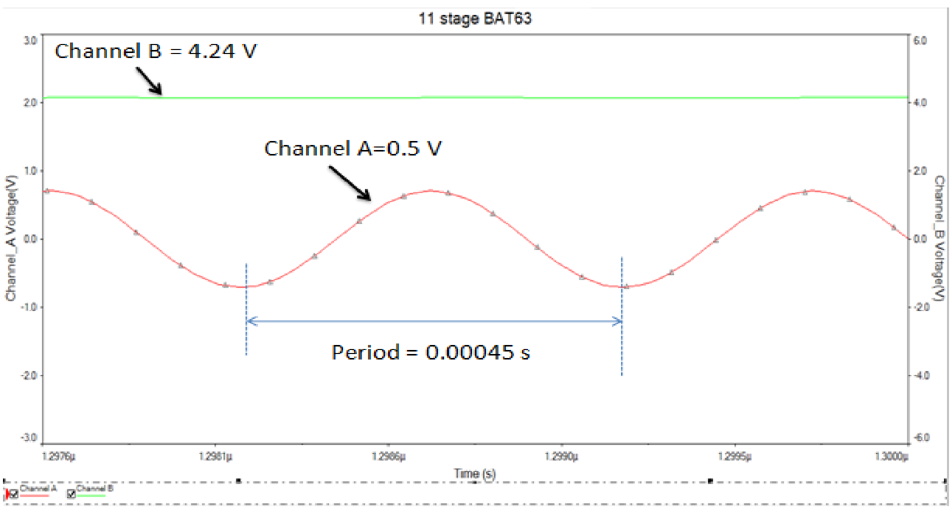


Figure 26: Output waveform of 11 stages voltage multiplier

DC output voltage is actually not in straight line for all stages but they have ripples in the waveform as shown in Figure 27.

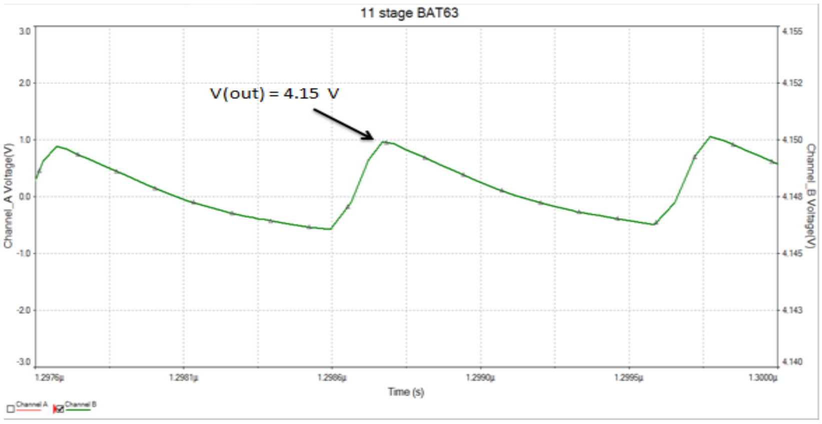


Figure 27: ripples at DC output voltage

## 4.2 Current amplifier

As described in section 3.3.2, LT1763 low dropout micropower voltage regulator is simulated to increase the output current. By using LT1763, it can be observed that the output current can be increased while the output voltage is slightly decreasing due to 300 mV dropout voltage characteristic of the LT1763 series. The simulation of LT1763CS8-5 as shown in section 3.3.2 shows that the regulator is able to increase the current up to 800 mA and gives the output voltage of 4.231 V if no load connected at the output. Hence by using this circuit, it can decrease the charging period for the battery. For example, if the battery capacity is 1600 mAh, it can fully charge within two hours if the current output of the regulator is 800 mA. The circuit is tested with the load connected at the output to measure the new output with the load present. For the simulation purpose, 4.7 ohm load resistor is connected at the output as a load. As a result, the voltage produced at the output is 3.80 V which is indicates the minimum output voltage of the regulator circuit. The special characteristic of this regulator is limiting the output voltage up to 5 V maximum, means that for any voltage enter the regulator (input voltage) that is exceed 5 V, the output produced by this regulator is still fixed to 5 V. Hence, it is suitable to battery charging and prevents any over voltage to occur although the input fed into regulator is higher than 5 V. The output DC current waveform is shown in Figure 28.

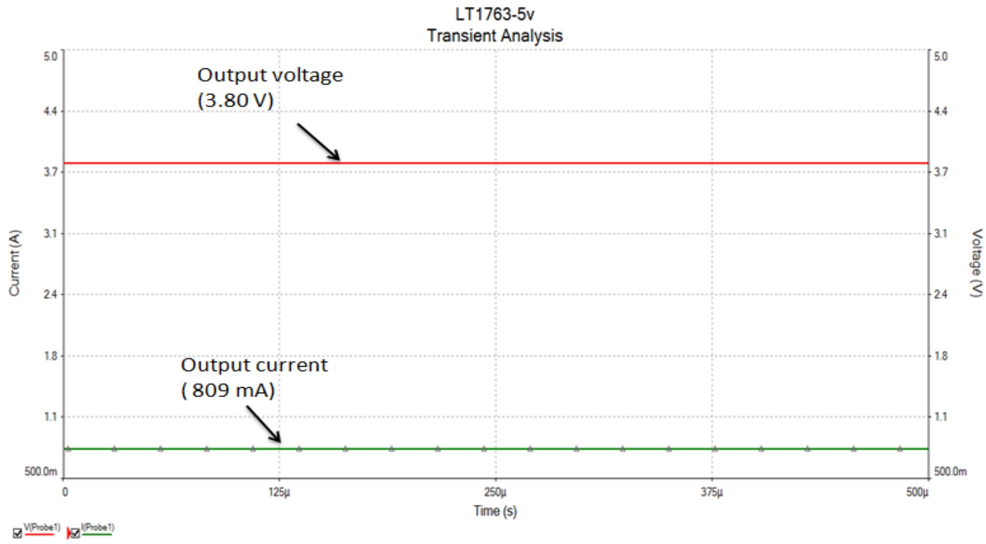


Figure 28 : Output waveform for LT1763

### 4.3 Experimental result

The simulation and experimental findings of voltage multiplier is tabulated in Table VII.

Table VII : simulation vs. experimental result for voltage multiplier

| Number of stages | DC Output voltage (V) | | |
|---|---|---|---|
| | Simulation | Experiment | Differences (\|simulation-experiment\|) |
| 3 | 1.643 | 0.930 | 0.713 |
| 5 | 2.340 | 1.296 | 1.044 |
| 7 | 3.035 | 2.720 | 0.315 |
| 9 | 3.670 | 2.960 | 0.71 |
| 11 | 4.250 | 3.975 | 0.275 |

From the experiment, it is verified that the voltage multiplier can be used to increase the output voltage. The experimental value is slightly different with simulation due to the different type of diode is used during the experiment. The germanium diode is used instead of Schottky diode due to the unavailability of BAT 63 Schottky diode. Although the different type of diode is used, the diode rating does not vary that much. However, the differences not give as much effect to the actual required output since the chosen germanium diode having quite similar characteristics with BAT 63.

# CHAPTER 5

# CONCLUSION

For overall, this project is presented as having three implementation phases. Further research and study has been carried out in first phase, thus give an idea for circuit designing and simulation in second phase. From the circuit simulation done in Multisim 12.0, it shows that the load requirement of 3.7 V can be achieved at eleventh stage of voltage multiplier circuit. BAT63 silicon schottky diode is used since it gives the best output voltage rather than other type of diode, very small in size and low threshold voltage level. The simulation shows that the output voltage at eleventh stage voltage multiplier is 4.2 V with low output current. Hence the current amplifier circuit is added at the voltage multiplier in order to increase the output current.

In this project, LT1763 low dropout micropower regulator is chosen for current amplifier circuit which can increases the current up to 800 mA and gives the stable DC output voltage for maximum of 5 V. Based on the fact that it is capable to limit the output voltage for maximum 5 V, the over voltage phenomena can be avoided. The output voltage of eleventh stage voltage multiplier is slightly decreased to 3.8 V when it is passing through current amplifier due to dropout voltage characteristic of LT 1763.

As a conclusion, the objectives are successfully achieved by designing eleventh stages of voltage multiplier and current amplifier circuit with the output voltage and current of 4.2 V and 809 mA respectively. By using these results it can say that it is possible to charge the battery using GSM energy that can be harvested in the surrounding. In the future work, the actual prototype by using phone battery will be demonstrated to show the real project achievement. Besides, the circuit should be small in size in order to be fabricated in the phone.

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# APPENDICES


| APPENDIX | TITLE |
|---|---|
| A | FYP 1 Gantt Chart |
| B | FYP 2 Gantt Chart |
| C | Datasheet for OA 90 germanium diode |
| D | Datasheet for LT 1763 |

Appendix A: FYP 1 gantt chart

| NO. | | ACTIVITIES | DATE | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | MAY | | JUNE | | | | JULY | | | | | AUGUST | | | | |
| | | | 24 | 31 | 7 | 14 | 21 | 28 | 4 | MIDSEM BREAK | 12 | 19 | 26 | 2 | 9 | 15 | 23 |
| **1** | | **PROJECT TOPIC SELECTION** | | | | | | | | | | | | | | | | |
| **2** | | **RESEARCH AND STUDY** | | | | | | | | | | | | | | | | |
| | 2.1 | Background study | | | | | | | | | | | | | | | | |
| | | - research and study background of the project | | | | | | | | | | | | | | | | |
| | 2.2 | Literature Review | | | | | | | | | | | | | | | | |
| | 2.2.1 | - Radio Frequency (RF) | | | | | | | | | | | | | | | | |
| | 2.2.2 | -Global system for Mobile communication (GSM) | | | | | | | | | | | | | | | | |
| | 2.2.3 | -Antenna | | | | | | | | | | | | | | | | |
| **3** | | **EXTENDED PROPOSAL** | | | | | | | | | | | | | | | | |
| | 3.1 | Extended proposal preparation | | | | | | | | | | | | | | | | |
| | 3.2 | Extended proposal submission | | | | | | | | | | | | | | | | |
| **4** | | **PROPOSAL DEFENSE** | | | | | | | | | | | | | | | | |
| | 4.1 | Proposal defence preparation | | | | | | | | | | | | | | | | |
| | 4.2 | Proposal defence presentation | | | | | | | | | | | | | | | | |
| **5** | | **DESIGN CONVERTER AND CHARGE CONTROLLER CIRCUIT** | | | | | | | | | | | | | | | | |
| | 5.1 | block diagram of the design | | | | | | | | | | | | | | | | |
| | 5.2 | optimize the whole design | | | | | | | | | | | | | | | | |
| | 5.3 | Simulate the design in MultiSim (simulation will be continued during FYP 2) | | | | | | | | | | | | | | | | |
| | 5.4 | Place order for components | | | | | | | | | | | | | | | | |
| **6** | | **INTERIM REPORT** | | | | | | | | | | | | | | | | |
| | 6.1 | Interim report preparation | | | | | | | | | | | | | | | | |
| | 6.2 | Draft interim report submission | | | | | | | | | | | | | | | | |
| | 6.3 | Final interim report submission | | | | | | | | | | | | | | | | |

Appendix B: FYP 2 gantt chart

| NO. | | ACTIVITIES | DATE | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | SEP | OCT | | | | | NOV | | | | DEC | | | | | JAN |
| | | | 27 | 4 | 11 | 18 | 25 | | 4 | 11 | 22 | 29 | 4 | 13 | 16 | 23 | 31 | 10 |
| **1** | **SIMULATION** | | | | | | | MIDSEM BREAK | | | | | | | | | | |
| | 1.1 | Simulation in Multisim | | | | | | | | | | | | | | | | |
| | 1.2 | analyze the output current and voltage | | | | | | | | | | | | | | | | |
| **2** | **PROTOTYPE** | | | | | | | | | | | | | | | | | |
| | 2.1 | circuit fabrication | | | | | | | | | | | | | | | | |
| | | 2.1.1 voltage multiplier | | | | | | | | | | | | | | | | |
| | | 2.1.2 current amplifier | | | | | | | | | | | | | | | | |
| | 2.2 | testing on circuits | | | | | | | | | | | | | | | | |
| | 2.3 | final prototyping | | | | | | | | | | | | | | | | |
| **3** | **PROGRESS REPORT** | | | | | | | | | | | | | | | | | |
| | 3.1 | Progress report preparation | | | | | | | | | | | | | | | | |
| | 3.2 | Progress report submission | | | | | | | | | | | | | | | | |
| **4** | **PRE- EDX** | | | | | | | | | | | | | | | | | |
| | 4.1 | Pre- EDX preparation | | | | | | | | | | | | | | | | |
| | 4.2 | Pre- EDX presentation | | | | | | | | | | | | | | | | |
| **5** | **TECHNICAL REPORT** | | | | | | | | | | | | | | | | | |
| | 5.1 | Technical report preparation | | | | | | | | | | | | | | | | |
| | 5.2 | Technical report submission | | | | | | | | | | | | | | | | |
| **6** | **FINAL REPORT** | | | | | | | | | | | | | | | | | |
| | 6.1 | Final report preparation | | | | | | | | | | | | | | | | |
| | 6.2 | draft final report submission | | | | | | | | | | | | | | | | |
| | 6.3 | final report submission | | | | | | | | | | | | | | | | |
| | 6.4 | final report (hard bound) submission | | | | | | | | | | | | | | | | |
| **7** | **VIVA** | | | | | | | | | | | | | | | | | |