Sudan University of Science and Technology

College of Graduate Studies

Electrical Engineering

Wireless Electrical Power Transfer for Charging Low Power Appliances

نقل القدرة الكهربائية لاسلكيا لشحن الاجهزة ذات القدرات المنخفضة

A thesis Submitted in Partial Fulfillment for the Requirements For the Degree of M.Sc. In Electrical Engineering (Power)

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الآيــــة

بسم الله الرحمن الرحيم

قال تعالى:

﴿ لَا يُكَلِّفُ اللَّهُ نَفْسًا إِلَّا وُسْعَهَا لَهَا مَا كَسَبَتْ وَعَلَيْهَا مَا اكْتَسَبَتْ رَبَّنَا لَا تُؤَاخِذْنَا إِن
نَّسِينَا أَوْ أَخْطَأْنَا رَبَّنَا وَلَا تَحْمِلْ عَلَيْنَا إِصْرًا كَمَا حَمَلْتَهُ عَلَى الَّذِينَ مِن قَبْلِنَا رَبَّنَا وَلَا تُحَمِّلْنَا مَا لَا
طَاقَةَ لَنَا بِهِ وَاعْفُ عَنَّا وَاغْفِرْ لَنَا وَارْحَمْنَا أَنتَ مَوْلَانَا فَانصُرْنَا عَلَى الْقَوْمِ الْكَافِرِينَ ﴾

صدق الله العظيم

سورة البقرة الآية: 286

Dedication

Without you I could not go left or right and life would be darkness, world has no hope no light:

(My parent)

To whom that they made our life colorful

(My brothers and my sisters)

To all special people in our life

With all love.

ACKNOWLEDGEMENT

It gives me immense pleasure and satisfaction in presenting the project report on Wireless Power Transfer" towards the partial fulfillment of Master of Science Degree in Electrical Engineering.

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I would like to thank my parents and friends for their constant encouragement and help.

ABSTRACT

Wireless charging through inductive coupling could be one of the next technologies that carry the futures forward. In this study it has been shown that it is possible to charge low power devices wirelessly via inductive coupling. It minimizes the complexity that arises for the use of conventional wire system. In addition, the thesis also opens up new possibilities of wireless systems in other daily life uses. Much interest in the research has been conducted to determine the feasibility of system design and implementation of wireless power transmission and simulation process of charging the load at different distances by using MATLAB computer program.

مســــتخـــــــــــــلـــــــص

الشحن اللاسلكي من خلال الاقتران الحثي يمكن ان يكون أحد التقنيات الحديثة التي تحمل المستقبل الى الامام. في هذه الدراسة تم توضيح انه من الممكن شحن بطارية تلفون لا سلكيا من خلال الاقتران الحثي . ذلك الشئ الذي يقلل من التعقيد الناشي عند استخدام الشحن التقليدي السلكي. بالاضافة الى ذلك فإن هذا البحث فتح امكانية جديدة للانظمة اللاسكية في مختلف استخدامات الحياة اليومية. أولى هذا البحث من الاهتمام تطبيق وتصميم النقل اللاسلكي وتنفيذه ومحاكاة عملية شحن الحمل على مسافات مختلفة باستخدام برنامج الحاسوبMATLAB.

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LIST OF ABBREVIATIONS

Abbreviations	Descriptions
Ac	Alternating Current
Cm	Centimeter
D	Diode
DC	Direct Current
EM	Electro-Magnetic
EV1	Electric Vehicle
IGBT	Insulated Gate Bipolar Transistor
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
NASA	National Aeronautics and Space Administration
PCB	Printed Circuit Board
Q	Quality Factor
UAV	unmanned aerial vehicle
V	Volt
W	Watt
WII	Wireless Remote

`CHAPTER ONE

INTRODUCTION

1.1 General

Electrical transmission lines are used to transmit electric energy and signals from one point to another, specifically from a source to a load, this may include the connection between a transmitter and antenna, connections between computers in network, or between a hydroelectric generating plant and a substation several hundred miles away [1].Such as electromagnetic waves or acoustic waves, as well as electric power transmission.

However in communications and electronic engineering, the term has amore specific meaning. In these fields, transmission lines are specialized cables and other mediate signal carry alternating current and electromagnetic waves of high frequency (radio frequency),high frequency enough to be taken into account. Transmission lines are used for purposes such as connecting radio transmitters and receivers with their antennas, distributing cable ,television signals, and computer network connections.

Ordinary electrical cables suffice to carry low frequency AC, such as mains power, which reverses direction 50 to 60 times per second. However, they cannot be used to carry currents in the radio frequency range or higher, which reverse direction millions to billions of times per second, because the energy tends to radiate off the cable as radio waves, causing power losses. Radio frequency currents also tend to reflect from discontinuities in the cable such as connectors, and travel back down the cable toward the source. These reflections act as bottlenecks, preventing the power from reaching the destination. Transmission lines use specialized construction such as precise conductor dimensions and spacing, and impedance matching, to carry electromagnetic signals with minimal reflections and power losses. Types of transmission line include the higher frequency; the shorter are the waves in a transmission medium. Transmission lines must be used when the frequency is high enough that the wavelength of the waves begins to approach the length of the cable used. To conduct energy at frequencies above the radio range, such as millimeter waves, infrared, and light, the waves become much smaller than the dimensions of the structures used to guide them, so transmission line techniques become inadequate and the methods of optics are used.

The theory of sound wave propagation is very similar mathematically to that of electromagnetic waves, so techniques from transmission line theory are also used to build structures to conduct waves through the space; and these are also called transmission lines [2].

1.2 Statement of Problem

Due to complex procedure of transmission lines and have more faults as well as affected by the air factors and interference with the magnetic field, for that they need a huge insulators to avoid all of these problems, which have made them require a large cost of maintenance and low efficiency. As well as ordinary electrical cables suffice to carry low frequency AC, such as mains power, which reverses direction 50 to 60 times per second. However, they cannot be used to carry currents in the radio frequency range or higher, which reverse direction millions to billions of times per second, because the energy tends to radiate off the cable as radio waves, causing power losses.

1.3 Objectives

The main objective of this thesis is to design and implement a wireless charger of 12 volt power source so as to provide a new charging technique. The study will be capable of charging cell phone battery. Also other objectives of this thesis are:

- To design and implement a DC to AC inverter.
- To interface Loop Antenna to the circuit.
- To isolate DC from AC using Bridge rectifier circuit.
- To use power transistor to transmit a frequency through antenna.

1.4 Methodology

A modern power wireless transmission program includes:

- Study of all related previous works.

- PCB (Printed Circuit Board) which will be used in this research to implement the proposed study.
- The designer software **(MATLABPROGRAM)** will play a role of results verification.
- Radio Frequency would carry the remote signal.

1.5 Layout

This thesis consists of five chapters:

Chapter one covers the introduction to transmission lines, as well as the problem Statement and methodology. It is also covers the objectives of this project.

Chapter two describes theoretical backgrounds of inductive coupling and literature review.

Chapter three discusses the components and circuits used in the study. Also it describes some of these circuits and components briefly and circuit simulation.

Chapter four gives a general idea of system implementation and experimental result. In addition; it evaluates the performance of the circuits and efficiency.

Chapter five provides the conclusion and recommendations of the thesis.

CHAPTER TWO

THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1General Overview

Wireless Power Transmission (WPT) refers to energy transmission from one point to another without interconnecting wires. There are many applications for WPT, such as wireless power charging for mobile phones, wireless power distribution systems in buildings and wireless charging for Battery Electric Vehicles (BEVs) . The range for these applications varies widely but can be divided into three main regions: short distance, intermediate distance and long distance .

The principle of WPT is to convert prime Direct Current (DC) power to Radio Frequency (RF)and then transmit the power by Electro-Magnetic (EM) wave propagation. A block diagram of energy transfer is shown in Figure (2.1). At receiver, there is a rectifier which has the ability to convert EM waves back to direct current [3].

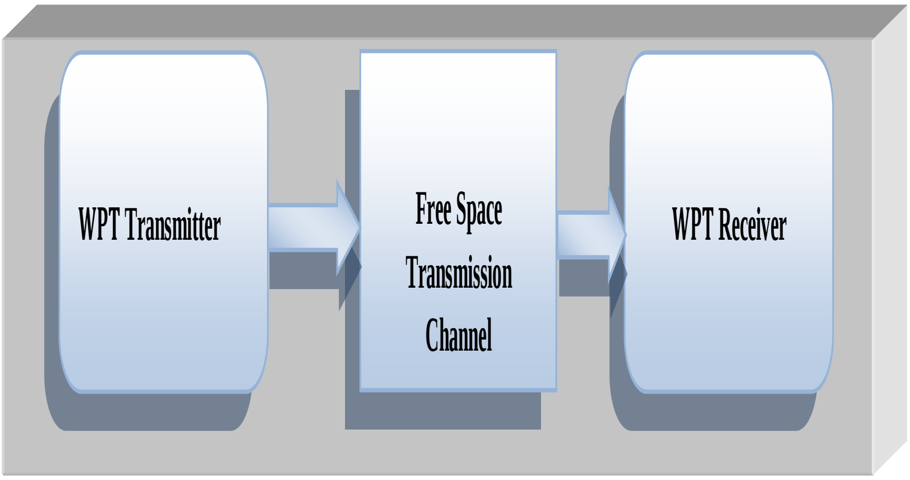

Figure 2.1 Wireless power transmission diagrams

2.2 Approaches of WPT

At present, energy has been transferred wirelessly using such diverse physical mechanisms like:

i. Laser

The laser beam is coherent light beam capable to transport very high energies; this makes it an efficient mechanism to send energy point to point in a line of sight. NASA introduced in 2003 a remote-controlled aircraft wirelessly energized by a laser beam and a photovoltaic cell infra-red sensitive acting as the energy collector. In fact, NASA is proposing such scheme to power satellites and wireless energy transfer where none other mechanism is viable.

ii. Piezoelectric principle

HUETAL in 2008, It has been demonstrated the feasibility to wirelessly transfer energy using piezoelectric transducers capable to emit and collect vibratory waves.

iii. Radio waves and microwaves

In 1973 Glaser is shown how to transmit high power energy through long distances using Microwaves.

iv. Inductive coupling

The inductive coupling works under the resonant coupling effect between coils of two LC circuits. The maximum efficiency is only achieved when transmitter and receiver are placed very close to each other. Which used in this study and mentioned in this chapter.

v. Strong electromagnetic resonance

Was introduced the method of wireless energy transfer, which use the "strong" electromagnetic resonance phenomenon, achieving energy transfer efficiently at several dozens of centimeters. Transferring great quantities of power using magnetic field creates, inevitably, unrest about the harmful effects that it could cause to human health [4].

2.3 Application of WPT

There are many application of WPT, can be mention as follows:

2.3.1 Consumer electronics

i. Automatic wireless charging of mobile electronics (phones, laptops, game controllers, etc.) in home, car, office, Wi-Fi hotspots etc., while devices are in use and mobile.
ii. Direct wireless powering of desktop PC peripherals: wireless mouse, keyboard, printer, speakers, display, etc, Eliminating disposable batteries and awkward cabling [3].

2.3.2 Industrial

i. Direct wireless power and communication interconnections across rotating and moving “joints” (robots, packaging machinery, assembly machinery, machine tools).Eliminating costly and failure-prone wiring.
ii. Direct wireless power and communication interconnections at points of use in harsh environments (drilling, mining, underwater, etc.), where it is impractical or impossible to run wires.
iii. Direct wireless power for wireless sensors and actuators, eliminating the need for expensive power wiring or battery replacement and disposal.
iv. Automatic wireless charging for mobile robots, automatic guided vehicles, cordless tools and instruments, Eliminating complex docking mechanisms and labor intensive manual recharging and battery replacement [3].

2.3.3 Other applications

i. Direct wireless power interconnections and automatic wireless charging for Implantable medical devices (ventricular assist devices, pacemaker, etc.).

ii. Automatic wireless charging and for high tech military systems (battery powered mobile devices, covert sensors, unmanned mobile robots and aircraft, etc.).
iii. Direct wireless powering and automatic wireless charging of smart cards.
iv. Direct wireless powering and automatic wireless charging of consumer appliances, mobile robots, etc [3].

2.4 Inductance and Inductive Coupling

In electromagnetism and electronics, inductance is the ability of an inductor to store energy in a magnetic field. Inductors generate an opposing voltage proportional to the rate of change in current in a circuit. This property is also called self-inductance to discriminate it from mutual inductance ، describing the voltage induced in one electrical circuit by the rate of change of the electric current in another circuit .The quantitative definition of the self-inductance L of an electrical circuit in SI units (Weber's per ampere, known as Henries) is

$$v = L * \frac{d_i}{\mathrm{d_t}} \qquad \ldots\ldots \qquad (2.1)$$

Where:

v Induced voltage in volts.

I Current in amperes.

The simplest solutions of this equation are a constant current with no voltage or a current changing linearly in time with a constant voltage.

Inductance is caused by the magnetic field generated by electric currents according to Ampere's law .To add inductance to a circuit, electronic components called inductors are used, typically consisting of coils of wire to concentrate the magnetic field and to collect the induced voltage.Mutual inductance occurs when the change in current in one inductor induces a voltage in another nearby inductor. It is important as the mechanism by which transformers work, but it can also cause unwanted coupling between conductors in a circuit .

2.4.1 Magnetic field due to moving charges and electric currents

All moving charged particles produce magnetic fields. Moving point charges, such as electrons, produce complicated but well known magnetic fields that depend on the charge, velocity, and acceleration of the particles. Magnetic field lines form in concentric circles around a cylindrical current-carrying conductor, such as a length of wire. The direction of such a magnetic field can be determined by using the right hand grip rule as shown in Figure (2.2). When a rotation is specified by a vector, it is necessary to understand the way in which the rotation occurs. The right-hand grip rule is applicable in this case. The rule is used in two complementary applications of Ampere's circuital law:

i. An electric current passes through a solenoid, resulting in a magnetic field. When someone wraps his/her right hand around the solenoid with their fingers in the direction of the conventional current, the thumb points in the direction of the magnetic north pole.

ii**.** An electric current passes through a straight wire. Here, the thumb points in the direction of the conventional current (from positive to negative), and the fingers point in the direction of the magnetic lines of flux.

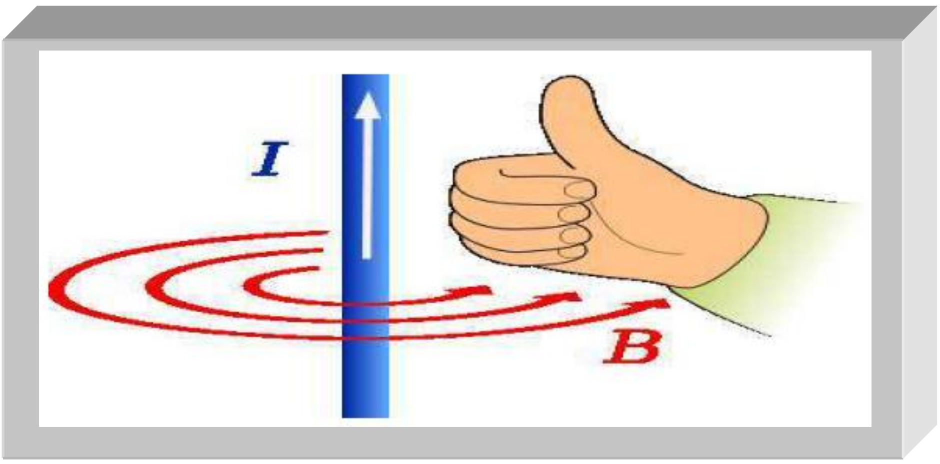

Figure 2.2: Right hand grip rule

The strength of the magnetic field decreases with distance from the wire. Bending a current-carrying wire into a loop concentrates the magnetic field inside the loop while weakening it outside. Bending a wire into multiple closely spaced loops to form a coil enhances this effect [4].

2.4.2 Inductive coupling

Inductive or Magnetic coupling works on the principle of electromagnetism. When a wire is proximity to a magnetic field, it generates a magnetic field in that wire. Transferring energy between wires through magnetic fields is inductive coupling.

If a portion of the magnetic flux established by one circuit interlinks with the second circuit, then two circuits are coupled magnetically and the energy may be transferred from one circuit to the another Circuit. This energy transfer is performed by the transfer of the magnetic field which is common to the both circuits.

In electrical engineering, two conductors are referred to as mutual-inductively coupled or magnetically coupled when they are configured such that change in current flow through one wire induces a voltage across the end of the other wire through electromagnetic induction. The amount of inductive coupling between two conductors is measured by their mutual inductance.

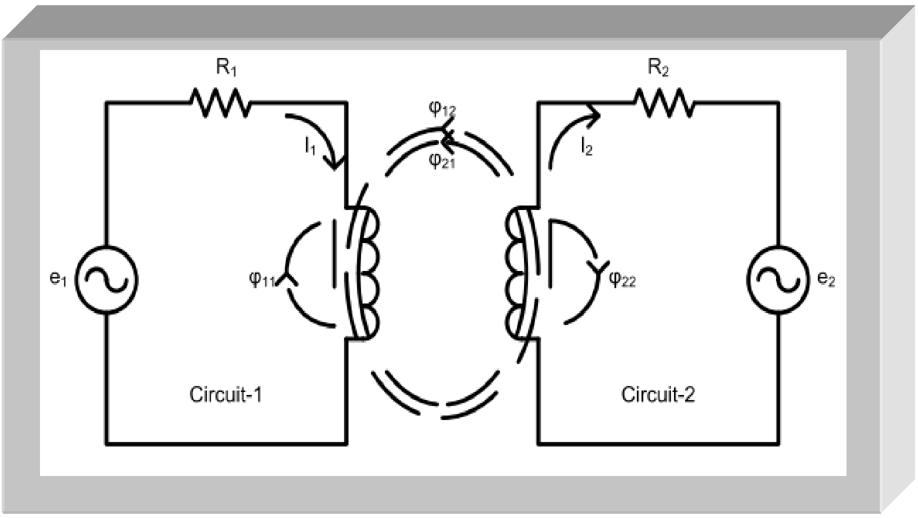

Figure 2.3: Inductive coupling with four component fluxes

Magnetic coupling between two individual circuits are shown in Figure 2.3. For the purpose of analysis we assume the total flux which is established by i_1 (circuit-1 current) is divided into two components. One component of it is that part which links with circuit-1 but not with circuit-2, $\emptyset_{11}$. The second component of it is which links with both circuit-2 and circuit-1,$\emptyset_{12}$. In this si milarway the flux established by i_2 (circuit-2 current) also has two components. One -component is the flux in circuit 2 ($\emptyset_{22}$) which links with only circuit-2 but not with circuit-1 and the other component is $\emptyset_{21}$which link with both circuit-2 and circuit-1.

$$\emptyset_1 = \emptyset_{11} + \emptyset_{12} \ldots\ldots \quad (2.2)$$

And,

$$\emptyset_2 = \emptyset_{22} + \emptyset_{21} \ldots\ldots \quad (2.3)$$

In equation (2.2), $\emptyset_{12}$ is a fractional part $\emptyset_1$ of, which links with the turns of circuit-2. So $\emptyset_{12}$ is called the mutual flux produced by circuit-1. In the same way, in equation (2.3), $\emptyset_{21}$ is the fractional part of $\emptyset_2$ which links with the turns of circuit-1. So $\emptyset_{21}$is called the mutual flux produced by circuit-2.

This is the phenomenon how the inductive coupling takes place between two individual circuits. This effect can be magnified or amplified through coiling the wire.

Power transfer efficiency of inductive coupling can be increased by increasing the number of turns in the coil, the strength of the current, the area of cross-section of the coil and the strength of the radial magnetic field. Magnetic fields decay quickly, making inductive coupling effective at a very short range [4].

2.4.3 Inductive charging

Inductive charging uses the electromagnetic field to transfer energy between two objects. A charging station sends energy through inductive coupling to an electrical device, which stores the energy in the batteries. Because there is a small gap between the two coils, inductive charging is one kind of short- distance wireless energy transfer.

Induction chargers typically use an induction coil to create an alternating electromagnetic field from within a charging base station, and a second induction coil in the portable device takes power from the electromagnetic field and converts it back into electrical current to charge the battery. The two induction coils in proximity combine to form an electrical transformer.

Greater distances can be achieved when the inductive charging system uses resonant inductive coupling.

2.4.4 Uses of inductive charging and inductive coupling

i. Inductive charging is used in Transcutaneous Energy Transfer (TET) systems in artificial hearts and other surgically implanted devices.

ii. It is used in Oral-B rechargeable toothbrushes by the Braun (company) since the early 1990s.

iii. Hughes Electronics developed the Magnetic Charge interface for General Motors. The General Motors EV1electric car was charged by inserting an inductive charging paddle into a receptacle on the vehicle.

iv. Nintendo WII uses an energizer inductive charging station for inductively charging the WII remote.

v. Pre smart phone by Palm Inc. gives an optional inductive charger accessory, the "Touchstone". The charger comes with a required special back plate that became standard on the subsequent Pre Plus model.

vi. Inductive coupling is also used in the induction cookers [4].

2.4.5 Advantages and drawbacks of inductive charging

Inductive charging carries a far lower risk of electrical shock, when compared with conductive Charging, because there are no exposed conductors. The ability to fully enclose the charging connection also makes the approach attractive where water impermeability is required; for instance, inductive charging is used for implanted medical devices that require periodic or even constant external power, and for electric hygiene devices, such as toothbrushes and shavers, that are frequently used near or even in water. Inductive charging makes charging mobile devices and electric vehicles more convenient; rather than having to connect a power cable, the unit can be placed on or close to a charge plate.

The Main disadvantages of inductive charging are its lower efficiency and increased resistive heating in comparison to direct contact. Implementations using lower frequencies or older drive technologies charge more slowly and generate heat for most portable electronics. Inductive charging also requires drive electronics and coils that increase manufacturing complexity and cost.

newer approaches diminish the transfer losses with ultra-thin coils, higher frequencies and optimized drive electronics, thus providing chargers and receivers that are compact, more efficient and can be integrated into mobile devices or batteries with minimal change. These technologies provide charging time that is the same as wired approaches and are rapidly finding their way into mobile devices. The magnetic charge system employed high-frequency induction to deliver high power at high efficiency [5].

2.4.6 Resonance

As per physics theory, the tendency of any system, generally a linear system, to oscillate at higher amplitude at specific frequencies compared to other is called as resonance. These particular frequencies are called as resonance frequencies and large amplitude oscillations can be produced at these frequencies even by small periodic driving forces.

The capability of a system to store and transfer energy between two or more storage modes gives rise to resonance. In case of a pendulum, it's kinetic and potential energy attribute to resonance. Every physical system has a natural frequency at which it oscillates at maximum amplitude. When the system is set to oscillations, the losses in each cycle called damping results in decrease of the amplitude. The resonant frequency of the system is approximately equal to its natural frequency when the damping is minimal.

Consider a circuit consisting of inductors and capacitors. When the magnetic field of the inductor collapses, electric current is induced in the winding which leads to charging of the capacitor. Now, when the capacitor discharges the resulting electric current creates a magnetic field in the inductor and this process repeats continuously.

Resonance can occur if the inductive reactance and the capacitive reactance of the circuit happen to be equal in magnitude and this results in oscillation of electrical energy between the electric and magnetic fields of capacitor and inductor respectively.

Under resonance, the inductor and capacitor have minimum series impedance and maximum parallel impedance whereas, the inductive and capacitive reactance are equal in magnitude. Hence.

$$\mathrm{w}l = 1/\mathrm{wc} \qquad \ldots\ldots (2.4)$$

$$\mathrm{w} = \frac{1}{\sqrt{\mathrm{lc}}}$$

Where(w)is: The resonant frequency of the circuit [5].

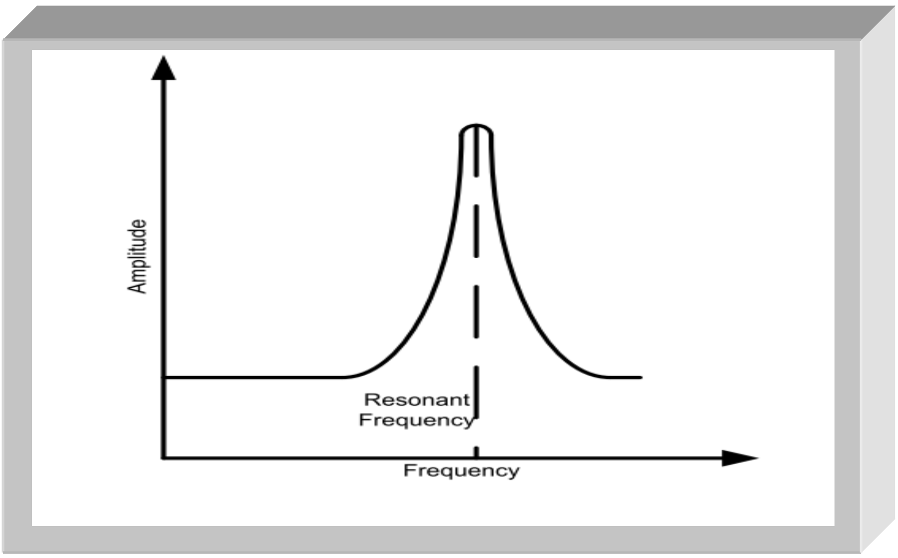

Figure 2.4: Resonant frequency

Resonance of a circuit involving capacitors and inductors occurs because the collapsing magnetic field of the inductor generates an electric current in its windings that charges the capacitor, and then the discharging capacitor provides an electric current that builds the magnetic field in the inductor.

2.4.7 Resonant energy transfer

Short range wireless energy transmission technologies such as WITRICITY, which use magnetic fields for the transmission, function on the principle of resonant energy transfer. It has been proved that magnetic fields are less likely to cause health issues in human beings as compared to electric fields.

For wireless transmission of energy using these kinds of systems require two coils which have the same resonant frequency. Another requirement, to have less losses and better efficiency, is that the coils should have high quality factor. Energy transmission takes place when these coils resonate at the resonant frequency. Sometimes such a system may be called a resonant transformer which uses air core to avoid iron losses. The two coils can be housed in the same equipment or separate enclosures may be used.

When an oscillating current is passed through a coil ring with high resonant frequency, it creates a strong oscillating magnetic field. Based on the phenomenon of resonant coupling, if any other coil with same resonant frequency is placed in the vicinity of this coil, energy gets transferred [5].

2.4.8 Resonant inductive coupling

Resonant inductive coupling or electrodynamics induction is the near field wireless transmission of electrical energy between two coils that are tuned to resonate at the same frequency. The equipment to do this is sometimes called a resonant or resonance transformer. While many transformers employ resonance, this type has a high Q and is often air cored to avoid iron losses. The two coils may exist as a single piece of equipment or comprise two separate pieces of equipment.

Using resonance can help efficiency dramatically. If resonant coupling is used, each coil is capacitively loaded so as to form a tuned LC circuit. If the primary and secondary coils are resonant at a common frequency, it turns out that significant power may be transmitted between the coils over a range of a few times the coil diameters at reasonable efficiency. Compared to the costs associated with batteries, particularly non-rechargeable batteries, the costs of the batteries are hundreds of times higher. In situations where a source of power is available nearby, it can be a cheaper solution. In addition, whereas batteries need periodic maintenance and replacement, resonant energy transfer can be used instead. Batteries additionally generate pollution during their construction and their disposal which is largely avoided[6].

2.5 History of Wireless Power Transmission

The concept of WPT is simply to transmit electrical power from one point to another through the atmosphere without the physical need of transmission lines or cables.

This process usually entails dc-to-ac power conversion, followed by the transmission of this Electro-Magnetic (EM) energy through the radiation of RF, microwave, laser or light. At the designated target, the reverse process occurs where the ac energy is rectified and converted into dc energy which is then used for power. The power can be used directly, but is most often used to charge a battery.

Brown wrote a descriptive paper on the history of WPT and its progress through the years. In it, he gives detailed accounts of the milestone advances in the work of WPT and the problems that it faced along the way. His references date back to Hertz who was the first to discover that electrical energy could be transmitted through electromagnetic fields in the air. His work was further explored by Tesla who noted that the earth had its own resonance that could be used to sustain low frequency power transmissions for a virtually endless amount of time. However, Tesla's work was hampered by funding issues and the requirement of extremely large plots of land to conduct his experiments [7].

2.5.1 Early experimentations

A number of advances in different areas came together around the late 1950s which enabled WPT to become a reality. The first advance was the ability to focus electromagnetic power into a beam and achieve high efficiencies, and the second was the amplifier tube, which created the required amount of transmitting power to power the electromagnetic beam. With these two advances, the efficient transmission of microwave power was satisfied and the next step was then to look at the reception and conversion of the microwave power. The first completed microwave power transmission system was conducted in May 1963, where 100 W of dc power was converted from a 400 W transmitter, was used to drive a motor attached to a fan. The advancement of WPT was, however, hampered by the short lifespan and unreliability of the thermionic diode used in the rectification process. Soon thereafter solid state semiconductor diodes were developed and the concept of a RECTENNA, consisting of a half-wave dipole antenna connected to the rectifying diode with a ground plate behind it, was conceived. Although the power handling capability of the diode in each RECTENNA was relatively small, these RECTENNA elements were then configured in an array to generate sufficient power required for the application. On 28 Oct 1964, the concept and demonstration of a microwave power helicopter was presented to the mass media. Following the build up of interest, a non-stop 10 hour hovering of a helicopter was conducted in November of that year [7].

2.5.2 Milestones of WPT

Milestones establish a lot of works in WPT such as:

i. Ability to work at higher frequencies

Working at the lower end of the frequency spectrum, as in Tesla's case, had its drawbacks. Because wavelength is in the tens of kilometers, large antennas require long stretches of land to lay the antennas. As RF transmission technology improved, transmissions at higher frequencies became possible. With this technology the move towards high frequency power transmission became prominent. The main advantage of using high frequencies is that the dimensions of the antennas could be reduced due to the reduction in wavelength. As the dimension of antenna is reduced, its application on mobile platforms or other places where space was limited became more feasible [7].

ii. Better rectification diodes

One of the most important milestones in the advancement of WPT is related to the diode used in the rectification process. Many papers have shown that the efficiency of the 28 is mainly attributed to the efficiency of the diode. This is supported by several references, Brown and Mc-Spadden to name a few. A good 28 diode would have characteristics such as low turn-on voltage, high reverse bias voltage, linear response to minimize harmonic generation and low power loss. Advances in this area began with the use of solid state silicon based PN junction diodes, which have a high turn on voltage of 0.7 V, and new fast switching Ga As

Schottky diodes that exhibit very fast switching capabilities suitable for high frequency rectification processes. The advances in the design of Schottky diodes which were capable of achieving good rectification efficiencies rejuvenated the interest in wireless power transmission to where we are today [7].

iii. Recent feasibility studies

Within the last decade a number of feasibility studies were carried out for WPT through the use of RECTENNAS. In 1999, a joint experimental study on a large RECTENNA array was conducted by the Radio Atmospheric Science Centre of Kyoto University and Kansai Electric Power Company. In their field experiment, they were able to attain $\mathrm{RF}-\mathrm{to}-\mathrm{dc}$ conversion efficiencies of 64% at $2.5\ \mathrm{W}$. In 1999, the Korea Electro-technology Research Institute conducted a study on the wireless power transmission system, where they were able to achieve single RECTENNA conversion efficiency of 75.6% and an overall system efficiency of 33%. Another feasibility study into the application of WPT, was whether ambient microwave energies could be recycled using RECTENNAS. This concept utilized broadband antenna arrays instead of narrowband ones in order to convert as much microwave power into dc power. In the study done by Hagerty , an array of 64 circularly polarized spiral elements was designed, where rectification efficiencies of 20% for $0.1\ \mathrm{mW/cm2}$ radiation was achieved [7].

iv.Power system implementation

of all the studies concerning the use of WPT, the one invention thought of by Peter Glaser in 1968, was directed towards Earth's growing need for an alternate source of energy on a global scale. In March of 2002, the IEEE Microwave Magazine published an article by Lin , spanning 3 pages, on the concept of Solar Power Satellites (SPS) and wireless power transmission. The concept was to build satellites with a sole function of gathering solar power and converting it into RF or microwave energy. This energy would then be transmitted through the vacuum of space using WPT technology back to Earth for use. The article highlighted supporting theory and present advances in technology that have made the possibility of SPS-WPT very real. In addition the concerns relating to both environmental and safety-related issues were mentioned. In December of 2002, another article was published in the IEEE Microwave Magazine written by Mc-Spadden. In the article, Mc-Spadden gave a detailed account of NASA's efforts of achieving a realizable Space Solar Power (SSP) program, and explained the different components required in the SSP system which entailed the use of WPT technology. The main components were the transmitter, beam control, and state-of-the-art RECTENNAS. Although it was mentioned that present technology has not achieved the state of maturity for successful implementation, the strategic roadmap highlights the incremental steps required for its assured growth. These points towards a day where its implementation will be the source of power for future generations. Another variant of similar intent is being explored by the TEXAS SPACE GRANT CONSORTIUM . Lunar bases are used in place of geo-synchronous satellites. Figure (2.5) shows the concept of such a system [7].

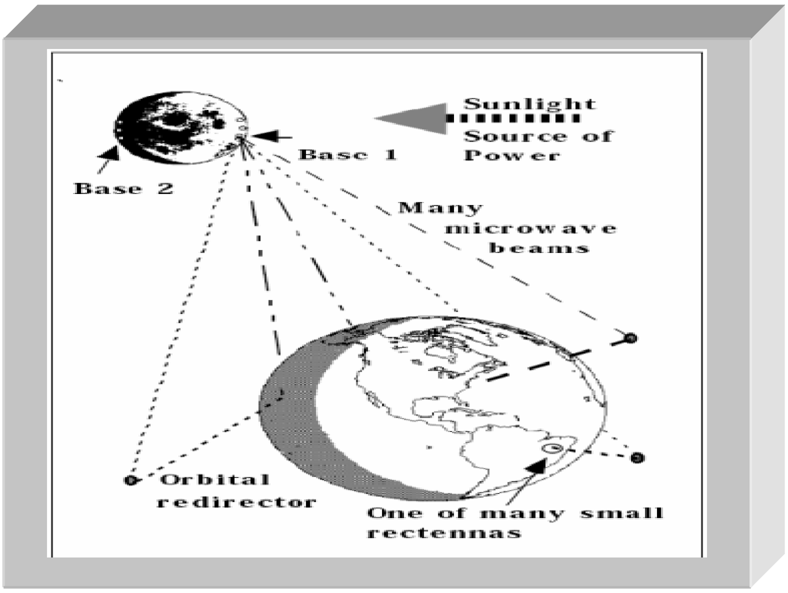

Figure (2.5): lunar solar power system reference model

v. Small scale implementation

The idea of WPT is, however, not limited to large scale implementations. In fact miniaturized applications have had their own fair share of interest, especially in the area of warfare. The concept of micro unmanned aerial vehicles, high altitude high endurance reconnaissance crafts, helicopters, and similar platforms, which utilize WPT technology, could possibly attain unlimited flight time, resulting in continuous availability. In fact the world's first un-tethered microwave powered flight was conducted on September 17, 1987. As shown in Figure (2.6), the plane flew in a circular path above the grid of antennas which directed the microwave beam onto the plane. The recorded flight duration was 20 minutes [7].

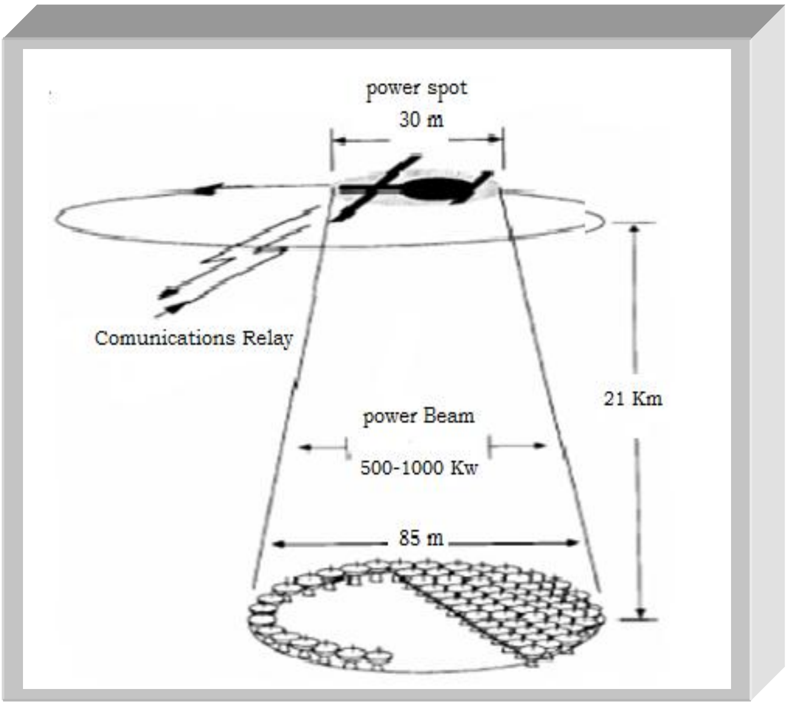

Figure (2.6): The sharp system.

There are other possible applications of WPT other than the attainment of unlimited sustenance of flight. Within the last decade, another area of science which has great potential for exploiting WPT is that of nanotechnology. Due to the miniaturization of both mechanical and electrical components, the energy requirements of such devices would generally be small and the physical size of the power source is very limited. In line with these requirements, WPT could very well be the ideal technology for powering these elements on a microscopic scale. In the NASA Tech Brief, Siegel proposed integrated-circuit modules called "nano-converters" that will be able to generate dc power from electromagnetic beams in the terahertz range. Each nano-converter will be composed of microscopic antennas and diodes which resemble conventional RECTENNAS used in the gigahertz range as shown in Figure (2.7) [7].

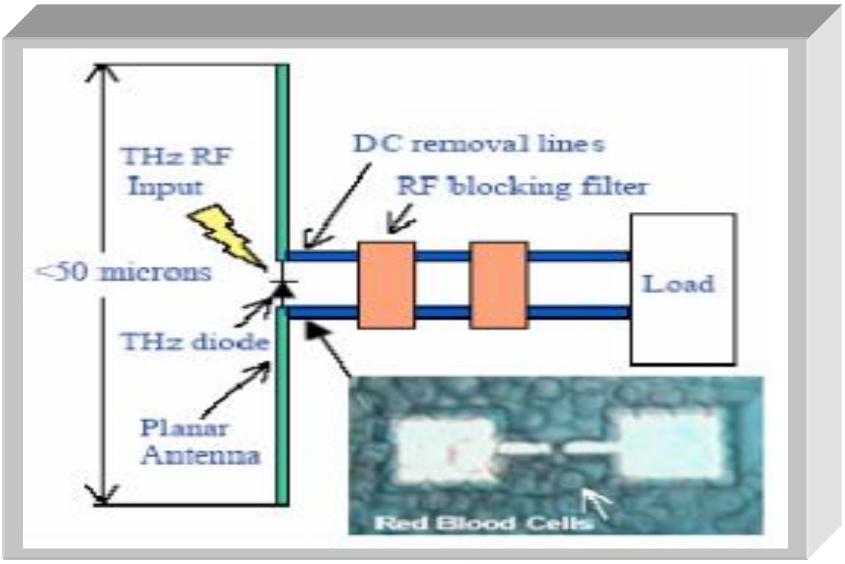

Figure (2.7): Nano-converter and the physical size with respect to red blood cells.

These nano-converters will supply sufficient power to nano-devices. The range of applications that could utilize such nano-devices would be extremely large ranging from medical, biological and, of course, military in nature. A recent article described a working model of a micro-UAV that was observed flying and believed to be remotely powered by an off-board source as in Figure(2.8). The report said it was equipped with nano-sensory capabilities [7].

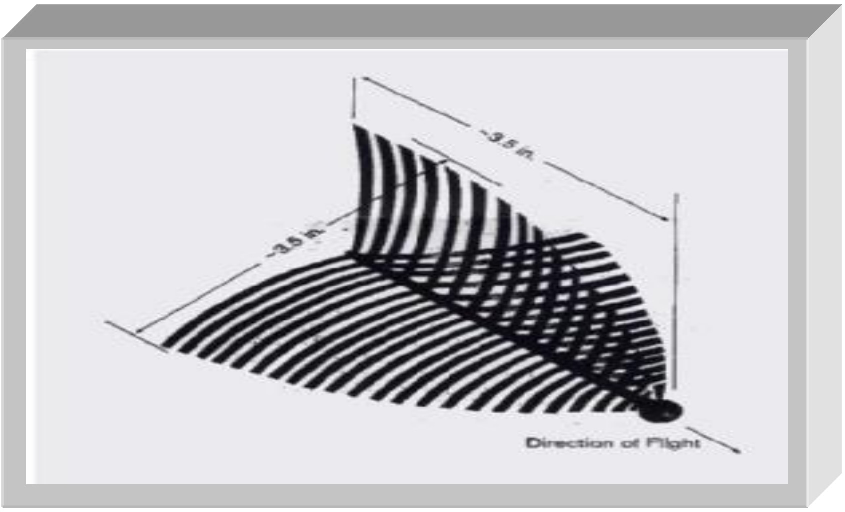

Figure 2.8: Drawing of a remotely powered Micro UAV, including dimensions

CHAPTER THREE

SYSTEM DESIGN AND SIMULATION

3.1 Circuit Description

The main idea of this study is to charge low power devices by using inductive coupling. The overall process requires a transmitter and a receiver using a power supply with a 12 volt entered to a DC to AC converter using two power transistors, in order to generate the specified frequency of signals fed to capacitor stages, which transmit through loop antenna. The AC power transmitted to the receiver circuit antenna is polarized using a capacitor and the output is connected to AC indicator which has brightness depending on the distance between transmitter antenna and receiver antenna. At the receiver, a diode rectifier converts the A.C voltage to D.C and this voltage is supplied to load [8].

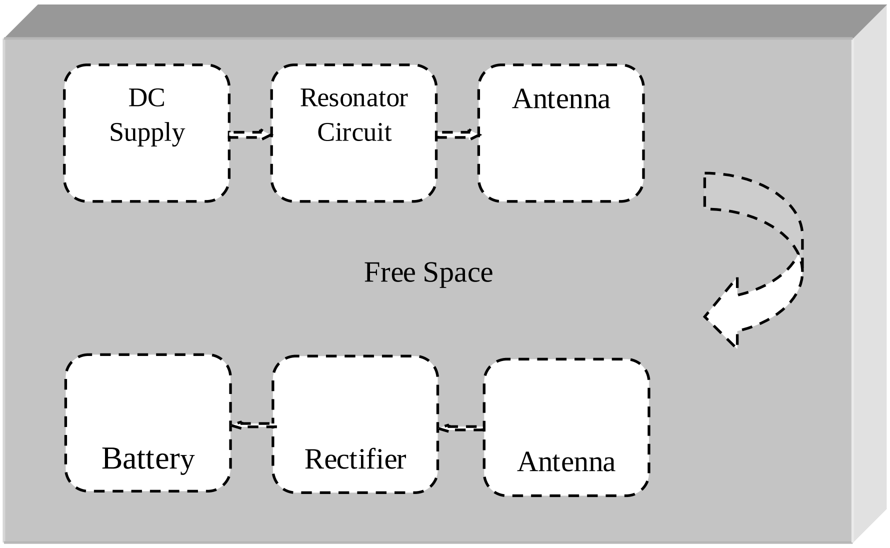

Figure (3.1): Circuit description

3.2 Transmitter Module

The transmitter module in this study is made up of a D.C power source, an oscillator circuit (commonly known as an inverter) and a transmitter coil.

The D.C. power source provides a constant D.C voltage to the input of the oscillator circuit. Therefore, this D.C power is converted to a high frequency A.C. power and is supplied to the transmitter coil. The transmitter coil, energized by the high frequency A.C. current, produces an alternating magnetic field [6]. The following block diagram (Figure 3.2) gives a general idea of the transmitter module:

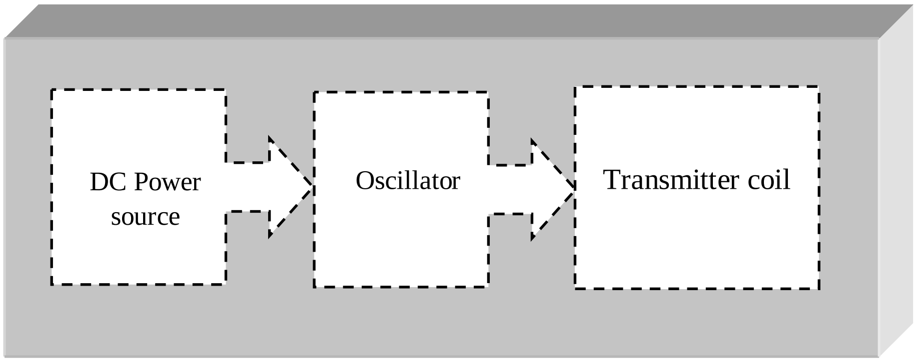

Figure (3.2):Transmitter module

3.2.1 The D.C. power source

The D.C Power Source consists of a simple step down transformer and a rectifier circuit. The transformer steps down the voltage to a desired level and the rectifier circuit convert the A.C. voltage to D.C[6].

3.2.2 The oscillator circuit

The prototype oscillator circuit designed for the project is a modified Royer oscillator in (Figure 3.3). This oscillator circuit is incredibly simple yet a very powerful design. Very high oscillating current can be achieved with this circuit depending on the semiconductor used. Here high current is necessary to increase the strength of the magnetic field. Although Insulated Gate Bipolar Transistors (IGBT) is recommended for this type of oscillator, but IGBTs have limitations in high frequencies. Thus, a HEXFET POWER MOSFET was used for its properties. The HEXFET is ultra-low on resistance and has an operating temperature of 175°C. It has an advanced process technology and is very fast in switching [6]. The modern power MOSFET in this project has an internal diode called a body diode connected between the source and the drain. This diode provides a reverse direction for the drain current, allowing a bidirectional switch implementation. Even though the MOSFET body diode has adequate current and switching speed ratings, in some power electronic applications that require the use of ultra-fast diodes [3].

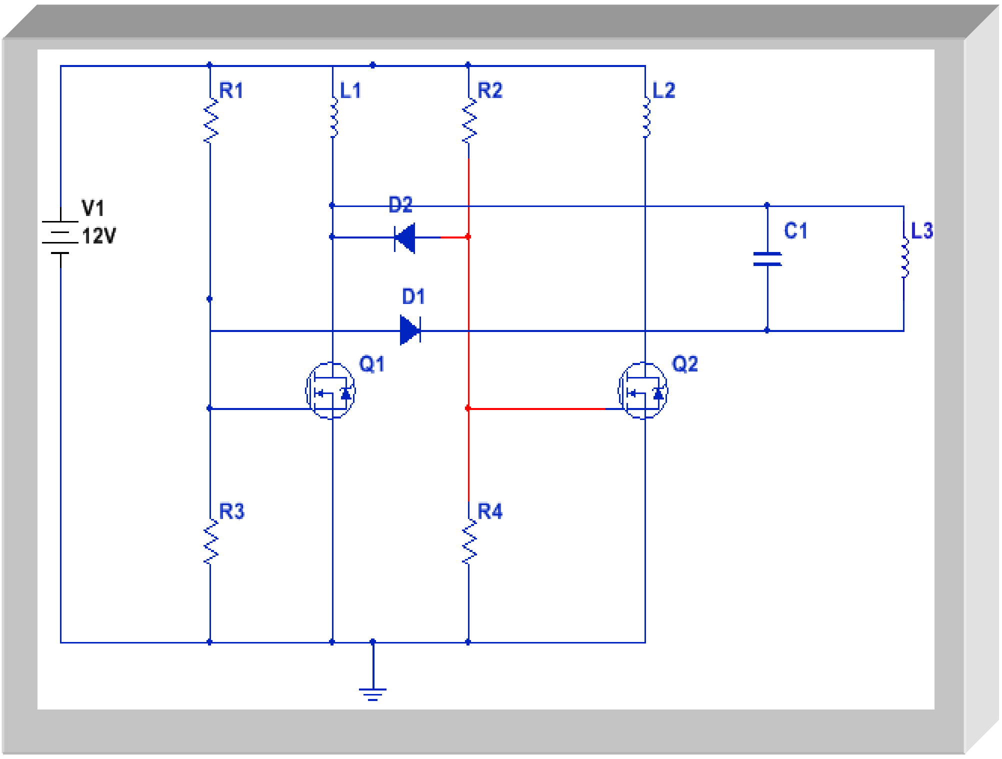

Figure (3.3): Modified royer oscillator

3.2.3 Operation of the oscillator circuit

The circuit consists of two coil labeled L1 and L2, two semiconductors (N-channel enhancement power-mosfets) labeled Q1 and Q2, a resonating capacitor labeled C and an inductor (the transmitter coil) labeled L. Cross-coupled feedback is provided via the diodes D1 and D2. R1, R3 and R2, R4 are the biasing network for MOSFETS Q1 and Q2. When power is applied DC current flows through the two sides of the coil and to the transistors' drain. At the same time the voltage appears on both gates and starts to turn the transistors on. One transistor is invariably a little faster than the other and will turn on more. The added current flowing in that side of the coil does two things. One, it takes away drive from the other transistor. Two, the coil action impresses a positive voltage on the conducting transistor, turning it hard on. The current would continue to increase until the coil saturates. The resonating capacitor C causes the voltage across the primary to first rise and then fall in a standard sine wave pattern. Assuming that Q1 turned on first, the voltage at the drain of Q1's will be clamped to near ground while the voltage at Q2's drain rises to a peak and then falls as the tank formed by the capacitor and the coil primary oscillator through one half cycle. The oscillator runs at the frequency determined by the inductance of the coil, and the capacitor value. The operating frequency is the familiar formula for resonance [6].

$$\mathrm{F} = 1/2 \times \pi \times \sqrt{LC} \qquad \ldots\ldots (3.1)$$

3.2.3 Antenna

The main function of the antenna is to collect as much RF radiation as possible and transfer this energy to the pre-rectification filter stage. The main factors considered in antenna design are its power handling capabilities, size and weight of the antenna, efficiency, broadband filter response, frequency of operation[8], A **loop antenna** is a radio antenna consisting of a loop (or loops) of wire, tubing, or other electrical conductor with its ends connected to a balanced transmission line. Within this physical description there are two very distinct antenna designs: the small loop (or magnetic loop) with a size much smaller than a wavelength, and the resonant **loop antenna** with a circumference approximately equal to the wave length. A technically small loop, also known as a magnetic loop, should have a circumference of one tenth of a wavelength or less. This is necessary to ensure a constant current distribution round the loop. As the frequency or the size is increased, a standing wave starts to develop in the current, and the antenna starts to have some of the characteristics of a folded dipole antenna or a self-resonant loop [9]. Loop antennas are usually classified as electrically small and electrically large. Electrically small loops of a single turn have very small radiation resistance (comparable to their loss resistance). Their radiation resistance can be substantially improved by adding more turns. Multi-turn loops have better radiation resistance although their efficiency is still poor. That is why they are used mostly as receiving antennas where losses are not so important. The radiation characteristics of a small loop antenna can be additionally improved by inserting a ferromagnetic core [11].

3.2.4 Components used in the transmitter module

The list of components that were used in the transmitter circuit is given in table (3.1).

Table (3.1): Transmitter components

Component's Name	**Component's Value or code**
Voltage Source, v_{dc}	12V
Resistor, R_1	100 ohm
Resistor, R_2	10 K ohm
Resistor, R_3	10 K ohm
Resistor, R_4	100 ohm
Radio Frequency Choke, L_1	0.207µH
Radio Frequency Choke, L_2	0.207µH
Diode, D_1	IN4148
Diode, D_2	IN4148
MOSFET, Q_1	IRFZ44
MOSFET, Q_2	IRFZ44
Capacitor, $C_1, C_2, C_3, C_4, C_5, C_6, C_7, C_8$	Each one of them 6.8 nf
Led Diode	Red

In addition, two heat sink were used with each **MOSFET** to keep them cool and avoid their damage during overheating.

3.3 Receiver Module

The receiver module of the project is made up of a receiver coil, a rectifier circuit and a filter. An A.C. voltage is induced in the receiver coil. The rectifier circuit converts it to D.C. The following block diagram shown in Figure (3.4) gives a general idea of the receiver module:

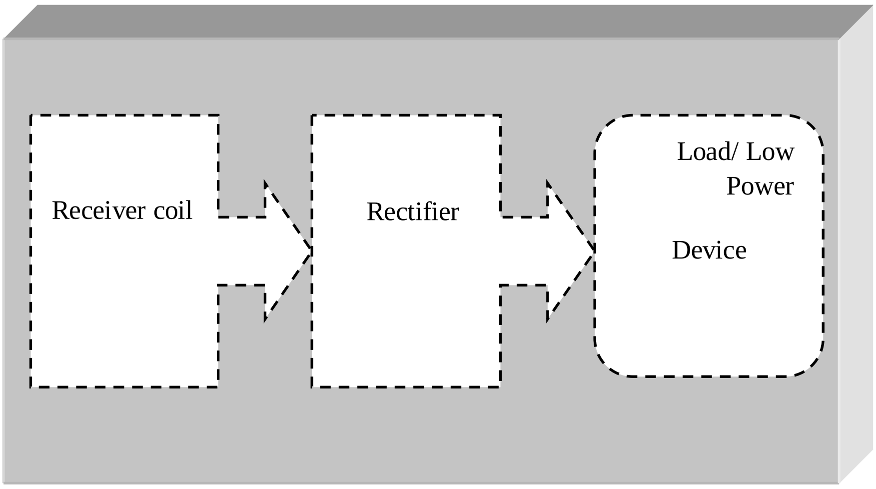

Figure (3.4): Receiver Module

3.3.2 Rectifier

a rectifier is an electrical device that converts Alternating Current (AC), which periodically reverses direction, to Direct Current (DC), which flows in only one direction. The process is known as rectification. Physically, rectifiers take a number of forms, including vacuum tube diodes, mercury-arc valves, solid-state diodes, silicon-controlled rectifiers and other silicon-based semiconductor switches. A diode bridge is an arrangement of four diodes in a bridge circuit configuration that provides the same polarity of output for either polarity of input. When used in its most common application, for conversion of an alternating current input into direct current output, it is known as a bridge rectifier. A bridge rectifier provides full-wave rectification from a two-wire AC input, resulting in lower cost and weight as compared to a rectifier with a 3-wire input from a transformer with a center-tapped secondary winding. The essential feature of a diode bridge is that the polarity of the output is the same regardless of the polarity at the input. The 4 diodes labeled D1 to D4 are arranged in series pairs with only two diodes conducting current during each half cycle shown in Figure(3.5) [10].

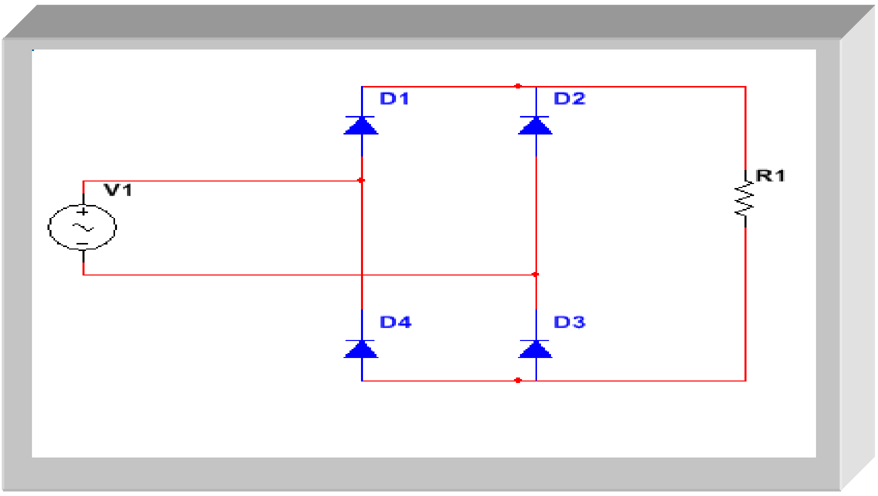

Fig (3.5): Diode Bridge Rectifier

3.3.3 Operation of a diode bridge rectifier

The full-wave rectifier only makes use of each half of the transformer winding for half of the time. The winding can be used all of the time, or the transformer can be omitted in certain cases by the application of the bridge rectifier network. Such a network is shown in Figure (3.6).When the potential of A is positive with respect to B, diodes D1 and D3 conduct and current flows in the load. When the potential of B is positive with respect to A, diodes D2 and D4 conduct and the current in the load is in the same direction as before. Thus a full-wave type of output is obtained. Note should be taken, however, that, at any instant, two diodes are conducting as well as it shows the active circuits during each half-cycle. The waveform diagrams shown in this figure, indicate that the current i taken from the supply is purely alternating yet the load current i_R is unidirectional and therefore basically a direct current [7].

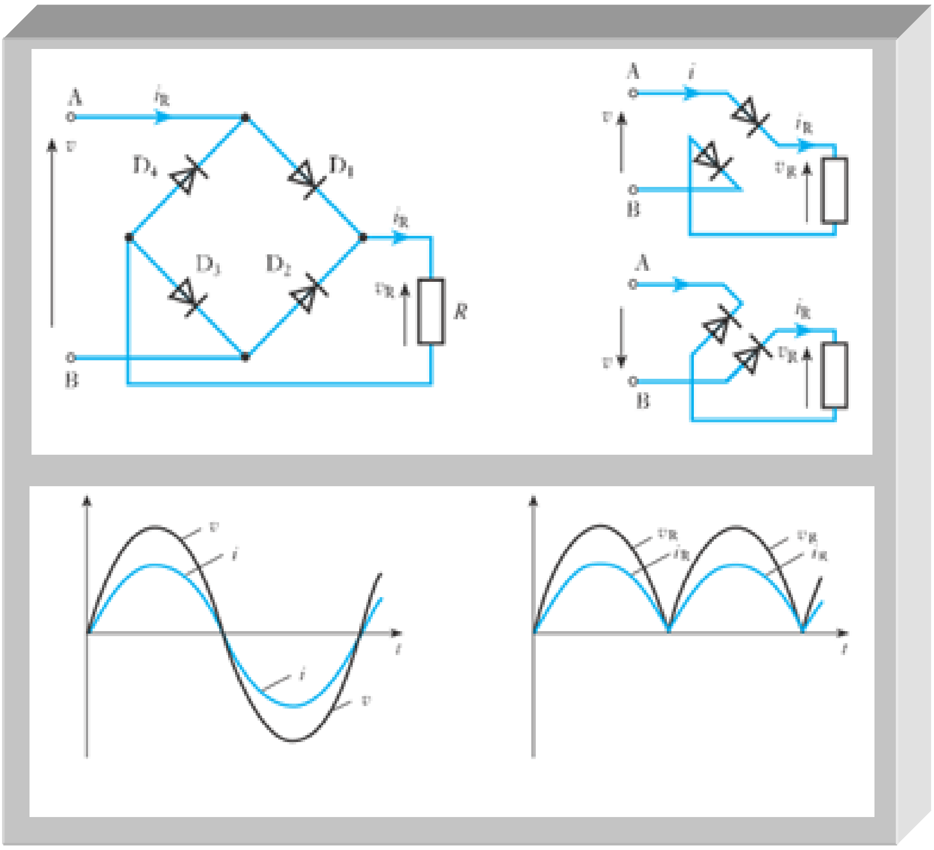

Figure (3.6): Bridge rectifier circuit in detail

3.3.4 Rectifier used in the receiver module

The rectifier used in the receiver module is similar to the one discussed above. The only addition to it is a smoothing capacitor. The smoothing capacitor converts the full-wave rippled output of the rectifier into a smooth DC output voltage. Figure (3.7) shows a rectifier with a smoothing capacitor [3].

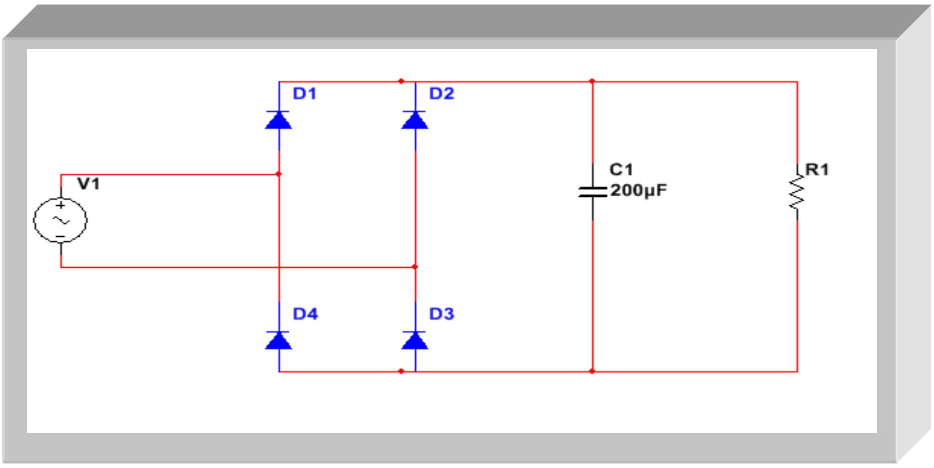

Figure (3.7): Rectifiers with a smoothing capacitor

3.3.5 Components used in the receiver module

The list of components that is used in the receiver circuit is given in table (3.2).

Table (3.2): Receiver components

Component's Name	**Component's Value or code**
Diode D_1	Silicone diode
Diode D_2	Silicone diode
Diode D_3	Silicone diode
Diode D_4	Silicone diode
AC lamp	12 V
Capacitor, C	200µF
USB junction	Samsung junction

3.4 Circuit Simulation

The circuit simulation has done by using MATLAB PROGRAM software for electronic circuits, and power systems research. The charge of the load at different distance and frequencies are computed in the simulations.

3.4.1 Circuit simulation description

In the circuit simulation, the single phase rectifier is fed by $7.35\ \mathrm{V}, 6.4\mathrm{V}$and $2.88\mathrm{V}$ at different distance (zero cm, 8 cm and 16 cm) which has received from the transmitter circuit and the rectified voltage is filtered by a 100 mH and 200 uF filter and applied to the resistive load. The load voltages are measured by voltage measurement block $\mathrm{V_{Load}}$.The system uses four individual diodes connected in a bridge configuration.

The currents of diodes 2 and 4 are obtained at the measurement $\mathrm{I_{D2}}$ and $\mathrm{I_{D4}}$ output of the diode blocks and sent to input of scope 2 and scope 3 through selector block, as shown in Figure (3.8).

3.4.2 Circuit simulation block diagram

Figure (3.8) represents simulation diagram of single phase rectifier, which is imitate the charging of load at different distances.

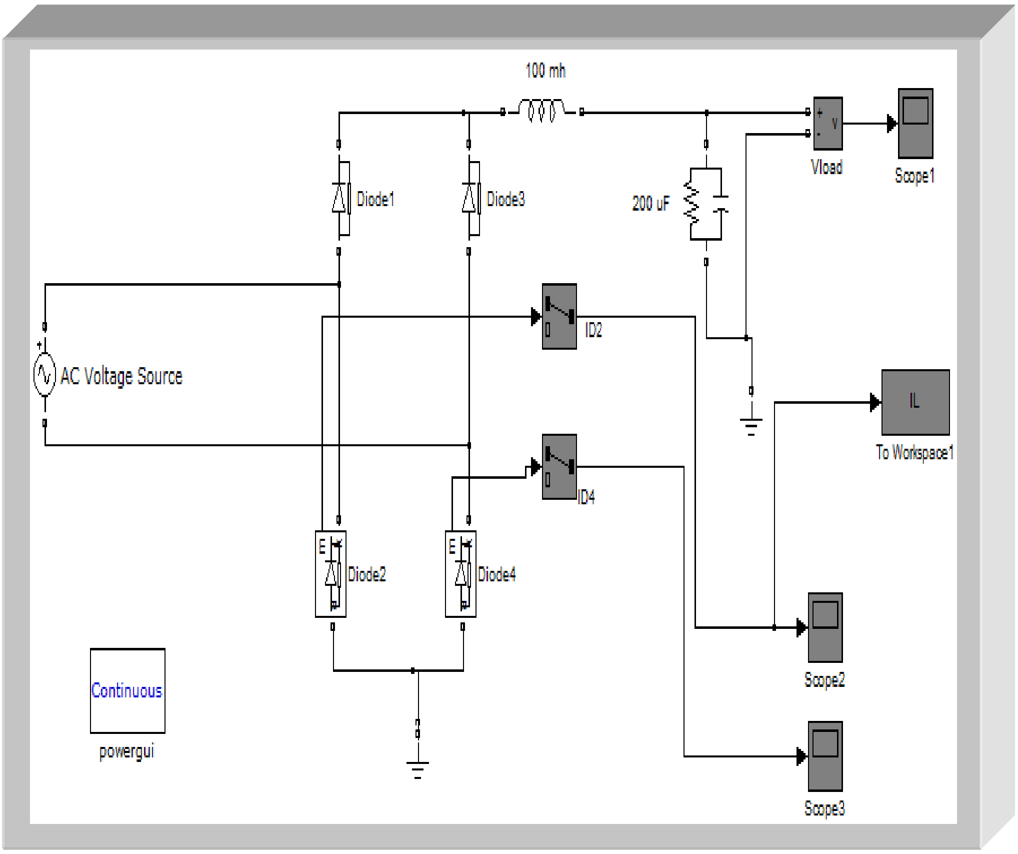

Figure (3.8): Simulation diagram

CHAPTER FOUR

SYSTEM IMPLEMENTATION AND EXPERIMENTALRESULTS

4.1 System Implementation

Further study about wireless power transfer came up with the idea of a wireless charger for the low power devices such as mobile phones, camera etc. The main idea was to charge these low power devices using inductive coupling. The overall process required a transmitter and a receiver [6].

4.1.1 The transmitter circuit as a whole

Figure (4.1) represents Transmitter Module; MOSFETS used are of code IRFZ44. All resistors (R_1, R_2, R_3 and R_4) used are very high value and rated power is of 1 W. Radio frequency chokes is of $0.207\mu H$. As well as diodes IN4148 similar small high-speed diodes are suitable.

Figure (4.1): Transmitter module

The LC tank circuit is the part where heavy current circulates, and are required to be sturdy. The copper pipe used as conductor heats up significantly under high current it is passing continuously. To handle the current while keeping losses tolerable, capacitor consists of 8 paralleled 6.8 nF are used. The transmitter still oscillated at relatively high frequency and is tuned by insertion of a ferrite core into the loop, as shown on the picture. This lowered the frequency to about 1.5 MHz. alternatively a copper plate can be brought near the loop to transfer the frequency [9].The transmitter module shown in Figure (4.2).

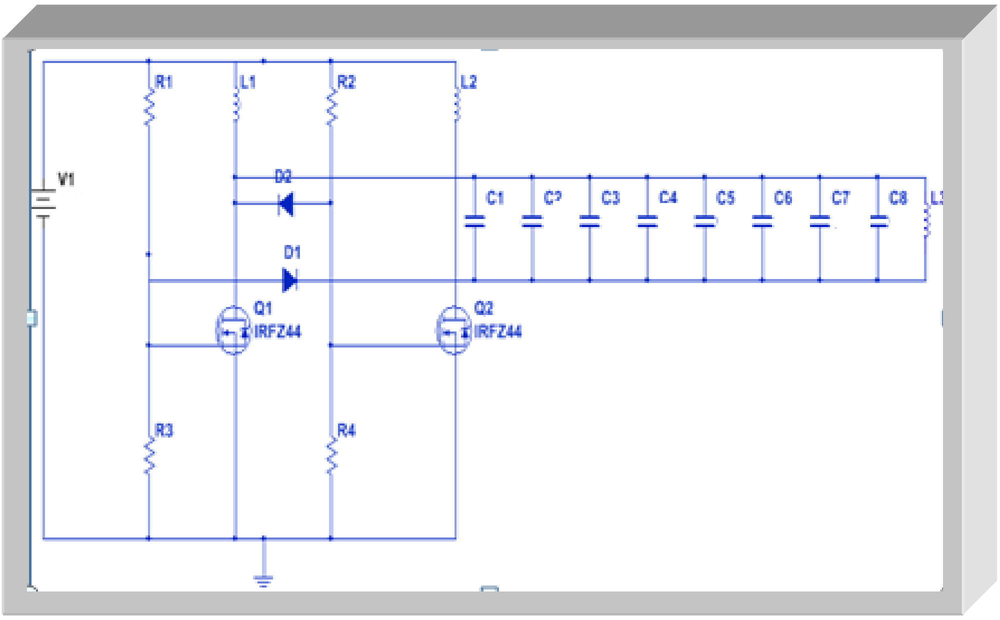

Figure (4.2): Transmitter circuit

Design layout (which is done by using printed circuit board), as a whole are given in Figure (4.3).

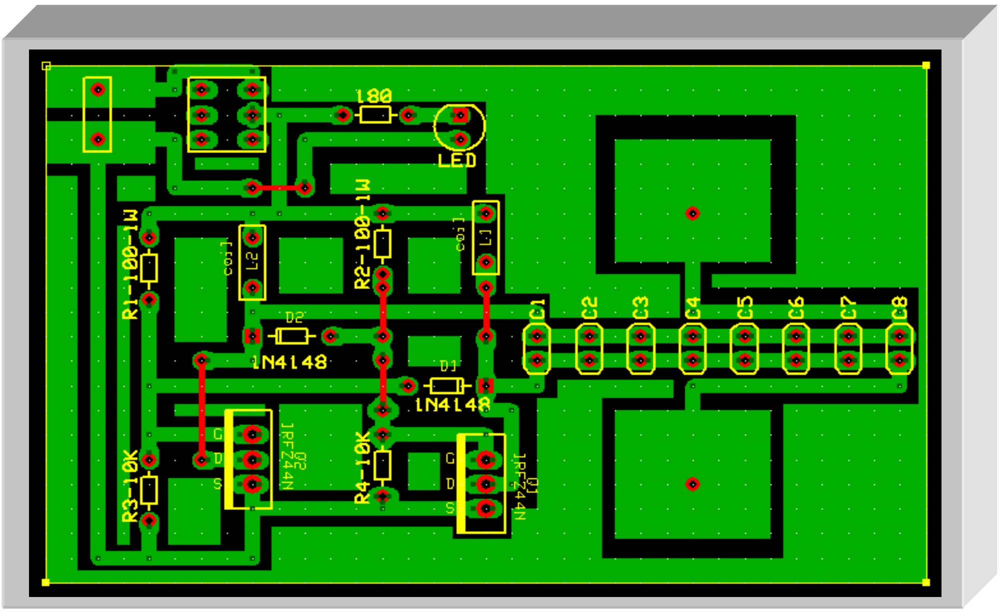

Figure (4.3): Layout of transmitter using printed circuit board

4.1.2 The Receiver circuit as a whole

The receiver module as a whole is given in Figure (4.4). On the receiver side a single capacitor and a loop of 3.3mm solid copper is used to receive the power, and AC lamp with 12 Vis used to indicate that power really has transferred from the transmitter circuit. As well as rectifier circuit to convert this ac voltage once again to DC voltage even has been easily to charge the load. The capacitor is used for smoothing the DC voltage which has drawn by the load. The receiver circuit and design of layout with printed circuit board as a whole are given in Figure (4.5) and (4.6).

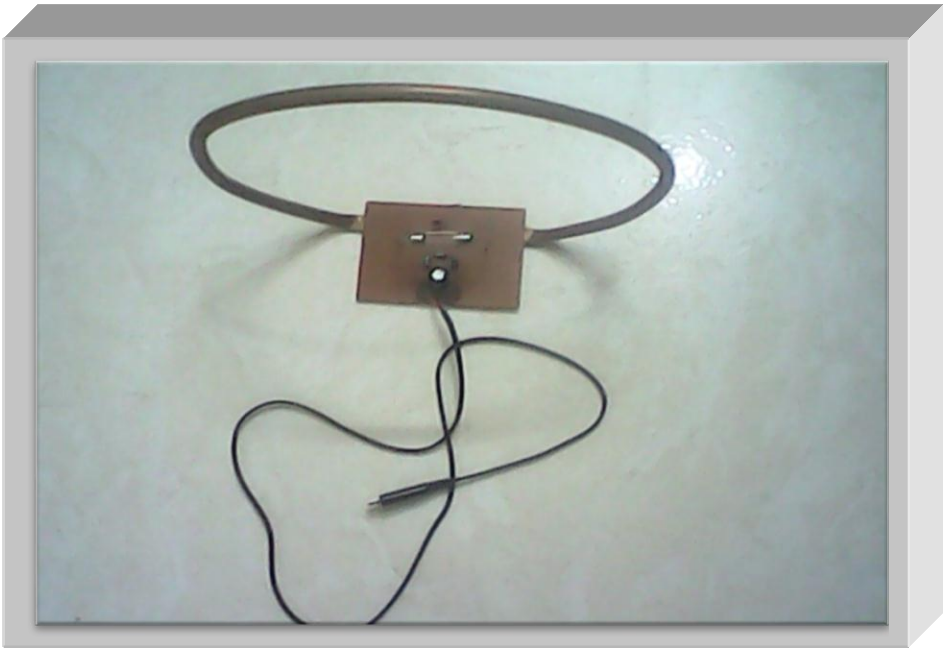

Figure (4.4): Receiver module

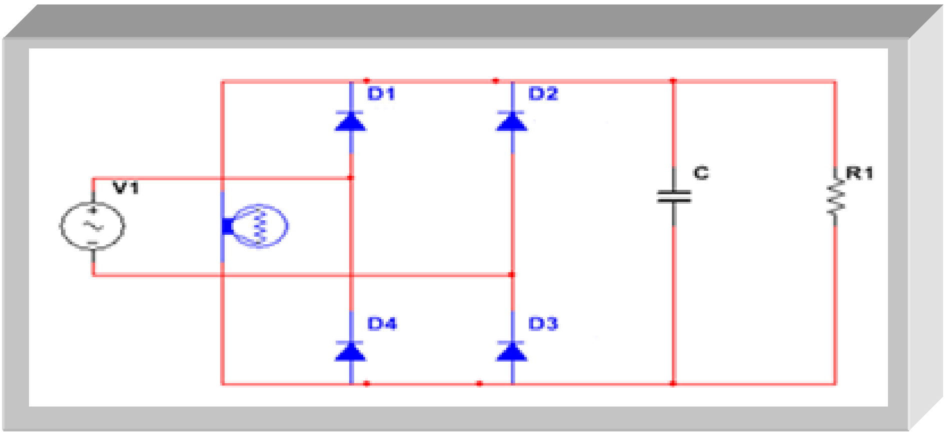

Figure (4.5): Receiver circuit

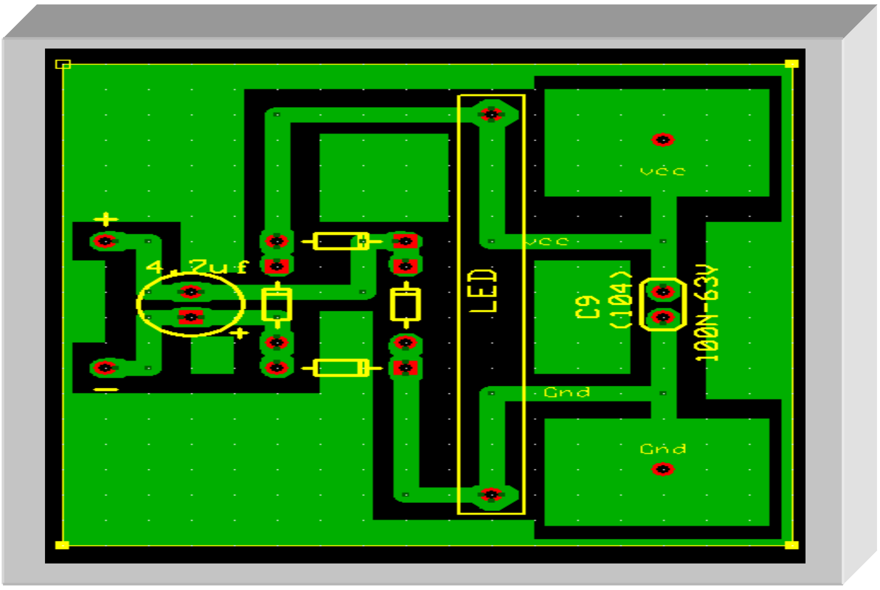

Figure (4.6): Layout of receiver using printed circuit board

4.2 The Experimental Results

After accomplish the study, it is found that can be charge the load wirelessly at specified distance and frequency.

4.2.1 Result with no distance

Figure (4.7) represents the load voltage or the battery charging simulation, and it's found that the battery is able to charge 3.3 V. However, battery is heavily loading, rectifier voltage and dropping it from 6.98 V_{dc} to almost 3.68 V_{dc}.and the current has been drown by the load is 0.13A.

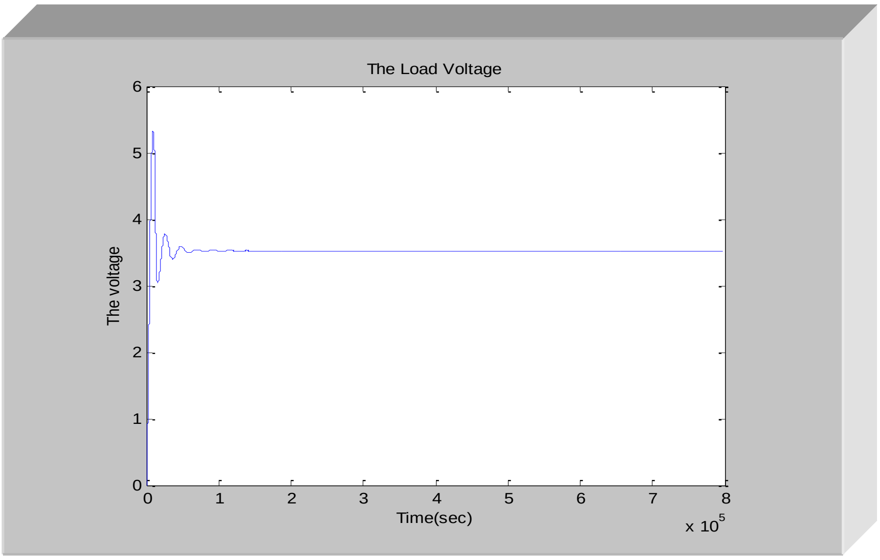

Figure (4.7): Load voltage

Figures (4.8), (4.9) represent the load current of each diode (D_2 and D_4), and it is found the load current, only about 0.13A has been drawn by the battery. Each one of that two diode charge in half cycle of the source voltage that means the diodes charge alternately, as has been shown in Figure (4.10).

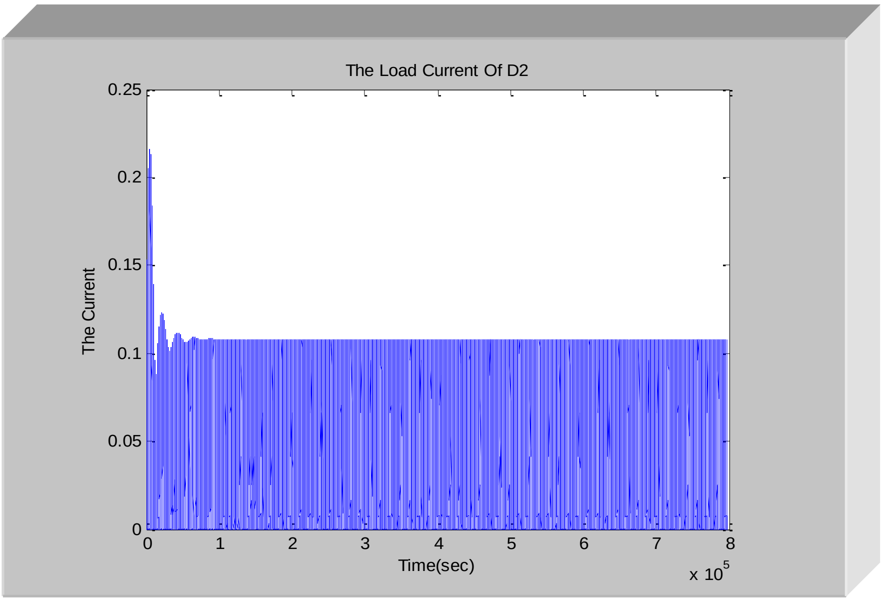

Figure (4.8): Load current of D2

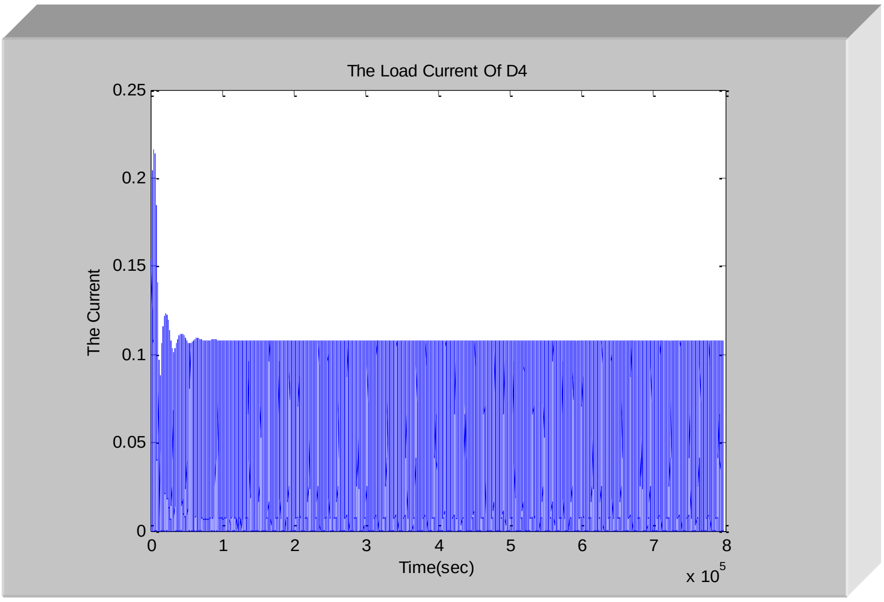

Figure (4.9): Load current of D4

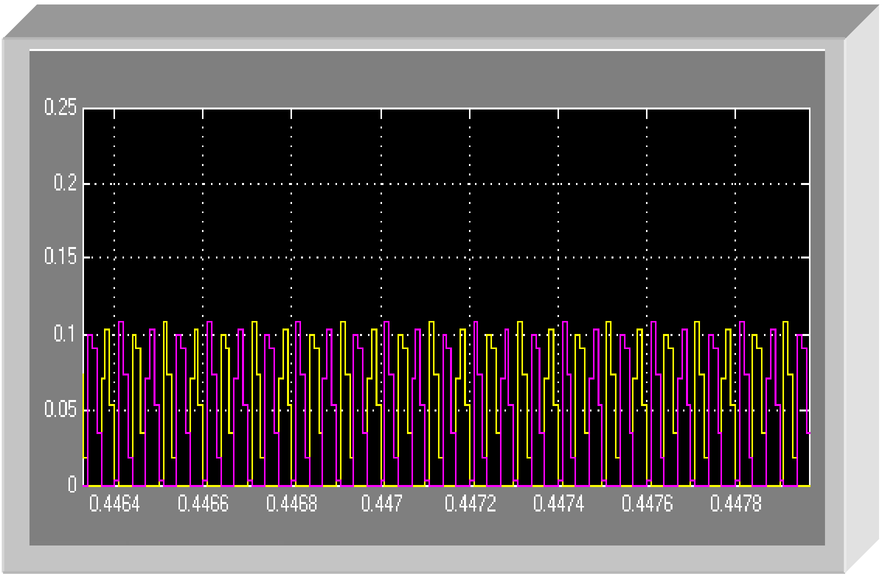

Figure (4.10): Load current of D2 and D4

4.2.2 Result with distance of8cm

Figure (4.11) represents the load voltage when the receiver has been putted at distance 8 cm, and it's found that the battery is able to charge 2.7 V. However the current drew by the load is 0.05A.

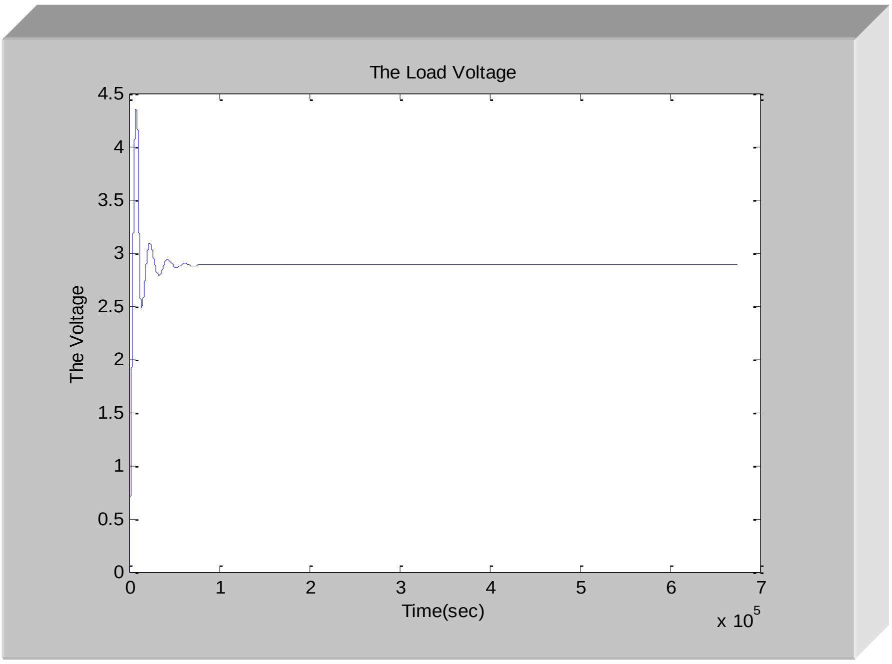

Figure (4.11): Load voltage

Figures(4.12), (4.13) represent the load current of each diode (D_2 and D_4), and it is found that the load current, only about 0.05A has been drawn by the battery.

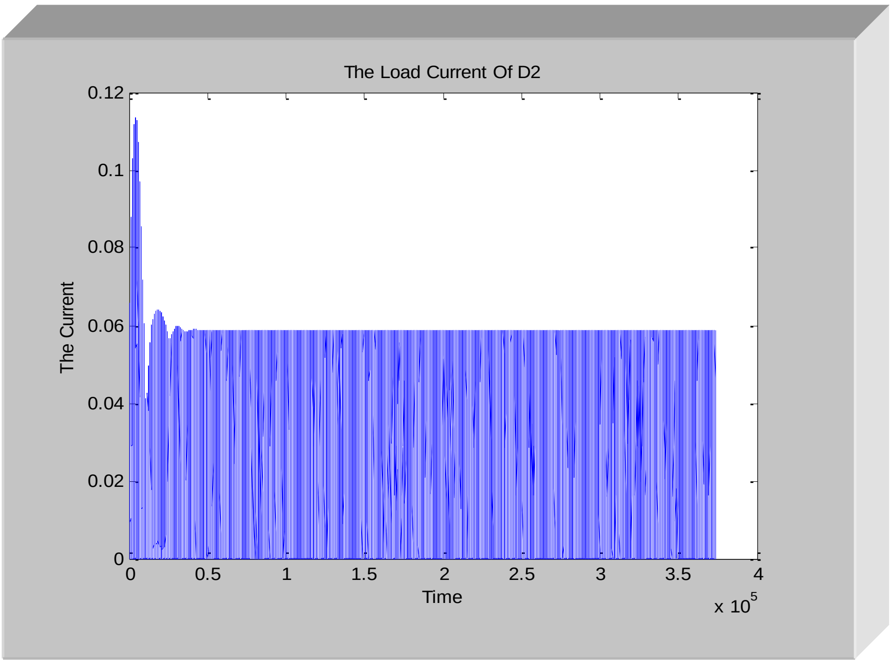

Figure (4.12): Load current of D2

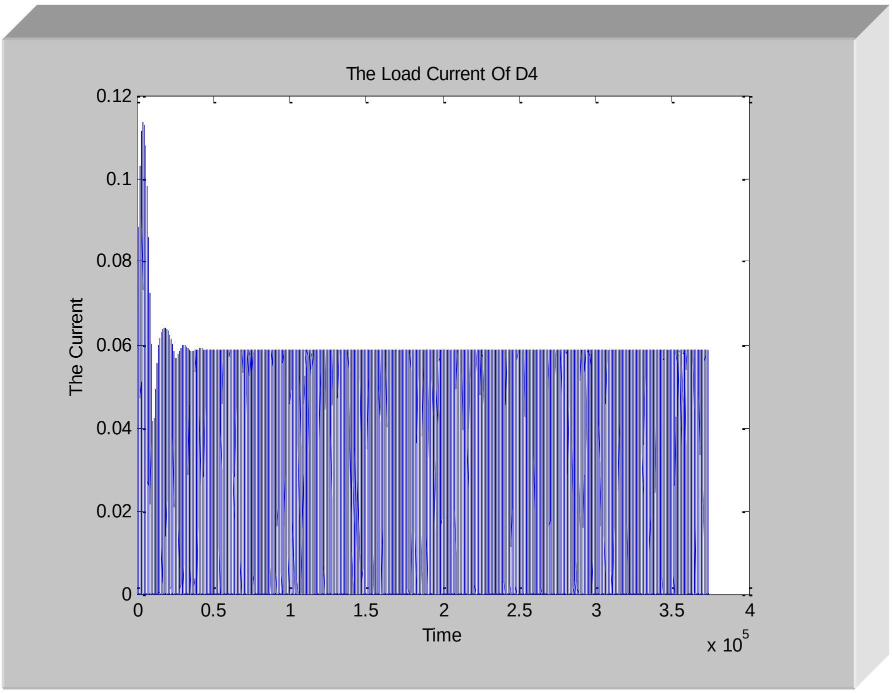

Figure (4.13): Load current of D4

Figure 4.14represents the load current of two diode at 8cm. when compared this result with the result in Figure (4.10) of load current at 0 cm, it is found that this result has more ripples than the load current at 0 cm and that indicate when decrease the distance amore radiation is transmit from transmitter to receiver with high frequency and verse visa.

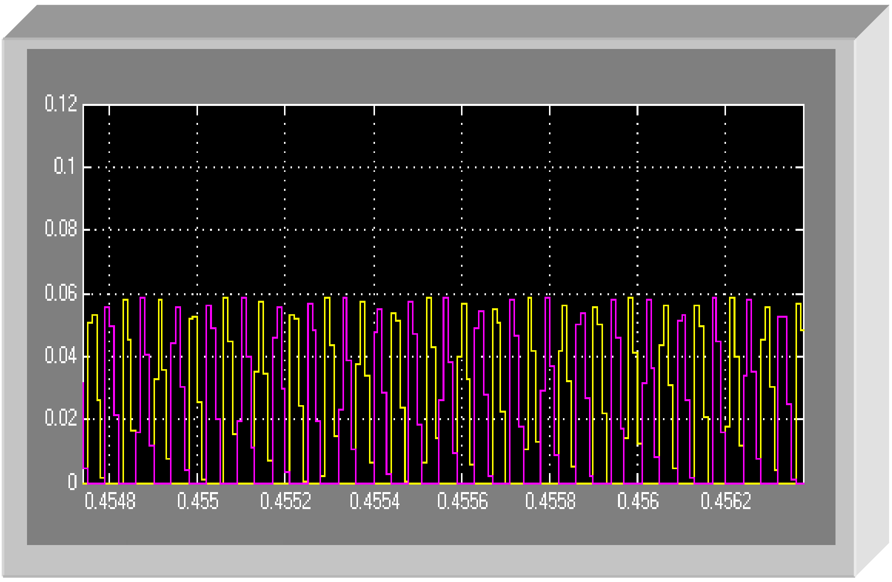

Figure (4.14): Load current of D2 and D4

4.2.3 Result with distance of16cm

When compared the voltage in Figure (4.15) with voltage in Figures(4.7) and (4.11) it is found that, the maximum voltage when the distance between transmitter and receiver is so small (there is no distance). The distance increased at the same input voltage in the transmitter, the voltage decreased, and respectively the transmitted power will decrease. By increasing the distance plenty times the load become unable to charge, because of the frequency which has been transferred from the transmitter become very low. This means that inductive coupling really is suitable to the small distance to charge the load.

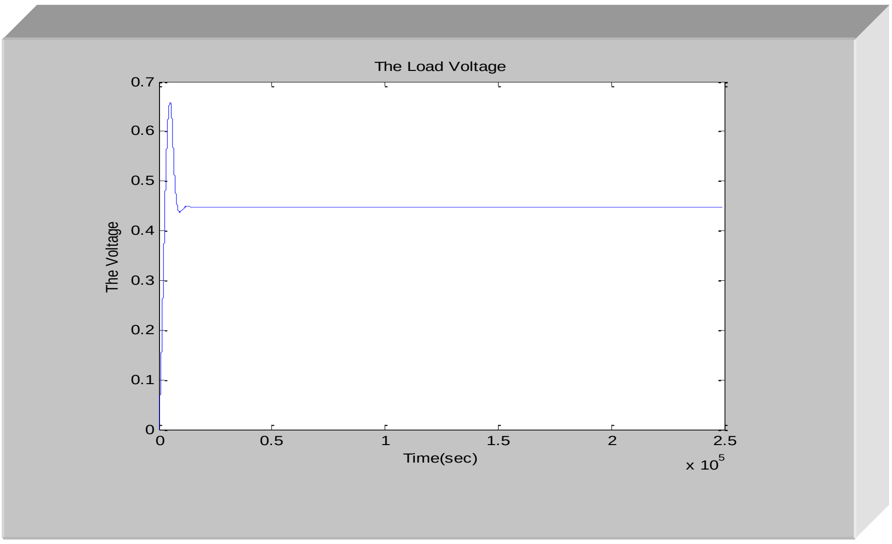

Figure (4.15): Load voltage

Figures (4.16) and (4.17) represent the load current of each diode (D_2 and D_4) at (16 cm), and load current, only about 0.017A has been drawn by the load.

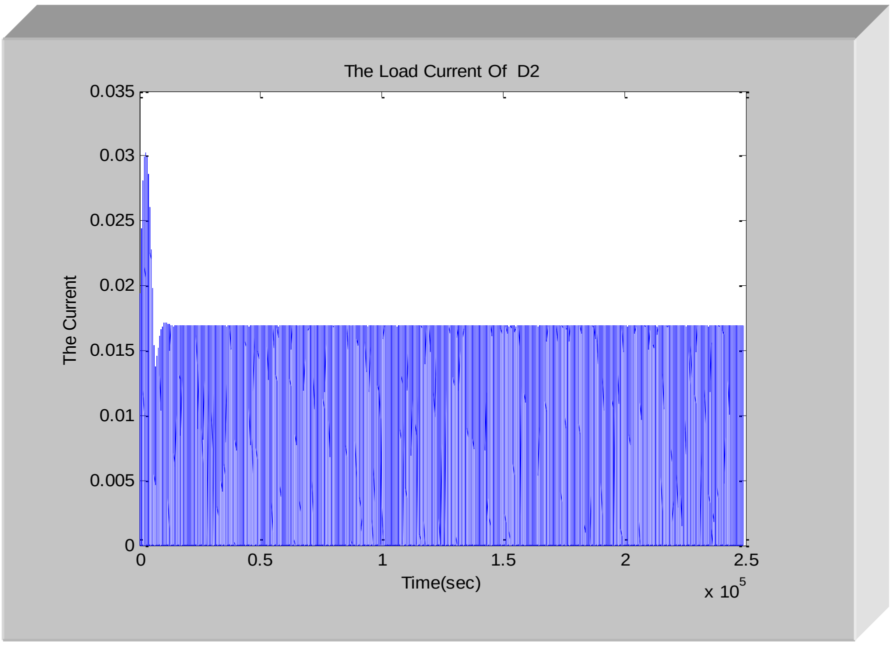

Figure (4.16): Load current of D2

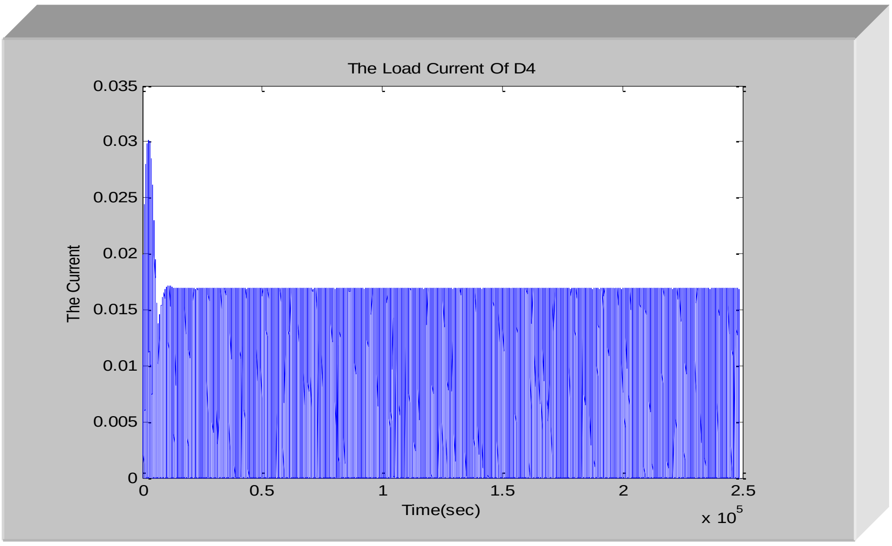

Figure (4.17): Load current of D4

Figure (4.18) represents the load current of two diode (D2, D4) at 16cm. it's found that when the distance is so far the current decrease to 0.017 A, and that will decrease the transmitted power from 0.91W at 0 cm to 0.043W at this distance.

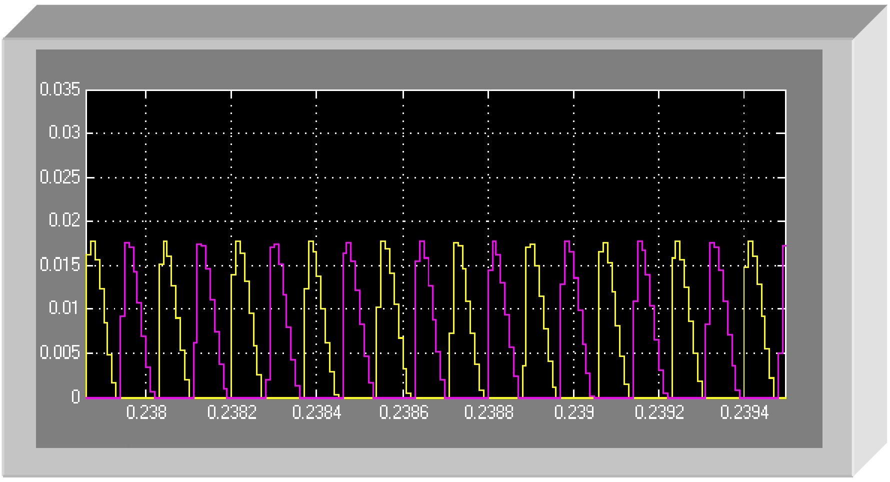

Figure (4.18) Load current of D2 and D4

The task of DC battery in this study**,** which has expected has been accomplished, but has many other drawbacks in its simplicity. All the most modern battery chargers are on. Charging can be stopped once a certain voltage is reached, it detects the battery is full, or if an unsafe temperature is detected. The battery charging circuit used in this project does not have any of these features nor does not protect against overcharging.

4.3 Performance and Analysis

The performance and analysis of this study is accomplished as shown in tables (4.1) and table (4.2).

Table (4.1): Result of the AC Circuit

Distance (cm)	Receiver Voltage(V)	Current(mA)
0	7.35	16
2	7.15	15
4	6.86	12
6	6.61	11
8	6.4	11
10	5.51	10
12	5.04	9
14	3.81	7
16	2.88	5

Table (4.2): Result of the DC Circuit

Distance(cm)	Dc Voltage(V)	Current(mA)	Power(W)
0	6.98	130	0.91
2	6.8	110	0.75
4	6.5	90	0.6
6	6.27	61	0.38
8	6.08	50	0.3
10	5.2	32	0.17
12	4.78	24	0.11
14	3.6	19	0.06
16	2.7	17	0.043

The voltage curve at different distance which has drawn from table (4.1) .It realized that when the distance increase the voltage decrease until reach the cut off frequency point is shown in Figure (4.19).

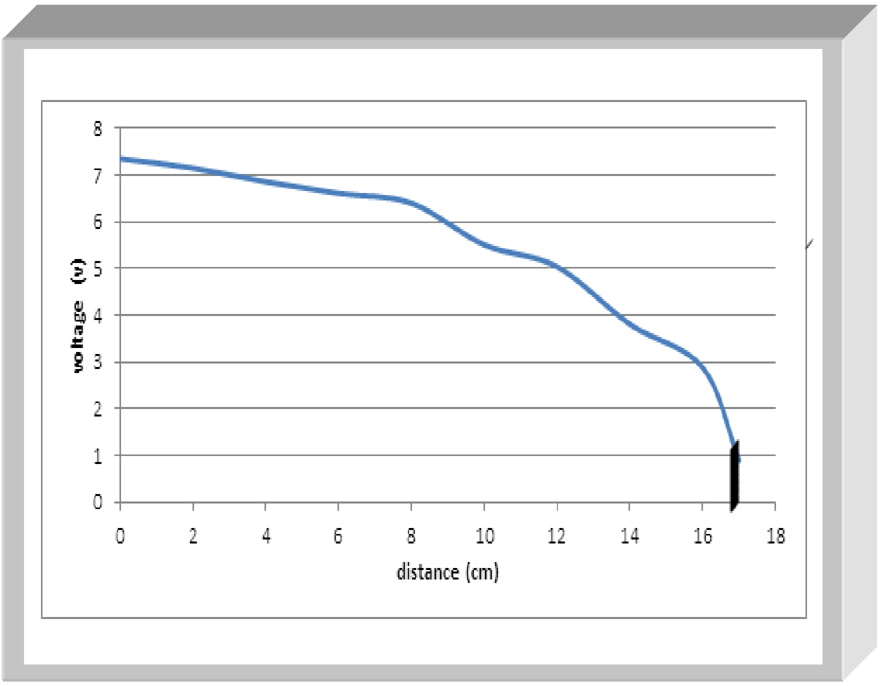

Figure (4.19): The voltage curve

4.4 The Efficiency of the Circuit

The efficiency of wireless power is the ratio between power that reaches the receiver and the power supplied to the transmitter.12Vis provided to the input of the oscillator circuit. 8.6Vis calculated across the transmitter coil, and the efficiency evaluated in this project as the following:

When the distance between transmitter coil and receiver coil is 0 centimeter, the voltage measured across the receiver coil is 7.35V. So the energy transfer efficiency is 85%.

When the distance between transmitter coil and receiver coil is 2 cm, the voltage measured across the receiver coil is 7.15V. So the energy transfer efficiency is 83%.

When the distance between transmitter coil and receiver coil is 4 cm, the voltage measured across the receiver coil is 6.86V. So the energy transfer efficiency is 79.8%.

When the distance between transmitter coil and receiver coil is 6 cm, the voltage measured across the receiver coil is 6.61V. So the energy transfer efficiency is 76.7%.

When the distance between transmitter coil and receiver coil is 8 cm, the voltage measured across the receiver coil is 6.4V. So the energy transfer efficiency is 74%.

When the distance between transmitter coil and receiver coil is 10 cm, the voltage measured across the receiver coil is 5.51V. So the energy transfer efficiency is 64%. When the distance between transmitter coil and receiver coil is 12 cm, the voltage measured across the receiver coil is 5.04V. So the energy transfer efficiency is 58%. When the distance between transmitter coil and receiver coil was 14 cm, the voltage measured across the receiver coil is 3.81V. So the energy transfer efficiency is 44%. When the distance between transmitter coil and receiver coil is 16 cm, the voltage measured across the receiver coil is 2.88V. So the energy transfer efficiency is 33%. The above mentioned measurements suggests that the system is suitable for use only when the distance between transmitter coil and receiver coil ranges from 0 to about 8 cm . The efficiency curve can be plotted with different distance as shown in Figure (4.20).

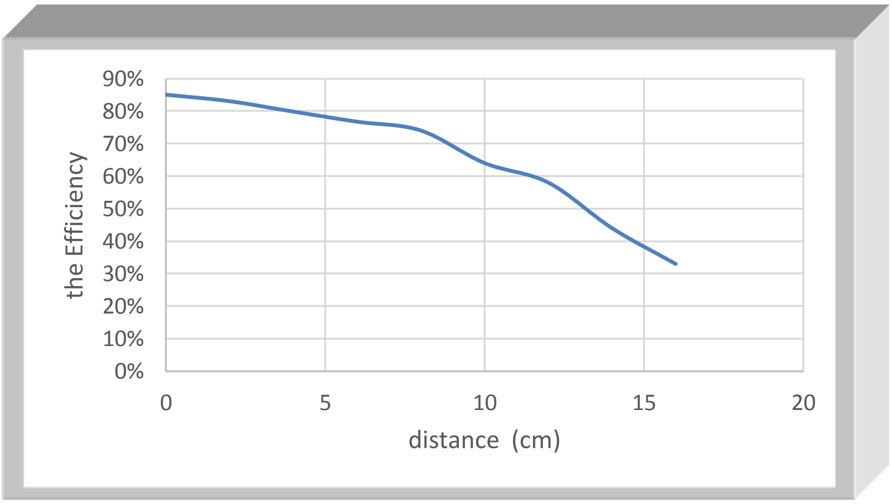

Figure (4.20): Efficiency curve

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The goal of this study is to design and implement a wireless charger for low power devices via inductive coupling. After analyzing the whole system step by step for optimization, a system was designed and implemented. Experimental results showed that significant improvements in terms of power-transfer efficiency have been achieved. Measured results are in good agreement with the theoretical models .

It was described and demonstrated that inductive coupling can be used to deliver power wirelessly from a source coil to a load coil and charge a low power device (battery of telephone). This mechanism is a potentially robust means for charging low power devices wirelessly .

The main disadvantages of inductive charging are its lower efficiency and increased resistive heating in comparison to direct contact. Implementations using lower frequencies or older drive technologies charge more slowly and generate heat within most portable electronics and slower charging - due to the lower efficiency.

5.2 Recommendations

- Increase distance by using high power radio frequency amplifier connected with an oscillator to increase the efficiency.
- Design addition circuit (voltage doublers) to charge high power devices.
- A crystal oscillator circuit might be a better option for the transmitter circuit since it can produce a very high frequency A.C. current

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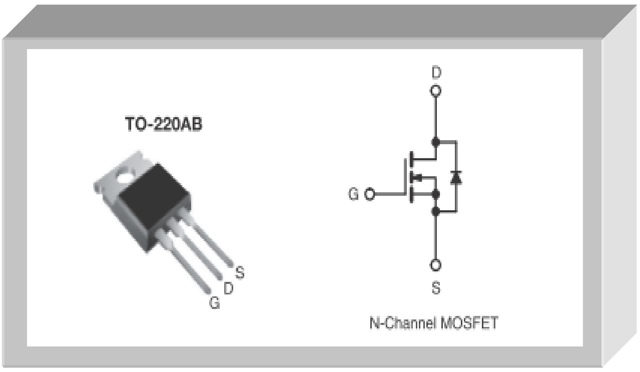
Appendices

Appendix (A)

The Data Sheet of Transistor IRFZ44

Features



- Dynamic dV/dt Rating.
- 175 °C Operating Temperature.
- Fast Switching.
- Ease of Paralleling.
- Simple Drive Requirements.
- Compliant to ROHS Directive 2002/95/EC.

Description

Third generation Power MOSFETs from Vishay provide the designer with the best combination of fast switching, ruggedized device design, low on-resistance and cost-effectiveness. The TO-220AB package is universally preferred for commercial-industrial applications at power dissipation levels to approximately 50 W. The low thermal resistance and low package cost of the TO-220AB contribute to it is wide acceptance throughout the industry.

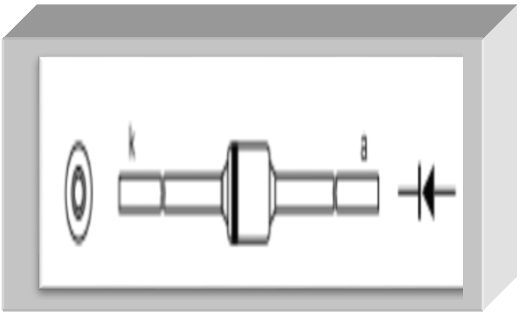
Product summary

V_{DS} (V)	60	
R_{DS} $(on)(\Omega)$	$V_{GS}(V) = 10$	0.028
Q_g (Max)(nC)	67	
Q_{gs}(nC)	18	
Q_{ds}(nC)	25	
Configuration	Single	

Appendix (B)

The Data Sheet of IN4148

Features



• High switching speed: max. $4\ ns$

• General application

• Continuous reverse voltage: max$100\ V$

• Repetitive peak reverse voltage: max$100\ V$

• Repetitive peak forward current: max. 450 mA.

Description

The 1N4148 and 1N4448 are high-speed switching diodes fabricated in planar technology, and encapsulated in hermetically sealed leaded glass SOD27 (DO-35) packages.