DESIGN OF WIRELESS POWER TRANSFER FOR HEART ASSIST DEVICES

ABSTRACT

Heart assist devices are designed to help damaged hearts maintain sufficient blood flow, with short term use required for patients recovering from heart attack or heart surgery and long term use for patients who are suffering congestive heart failure. The frequency with which the patients are being operated to replace the battery of these devices can be aided and reduced by wirelessly transmitting power.

The transcutaneous power transfer for the devices requires charges that move outside the body to induce charges to move inside the body which can ultimately be used to supply energy to the heart pump. WPT is a method of delivering wireless power using an external primary coil to generate a magnetic field. The magnetic field passes through the skin and induces current in an implanted secondary coil. The WPT method eliminates the should risk of infection caused due to surgery. The Wi-fi module is used here to observe the charging level of the battery. It also monitors the corresponding blood flow and the pulse during this function.

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LIST OF ABBREVIATIONS

WPT	Wireless power transfer
LED	Light emitting diode
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
LCD	Liquid Crystal Display
AH	Artificial Heart
QOL	Quality of life
TET	Transcutaneous Energy Transmission
IVF	In Vitro Fertilisation
ICN	Implantable Cardiac Microstimulator
EMF	Electromotive Force
IC	Integrated Circuit
IEEE	Institute of Electrical and Electronics Engineers
IEC	International Electrotechnical Commission
IOT	Internet-Of-Things
WiTricity	Wireless Electricity
LVAD	Left Ventricular Assist Device
RVAD	Right Ventricular Assist Device
TAH	Total Artificial Heart

LMW	Litz Magneto Plated Wire
ET	Energy Transmission
EMR	Electronic Medical Record
EEPROM	Electrically Erasable Programmable Read Only Memory
LDR	Light Dependant Resistor
Op Amp	Operational Amplifier
WLAN	Wireless Local Area Network
Wi-Fi	Wireless Fidelity
MISO	Master in Slave out
MOSI	Master out Slave in
SCK	Serial Clock

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CHAPTER 1

INTRODUCTION

1.1 Overview

Electricity is one of the most important blessings that science has given to mankind. It has also become a part of modern life and one cannot think of a world without it. From the beginning of mankind, there always has been the necessity of power, which brought us to the inventions of fire, steam engines and most importantly, electricity. Majority of today's residences and commercial buildings are powered by alternating current (AC) from the power grid.

Electrical power stations generate AC electricity that is delivered to load centers through high voltage transmission lines and step transformers with losses. At the distribution end the voltage is RI 2 step down for efficient distribution of transmitted power and the consumers consume at its desired low voltage level. This AC current is a daily necessary for our everyday life, for example, lights, fans, kitchen appliances, chargers, and so on. Almost all the components are standardized with the electrical wire.

Any device rated for standard current and voltage will work in any of the millions of outlets throughout the country. While standards differ between countries to countries, within the limit of a given electrical system, any perfectly rated device will work. But in this case, the complexity is wire or cord. Problems like short circuited, burning wires, plug in/out, twisting etc. Apart from the conventional transmission system, wireless power transmission is more efficient, modern and really needed technology to be developed.

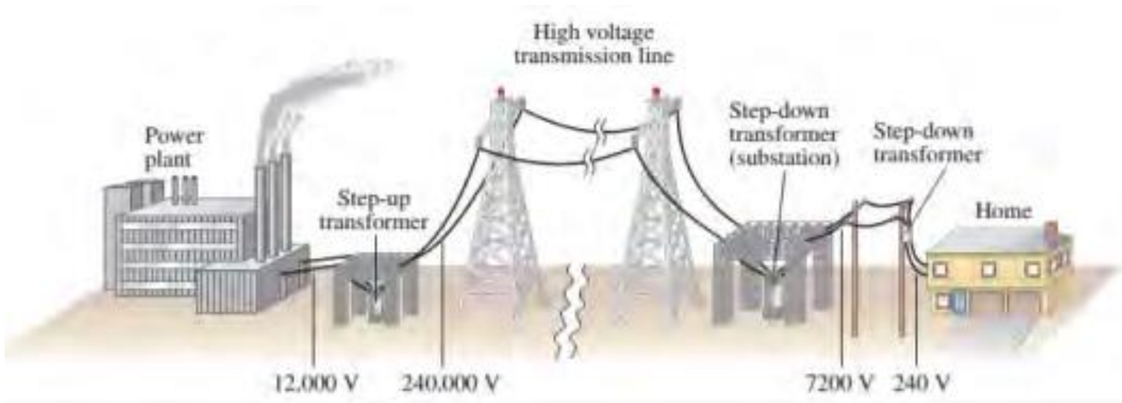


Figure 1.1 Power transmission from Power station

1.2 Drawbacks of Wired Power transmission

Wired technology can, after all, be traced back over a hundred years, making it a much older technology than wireless. However, it also has a number of notable disadvantages that wireless technology does not have. A lack of mobility, risk of damage, cost and scalability are all issues with the use of wired technology[5].

Equipment Portability

Wired technology is not portable. The units must be plugged into power outlets and network ports in order to function. Moving units takes time, energy and, potentially, information- technology personnel. These hard-wired requirements can make arranging personnel, furniture and equipment difficult. Moves of equipment or employees may require running additional network cabling, installing new electrical outlets and reconfiguring network-port structures. Network configuration may limit the options for employee and equipment placement.

Space

Wired-technology products, such as desktop computers, take up more space than equivalent wireless options. Wires, cables and multiple components require more desktop space than their wireless counterparts. Office-furniture decisions and employee-space allocation must account for the added space needs of wired computer and technology products.

Employee Mobility

Employees are restricted in their work location when using wired office products. Wireless options allow work in conference rooms, at home, in a coffee shop or at a business contact's physical location. Some employees, such as sales personnel, may require a wireless unit to perform their work duties. Opting for wired-technology products may limit the amount and flexibility of work duties.

Safety

The physical requirements of a wired-technology product present some opportunities for damage not noted in wireless products. Cables can be damaged by cleaning crews and mislaid wires can cause tripping hazards. Additionally, always-on technology systems may be more prone to electrical surges and damage than wireless units that can be unplugged during storms or power outages.

Power

Wired units must have power to operate. Stormy weather, electrical problems or a utility-wire cut can cause work to stop if the only options are wired-technology products. Wireless units with batteries can continue to function for a period of time after being disconnected from power. Work stoppage can hurt productivity and customer service.

1.3 Introduction to Wireless Power Transfer

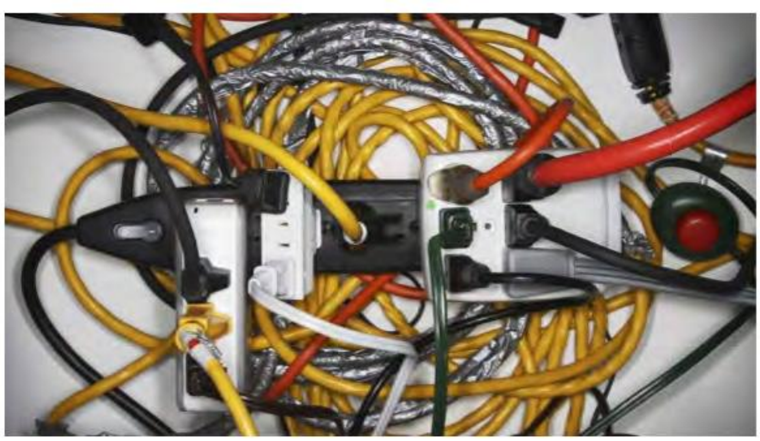


Figure 1.2.Wired charging systems

Transmission of electrical energy without wires is known as Wireless power transfer (WPT). It is WPT which enables to supply power through an air gap, without the necessity of current carrying wires. WPT can deliver power from an AC source to batteries or other electronic devices without physical connections. Mobile phones and tablets, drones, cars, even transportation equipment can be recharged by WPT. It may even be possible to wirelessly transmit power gathered by solar panel arrays. WPT has been an exciting development in consumer electronics, replacing wired chargers. WPT uses fields created by charged particles to carry energy between transmitters and receivers over an air gap. The air gap is bridged by converting the energy into a form that can travel through the air. The energy is converted to an oscillating field, transmitted over the air, and then

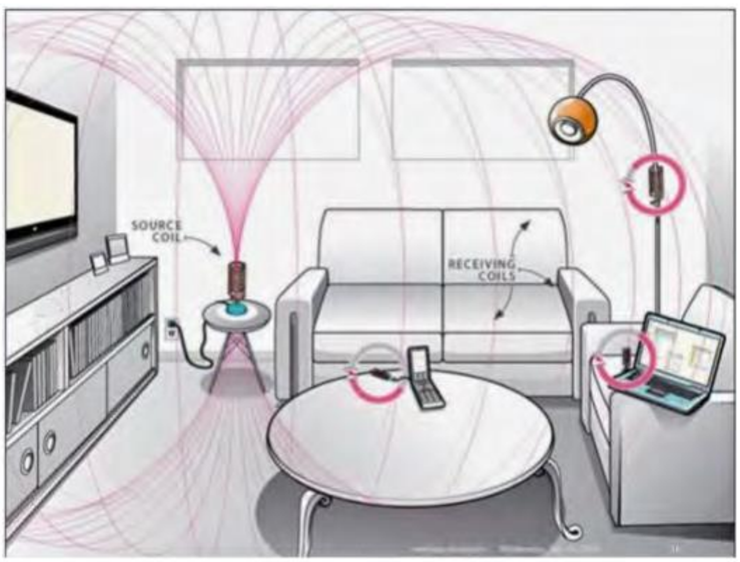


Figure 1.3. Wireless Power system

converted into usable electrical current by a receiver. Depending on the power and distance, energy can be effectively transferred through an electric field, a magnetic field, or electromagnetic waves such as radio waves, microwaves, or even light.

1.4 Advantages of Wireless Power Transfer

Multiple charging

Allows for charging of multiple devices. This is achieved by changing the coil geometry, as well as allocating large charging surface areas such as table tops and charging benches.

Efficiency

High charging speeds: though at the moment wireless charging offers a slower charging rate than the wired option, advances in resonance and induction technology promises an increased charging rate and improved efficiency in the future

Spatial freedom

Wireless power transfer allows for greater spatial freedom between the power source and the device. This means that the two do not have to be precisely aligned for power transfer.

Safety

Eliminating charging cords enables engineers to make compact and watertight devices, thus maximising on safety, and varied use such as in deep-sea applications[5].

Simple

Prevents corrosion and sparking by eliminating mechanical connectors and wired contacts. Since it is wireless there is lesser complexity and the circuit gets more simplified

Cost effective

Reduces costs associated with maintaining and replacing mechanical connectors. There is a great reduction in the cost. Maintenance and replacement costs are cut down.

1.5 Applications of Wireless power transfer

Industrial Applications

Wireless power transfer has seen tremendous applications and value addition to industries. The primary applications include wireless sensors on rotating shafts, wireless equipment charging and powering, and safe and watertight equipment through eliminating charging cords[5][6].

Subsea applications

Though subsea vehicles can self-navigate, human assistance is still required for power supply. Due to the rough terrain, as well as the distance, cabled conductors can prove to be a challenge. WPT comes in handy in these instances.

Charging mobile devices, unmanned aircraft, home appliances and electric vehicles

The charging system the smaller gadgets comes in the form of a charging pad and power benches, where the user places the device such as a mobile phone and electric toothbrushes[5].

Charging and operating medical implants such as subcutaneous drug supplies, pacemakers, and other implants. WPT, especially with high resonance allows convenient continual charging of these implants without the need for frequent surgeries and the inclusion of external charging ports.

Charging wearables

The convenience of wearables lies in the mobility and convenience. Considering that the wearer has to walk around, the primary problem thus is the charging[6]. Wireless power transfer accords the convenience of charging by eliminating the requirement for cables and connectors

1.6 Motivation

After Nikola Tesla had introduced the concept of wireless power transfer, and experimented for related technology patent in 1902. Since then, many scientists have done research on it. Some of them were able to gain some achievements in induction power transmission at close range. In our case, the main purpose of our analysis was to achieve a brighter output and thus contributing to the transmission of wireless power transfer. In order to keep pace with the modern technologies, the concept of wireless power transfer is needed to be brought to light which was another reason behind choosing this concept. In modern times, no one wants to use the wire or cord in case of charging any device and there comes the necessity of WPT.

In its latest World Economic Outlook, the IMF said India will grow 7.3% in FY19 and 7.4% in FY20. With the advance growth of economy, the standards of living are getting higher day by day. In that case, the uses of smart devices are getting very popular nowadays. The smart devices have various features but the transmission of power into them wirelessly in one of the spectacular features in recent times. People are much fond of using devices that does not require the connection through wires or cords. It has been mentioned earlier that, to get rid of the annoying wires, WPT is the perfect solution.

1.7 Contribution of this project

This project addresses the solution of providing substantial power sufficient for a heart pump operating continuously for the remaining lifetime of a patient. One of the applications of wireless power transmission is the passive telemetry sensor which is wireless, battery less sensor unit that is used for implantable sensors which monitors the vitals of the patient when the device is charged . The key challenges are related to alignment of components and avoidance of any heating problems.

1.8 Research objective

Previously, those who have worked researched on WPT have faced many challenges. The limitations that the researchers and engineers are recharging batteries, continuation of supplied power, dealing with moving points, optimizing the sensors and so forth. Though these challenges still exist, day by day the limitations and problems are getting minimized because of the continuous research going on WPT. The purpose of our research was to contribute to minimize the limitations of the transmission of power wirelessly.

CHAPTER 2

LITERATURE SURVEY

The various research articles related to the design of transcutaneous energy transmission systems, wireless multi bundle concentric coils for artificial heart and implantable cardiac microstimulator are discussed in this chapter.

Iwawaki et al (2004) proposed that the artificial heart (AH) has been recognized as an alternate method for a heart transplant. Though there are many problems and defects with the AH, it possesses long-term durability, miniaturization and a weight savings interfaced with flow rate performance, and device efficiency. Considering rehabilitation into the society and advancement of QOL (quality of life), the construction of a power source that supplies electric power to the device is important, but many problems need to be solved. Especially, the electric feeder line restricts behavior of the transplant recipient and disturbs rehabilitation into society. As a solution to these problems, the transcutaneous energy transmission system (TETS) is attracting attention and is being studied. This study proposes a core-type TETS. It achieves high magnetic coupling compared with the air-core-type TETS, as determined in a clinical study. Because the core-type TETS has high magnetic coupling, it is possible to reduce the input current and to miniaturize the transformer size. This paper presents the design and the characteristic of a core-type TETS. It is described that the design of a core-type TETS which is different from the conventional air-core-type TETS for artificial hearts. A pot-core-type transformer, which consists of a ferrite core, was designed using an equivalent magnetic circuit, and it was manufactured. A load test and a mock test were carried out using the pot-core-type transformer for an artificial heart, as proposed in this paper. From the result of the load test, we found that the maximum system efficiency was obtained for a transmission frequency of 60 kHz. Also, from the result of the mock test, when the air-gap was 1 mm, we confirmed that a 78% maximum system efficiency could be obtained. Since the design of the shape of an TETS for an artificial heart as an in-vivo device is an important field for electric power transmission, we consider the TETS as being suitable for the transmission electric power.

H.M. Amasha et al (2007) proposed that one coil is placed outside the chest and is fed with an electromagnetic field, while monitoring the output on a specifically designed multi-bundle concentric coil to be implanted inside the body. It is assumed that the proposed coil should be easier to implant to the chest wall and is less prone to possible misalignments of the outer and internal coils, easier to isolate with a biocompatible material and most important, the feasibility of a much better heat dissipation scenario. Results from the multi-bundle concentric coils were compared to results from single bundle coils and found to be better if not equal.

The output measured with skin alone compared to fat alone and when both combined together deteriorated, yet to an acceptable degree, partially because of the kind of material itself and also due to the increasing thicknesses. However, these results compare significantly to those when air or just a normal sheet of paper existed between the two coils. The temperature distribution was measured using three thermistors at positions in the middle between each two bundles. One was placed outside the external bundle and one in the centre of the coils. Temperature was measured in case of a single bundle coils and in the case of the multi-bundle coil. The measured values for the multibundle coil were 65% of the measured temperature values near the single bundle. In vivo results may vary due to clearance by blood flow.The proposed multi-bundle coil has shown comparable results to that of a single-bundle coil but it has advantages over it. Spacing between the bundles are preferable for two reasons; first, they allow for better isolation of each bundle with the biocompatible material, and second, these spaces allow for tissue to regenerate between these bundle and, hence, give better accommodation and fixation of the coil to the chest wall. A very thin wire is being designed with higher number of turns per bundle is currently under the process of being implanted under the skin of a rabbit to test for the feasibility of using this coil.

Shuenn Yue Lee et al (2012) propsed that an inductive coupling is presented with the help of a high-efficiency Class-E power amplifier for an implantable cardiac micro stimulator. The external coil inductively transmits power and data with a carrier frequency of 256 kHz into the internal coil of electronic devices inside the body. The detected cardiac signal is fedback to the external device with the same pair of coils to save on space in the telemetry device. To maintain the power reliability of the micro stimulator for long-term use, two small rechargeable batteries are employed to supply voltage to the internal circuits. The power management unit, which includes radio frequency front-end circuits with battery charging and detection functions, is used for the supply control. For cardiac stimulation, a high-efficiency charge pump is also proposed in the present paper to generate a stimulated voltage of 3.2 V under a 1 V supply voltage. A phase-locked-loop (PLL)-based phase shift keying demodulator is implemented to efficiently extract the data and clock from an inductive AC signal. The circuits, are implemented in a TSMC 0.35 □2P4M standard CMOS process. Measurement results reveal that power can be extracted from the inductive coupling and stored in rechargeable batteries, which are controlled by the power management unit, when one of the batteries is drained. Moreover, the data and clock can be precisely recovered from the coil coupling, and a stimulated voltage of 3.2 V can be readily generated by the proposed charge-pump circuits to stimulate cardiac tissues.

Mc Carthy et al (1994) describes the design and in vitro testing of the Cleveland Clinic-Nimbus electro hydraulic permanent total artificial heart as it has been developed. The total artificial heart uses an electric motor and hydraulic actuator to drive two diaphragm-type blood pumps. The inter ventricular space contains the pump control electronics and is vented to an air-filled compliance chamber. Pericardial tissue valves and biolized blood-contacting surfaces potentially eliminate the need for anticoagulation. In vitro studies on a mock circulatory circuit demonstrated preload-sensitive control of pump output over the operating range of the blood pump: 70 to 160 beats/min and 5 to 9.6 L/min at right and left atrial pressures of 1.0 to 7.0 mm Hg and 5.0 to 12.0 mm Hg, respectively. The pump output was found to be insensitive to afterload over a range of 15 to 40 mm Hg mean pulmonary artery pressure and 60 to 130 mm Hg mean systemic pressure. The left master alternate control mode balanced the ventricular outputs during simulated bronchial artery shunting of up to 20 % of cardiac output. A 10% to 15 % right-pump, stroke-volume limiter balanced ventricular outputs during maximum output of 9.6 L/min. In response to a sustained increase in systemic venous return, the pump increased output by 2 L/min (29%) in 35 seconds. Thus the Cleveland Clinic-Nimbus total artificial heart meets the National Heart, Lung, and Blood Institute hemodynamic performance goals for devices being developed for permanent heart replacement. The biolized blood-contacting surfaces should decrease the risk of thrombo embolism associated with circulatory assist devices.

CHAPTER 3

WIRELESS POWER TRANSFER

3.1 Introduction

Wireless power transmission (WPT) is not a new technology. Nikola Tesla first introduced the basic concept of wireless power transfer in nineteenth century. Over the years, some researchers continue their works on the same. The major disadvantages of wireless power transfer are low efficiency. So, researchers are trying to improve the efficiency using several types of techniques. The advantages of wireless power transfer are many that there has been an increasing interest in wireless power transfer technology[4][5]. Wireless power transfer technology can eliminate all the charging troublesome. It can make our daily life so smooth and easy. The traditional wired power transfer has the problems of power loss, damaging wire, electric spark and so on. In that case, wireless power transfer technology is a solution.

3.2 Basic concept of wireless power transfer

Wireless power transfer is the process where electric energy is transmitted from power source to an electrical load without any wire connection. Wireless power transfer is based on the magnetic resonance and near field coupling of two loop resonators was reported by Nicola Tesla a century ago. Power is wirelessly transfer when magnetic field is transferred over short distance. The magnetic field is created using inductive coupling between coils of wire or electric fields using capacitive coupling between electrodes[12]. The concept of inductive coupling and magnetic field comes from the following principles.

3.2.1 Ampere's law

According to Ampere's law, when current is passed through a closed loop of conductor or coil, a magnetic field is created around it[1]. The magnetic field created by the current is proportional to the size of that current with a constant of proportionality equal to the permeability of free space.

3.2.2 Faraday's law of induction

It states that the instantaneous electromotive force (emf) or voltage induced in a circuit due to changing magnetic field is directly proportional to the change of that magnetic field.

3.2.3 Lenz's law

It states that the induced emf generates current that sets up a new magnetic field which acts to oppose the existing magnetic field. In wireless power transfer system, these principles are adopted. In general a WPT system consists of a transmitter connected to power source and a receiver which receives the power and deliver it to the load. In the transmitter side, there is a primary coil and in the receiver side there is a secondary coil[3]. When the power is connected to the primary coil a current passed through it and a magnetic field is formed around it. When the secondary coil is brought close to the primary coil a voltage induces in the secondary coil which generates a current that causes another magnetic field around the secondary coil. The current produced in the secondary coil is used by any load without any physical connection

3.3 Types of wireless power transfer

There are mainly two categories of wireless power transfer, radiative and non radiative. Radiative are for far field and non radiative are for near field.

3.3.1 Far field or radiative region

In far field or radiative region, microwave or laser beams is used to transmit power wirelessly[17]. These techniques can transfer high power over distances. But a direct-line of transmission path is required as high level radiation transmits from transmitter to receiver. In microwave radiation system, frequency is very high so the antennas should be large enough to satisfy the power density limits. This technique is mostly used in space and military applications such as solar power satellite.

3.3.2 Near field or non radiative region

In near field or non radiative region, there are several techniques to transfer power wirelessly. They are inductive coupling, resonant inductive coupling, capacitive coupling, resonant capacitive coupling and magnetodynamic coupling. In inductive coupling, power is transferred between coils of wire by a magnetic field[16]. From two coils, one is in the transmitter side and another is in the receiver side. This is the oldest and most widely used wireless power technology. It is used to charge phones battery, electric vehicles battery, electric toothbrush battery and turn on a bulb. This technique is highly efficient when two coils are very close together. In resonant inductive coupling, power is transferred between two resonant circuits by magnetic fields. One circuit is in the transmitter side and another circuit is in the receiver side. Each resonant circuit consists of coil of wire connected to a capacitor. The resonant between the coils can highly increase coupling and power transfer. It is most efficient than inductive coupling technique. Power can be transferred over greater distances with high efficiency. Nowadays it is widely absorbed in modern wireless power systems. In capacitive coupling, power is transferred by electric field between electrodes such as metal plates. In this process, a capacitor is formed between the transmitter and receiver electrodes. The capacitive coupling has limitation on charging electric vehicles due to too small coupling capacitance. So, it is basically used in a low power applications. In resonant capacitive coupling, resonance are used with capacitive coupling to extend the range. In magnetodynamic coupling, power is transferred between two rotating armatures. One armature is in the transmitter side and another one is in the receiver side and both rotates synchronously. Both coil are coupled together by a magnetic field generates by permanent magnets on the armatures. It is an alternative process of inductive power transfer for non-contact charging of electric vehicles. It is claimed that this technique can transfer power over distances of 10 to 15 cm (4 to 6 inches) with high efficiency, over 90% .

3.4 Functional difference between wired and wireless power transfer

Wired is the term that refers to any physical connection consisting of cables. The cables are copper wire, twisted pair or fiber optic etc. Wired power transfer is the transmission of power through cables. On the other hand, wireless is the term that refers to the medium that is made of electromagnetic waves. All the wireless devices include antenna or sensors. Wireless power transfer is a method of transmitting energy from one physical device to another without any physical connection. The main difference between wireless and wired connection is the physical medium between two devices. For example, the cables can be damaged and require repair or replacement. The cost for the replacement or repair can be high. When compared with cables, wireless are easy to install and no need to worry about the damage of cables. Using wire, we can transfer power from one device to another. In wireless power transfer, one can easily transfer power from one device to different devices. In wired connection, there is a chance of power failure or power loss due to short circuit because of the existence of cables. Sometimes it is hard to manage the interconnecting wires between devices in wired connection. Wireless systems are comparatively maintenance free and if maintenance becomes necessary, they are easy to maintain.

3.5 Efficiency

Wireless power transfer (WPT) technology is developing rapidly and its efficiency increasing day by day. It is highly efficient in some cases. Using this technology, one can turn on more than one bulbs at a time. It is also possible to charge several batteries at the same time without using any cable. Many working group have experimented WPT technology using different types of methods[15]. In 1983, Donaldson's research showed that the optimal electromagnetic coupling coefficient of the transmitter and receiver can be achieved by using the S/P capacitance compensation technique. The transmission efficiency can reach 50%. In 2009, KAIST tested on the SUV car and got 17 kW power at the output with a distance of 170mm. The efficiency reached 71%. In 2010, University of Auckland tested on private vehicles and achieved 3kW power for charging the vehicles battery wirelessly. The efficiency was 85% at a distance of 180mm between source and load. A team from MIT has experimented and were able to light up a 60W light bulb from a power source at a distance of 2m. The efficiency of this experiment was 40%. Furthermore, they found that it is possible to increase the efficiency by shorten the distance. Researchers were able to power a 60W light bulb at roughly 90% efficiency at a distance of 3 feet . In 2010, MIT WiTricity tested on private vehicles and achieved 3.3kW power for charging the vehicle's battery at a distance of 180 mm. The efficiency was 90%. In WPT technology, distance is a big tissue and we got to know this through these experimented results. The efficiency of

WPT depends on the distance. The efficiency is higher if there is shorter distance between power source and load. The efficiency is lower if the distance between power source and load is longer. On the other hand, the efficiency also depends on the technique.

3.6 Types of Wireless Power Transmission Methods

There are different types of wireless power transmission methods: microwave power transmission, inductive-coupling-power transmission and laser-power transmission methods.

3.6.1 Microwave Power Transmission

William C Brown, the pioneer in the WPT technology, has designed and exhibited to show how power can be transmitted through free space by microwaves. The concept of the WPT is explained with a functional block diagram which is shown below.

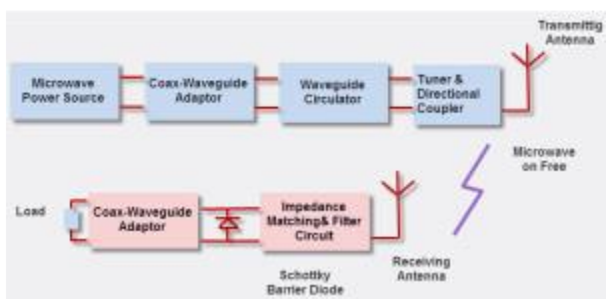


Fig 3.6.1 Microwave Power Transmission

The functional block diagram of WPT consists of two sections: transmitting section and receiving section. In the transmission section, the microwave power source generates microwave power which is controlled by the electronic control circuits. The waveguide circulator protects the microwave source from the reflected power, which is connected through the co-ax waveguide adaptor. The tuner contests the impedance between the microwave source and transmitting antenna. Then, based on the signal propagation direction, the attenuated signals are separated by the directional coupler. The transmitting antenna emits the power regularly through free space to the receiving antenna[16].

In the receiving section, the receiving antenna receives the transmitted power and converts the microwave power into DC power. The filter and impedance matching circuit is provided for setting the output impedance of a signal source which is equal to rectifying circuit. This circuit consists of Schottky barrier diodes which converts the received microwave power into DC power.

3.6.2 Inductive Coupling Power Transmission

Inductive coupling method is the most important methods transferring energy wirelessly through inductive coupling. Basically, it is used for near -field power transmission. The power transmission takes place between the two conductive materials through mutual inductance[13]. The general example of inductive coupling power transmission is a transformer.

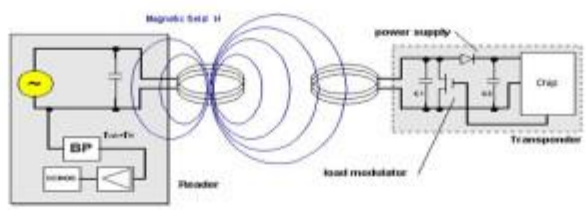
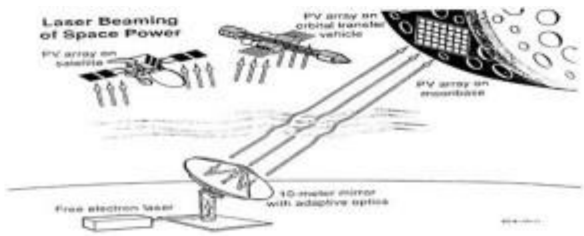


Fig 3.6.2 Inductive Coupling Power Transmission

3.6.3 Laser Power Transmission

In this type of power transmission method, a LASER is used to transfer power in the form of light energy, and the power is converted to electric energy at the receiver end. The LASER gets powered using different sources like sun, electricity generator or high-intensity-focused light. The size and shape of the beam are decided by a set of optics. The transmitted LASER light is received by the photovoltaic cells, that converts the light into electrical signals. Usually, it uses optical-fiber cables for transmission.



A LASER power Transmission System

Fig 3.6.3 Laser Power Transmission System

CHAPTER 4

WIRELESS POWER TRANSFER FOR IMPLANTABLE DEVICES

4.1. Background

Implantable medical devices have the potential to change a clinical condition almost instantly. One example is the use of a left ventricular assist device to restore blood flow when the natural heart is unable to maintain the flow rates required. Other examples of smart devices include pacemakers, nerve stimulators and drug pumps. These devices all require electrical power to operate, and the provision of power is a critical aspect of their design. This project addresses the issue of providing substantial power sufficient for a heart pump operating continuously for the remaining lifetime of a patient. The basis of what this design proposes is the use of inductive coupling and a magnetic field to move power from outside the body to inside[18]. The key challenges are related to alignment of components and avoidance of any heating problems. New power electronic techniques have been developed to address these issues.

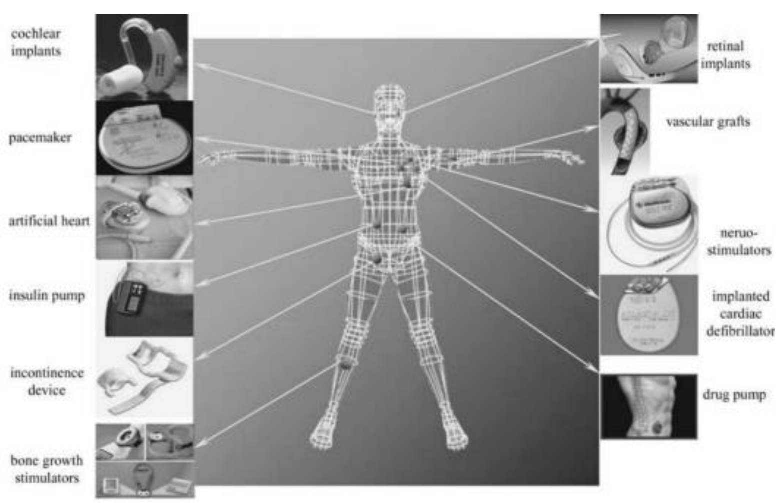


Figure 4.1 Schematic of applications of various implanted medical device

4.2. Need for Heart assisted devices

The lack of available heart donors paves way for a good opportunity for heart assist devices to be researched and developed for medical use. There are different types of heart assist devices, depending upon the location of an operation within the heart; for example the left ventricular assist device (LVAD), right ventricular assist device (RVAD) or biventricular assist device (BiVAD). All of these are different from a ‘total artificial heart’ (TAH) whereby the heart is completely replaced by the device[18]. Patients may be given a temporary mechanical circulatory support in the lead up to a heart transplantation, as shown in Figure 4.3, the percentage of adult transplants bridged by mechanical circulatory support is on the rise: from 22% in 2006 to around 32% in 2009. The mechanical circulatory support in Figure 4.3 includes LVAD, RVAD or TAH. Figure 4.2 and Figure 4.3 are related to each other, with the rising number of transplants being bridged by mechanical circulatory support, the total number of transplantation should also increase[19].

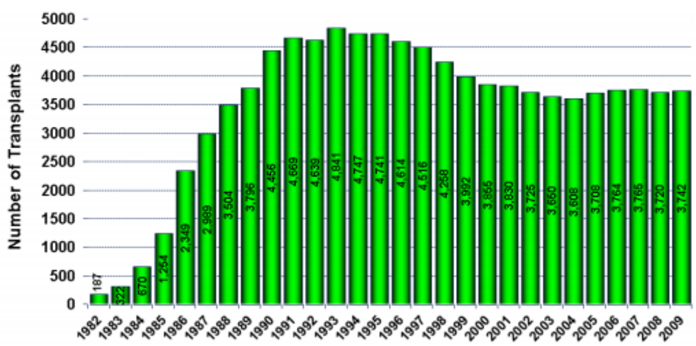


Figure 4.2 The no of heart transplants reported by year according to ISHLT registry

4.3 Risks in percutaneous cable

Heart assist devices are designed to help damaged hearts maintain sufficient blood flow, with short term use required for patients recovering from heart attack or heart surgery and long term use for patients who are suffering congestive heart failure. By 1998 continuous flow rotary blood pumps were introduced and soon these are followed by hydro dynamically and magnetically levitated rotary pumps[20]. The future aim is a transcutaneous energy transfer (TET) based rotary pump total artificial heart device.

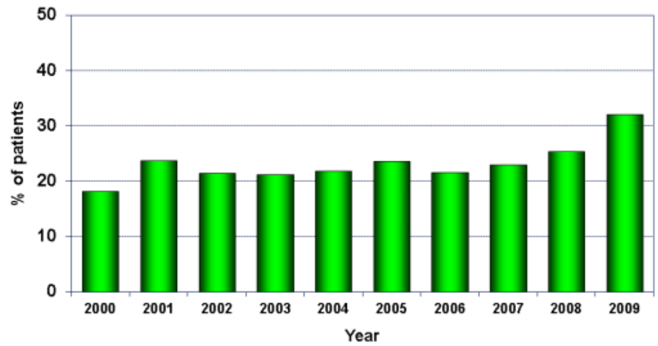


Figure 4.3 Percentage of adult transplantation bridged with mechanical circulatory support

Heart pumps typically require 10W to drive their motors to create blood flow, and this power is delivered through a percutaneous driveline from external batteries. The percutaneous drive line provides a reliable, highly efficient method of getting the power from outside the body to the heart pump motor controller, but its major drawback is its requirement for penetration through the skin and the associated risks of infection[18].

Figure 4.4 The driveline exit site can lead to infections

Figure 4.5 A model of left ventricular assist device (LVAD)

The driveline breaks the skin and the torque generated by everyday patient movements and the weight of the battery can damage this chronic wound, leading to relapsing infections and patient mortality. The initial driveline infection can spread elsewhere and cause bloodstream infection. Over time, driveline infections are very difficult to control despite on-going efforts to treat them . Eliminating this percutaneous driveline could significantly reduce the number of adverse infection effects.

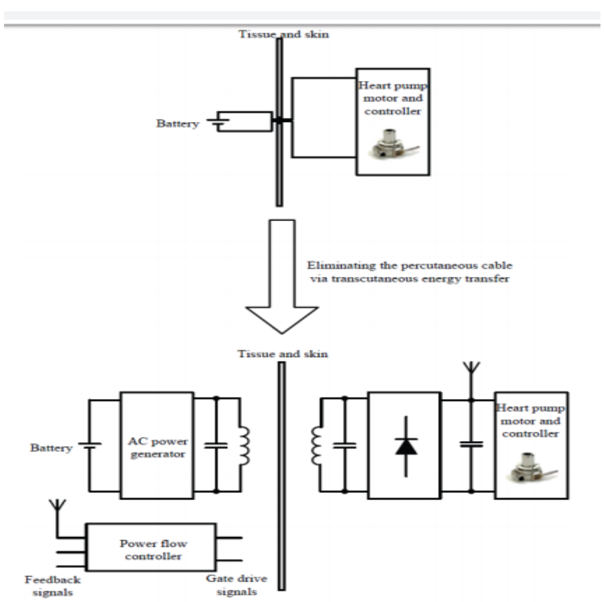


Figure 4.6 Removal of percutaneous cable

CHAPTER 5

PROJECT IMPLEMENTATION

5.1 General Principle of design

The general principle of operation was designed using inductive coupling and ensuring that the power transfer was as efficient as possible and the transfer within the near field. The design also ensured for purposes of versatility and optimization the battery charging circuit was energy efficient and prevented losses. The circuit was divided into two sections:

1. Transmitter Circuit
2. Receiver Circuit

The transmitter circuit comprised of the power supply, boost converter, royer oscillator and the copper laminated coils. The receiver side had the receiver coil, rectifier, Pulse sensor ,Flow sensor, Atmega 328 microcontroller and the switching circuit that used the CD4066

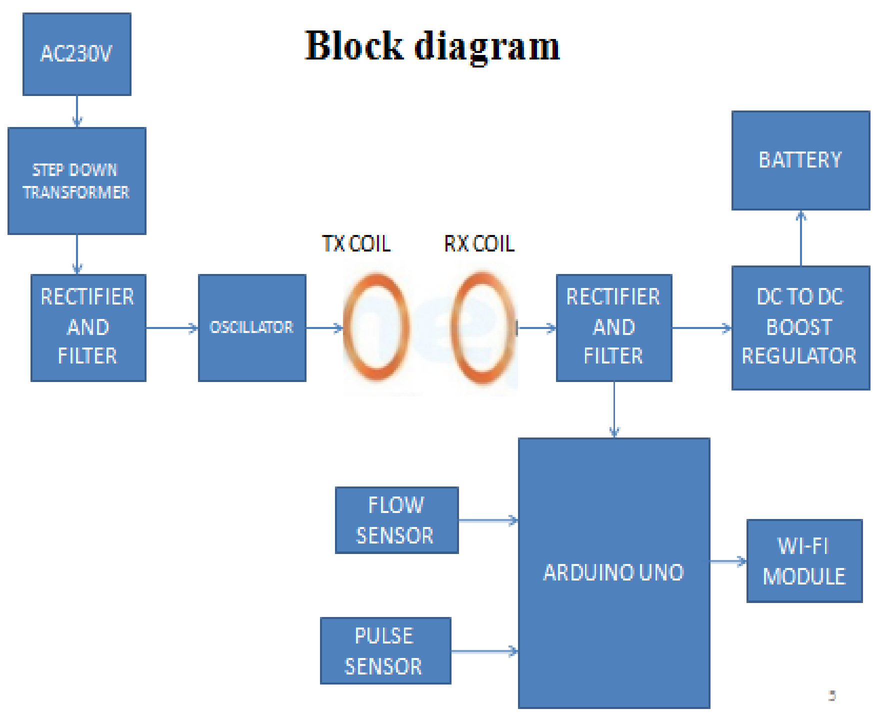


Fig. 5.1.1 Block diagram of experimental setup

AC power is supplied from the mains and fed to the power supply. It is stepped down and then rectified to give dc power. The dc voltage is then passed through the voltage regulator LM7805 so as to give a constant 12V dc. The 12V now becomes the input to the royer oscillator circuit. The oscillator then converts the received DC voltage to AC power with a high frequency.

The operating frequency of the oscillator is determined by the resonance formula given below

$F = ½ \times \pi \times \sqrt{(LC)}$

When the receiver coil is placed within the near field range from the transmitter coil, the magnetic field in the transmitter coil extends and it induces an AC voltage which generates a current flow in the receiver coil of the wireless charger. The transmitted AC voltage is then fed to the rectifier which converts it to DC. A capacitive filter is used to eliminate any ripples. The rectified voltage is fed to the voltage regulator LM7805 to ensure that the voltage is regulated and constant. The output is regulated 5V dc. This power then goes to the power the microcontroller.

5.2 Hardware and Software Components

5.2.1 Hardware Components

5.2.1.1 Step down transformer

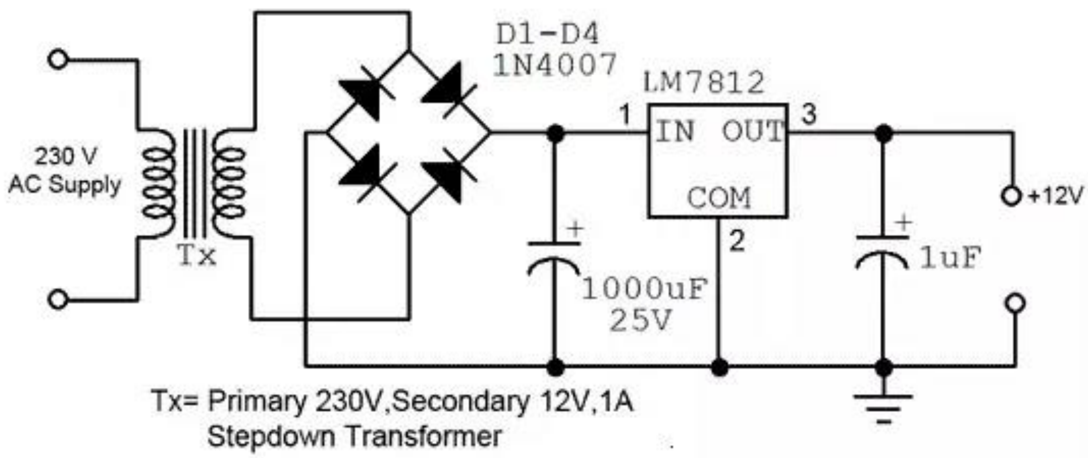


Fig. 5.2.1 Represents the Step down transformer

The power supply contained a transformer that stepped down the 230V ac supplied from the mains to 9V ac. A full-wave bridge rectifier then rectified the 9V ac. Full wave rectifier is preferred over the half wave rectifier since, for the half wave rectifier, a large capacitor will be required to hold up the voltage during the gap whereby an AC cycle is skipped. The full wave rectifier has an efficiency of 80% hence the rectified output was less than the input[2]. The output received was 7.2V dc. This voltage however is still erratic and pulsating thus a smoothening capacitor is required. The smoothening capacitor supplies charge when as the rectifier voltage falls thus evening out any fluctuations by the signal.

5.2.1.2 Voltage Regulator

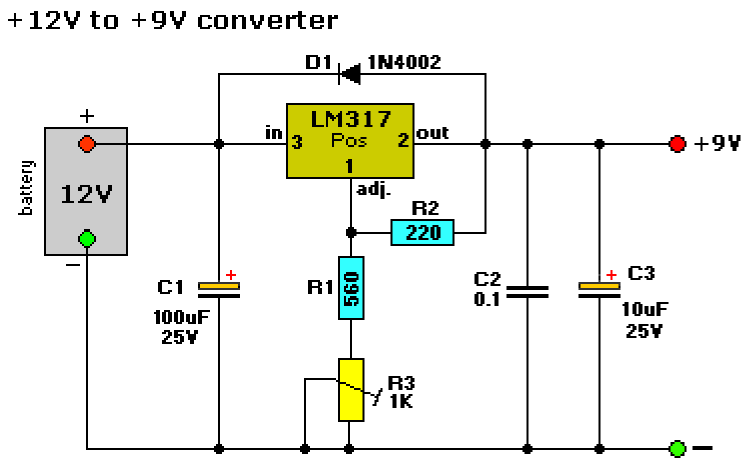


Fig. 5.2.2 Represents the Voltage Regulator

Voltage regulator uses a LM317 variable regulator to adjust the input voltage down to +9 volt, or whatever else you need. A 10uF capacitor for C1 is used close to this circuit. Without a cool rib it can easily handle 500mA. If you need more, or the maximum current (1.5A), then a good cool rib is required[3].

Trimmer potentiometer R3 will vary the output voltage. Ceramic capacitor C2 improves frequency/transient response. It can be omitted if not needed for your application. For extra protection in case the adjust pin is short circuited, add an extra 1N4001 diode over the input and the output. Cathode to input. But normally only used if the output is way over 25V.

R1 and R3 determine the output voltage which can be adapted.

The following formula is used

((R1+R3)/R2)+1)*1.25=V-out which comes to: ((560+1000)/220)+1)*1.25 = 10.11V

5.2.1.3 Full Wave Bridge Rectifier

The transmitted current received on the receiver side is ac. However for purposes of charging the battery, dc is needed hence the need for rectification. In the design, a full wave bridge rectifier instead of a half wave rectifier. It's basically a full wave rectifier but uses four diodes instead of two which then form arms that are the bridge rectifier. It was used because of the following reasons:

i. It doesn't require a center tap on the secondary winding thus ac voltage can be fed directly to the bridge circuit.
ii. For its construction, crystal diodes can be used. The diodes are easily available in the market and cheap. The circuit is also more compact.
iii. The transformer utilization power is higher

There are four diagonal arms. When ac voltage is applied to one arm, the rectified dc voltage is obtained from the opposite arm. The bridge rectifier operates in positive and negative half cycles. During the positive cycle point A is positive and point B becomes negative. In this case diodes D1 and D2 will be conducting while D3 and D4 will be off. D1 and D2 at this point are forward biased and conducting in series with the load[3]. The current flows in the direction as in the figure below

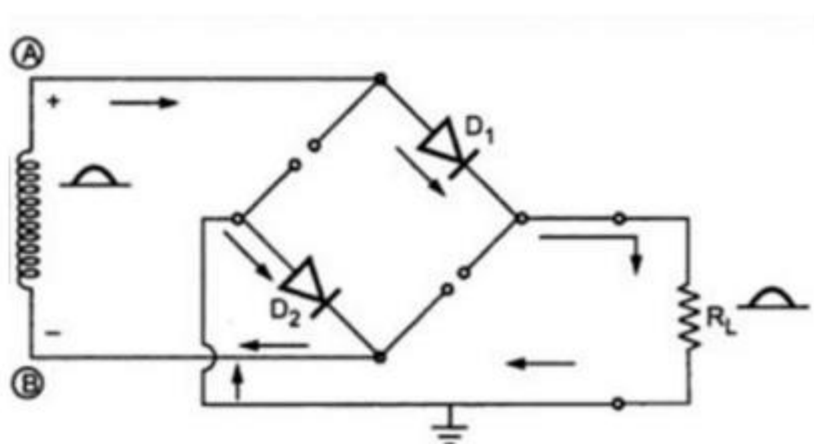


Fig. 5.2.3 Flow of current

During the negative half cycle, the polarity of the ac voltage being fed is reversed such that point B now is the positive while point A becomes negative. Diodes D3 and D4 in this case will be on meaning they are forward biased hence can conduct while D1 and D2 which are off will be reverse biased. Similarly to the positive ac cycle, D3 and D4 will conduct in series with the load and current will flow as in the figure below

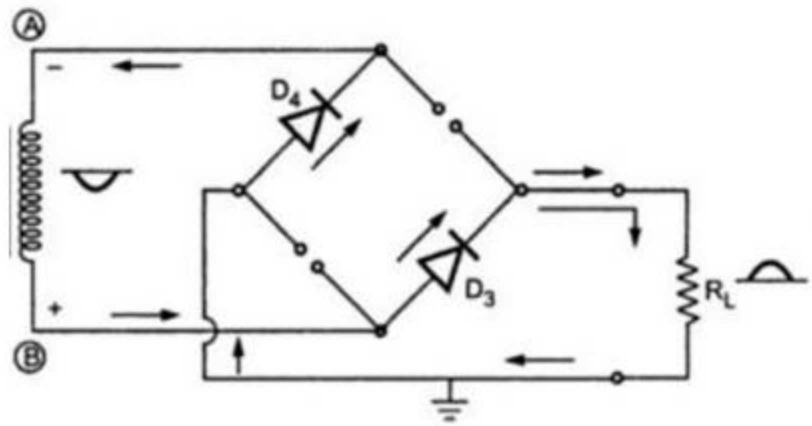


Fig. 5.2.4 Flow of current

It is worth noting that current in the load flows in the same direction for both ac cycles. This therefore means that the current in the full wave cycle is unidirectional. However the rectified dc voltage had ripples[3]. A capacitive filter was added instead of the inductive filter since the reactance of the capacitor is much smaller than the resistor value.

5.2.1.4 Royer Oscillator

Oscillators are systems that consist of both passive and active components of a circuit which then generate sinusoidal waveforms or repetitive waveforms. Oscillator circuits generate waveforms without the aid external inputs. They convert the dc supply power source to ac power which is supplied to a load. For this design I used a royer oscillator. This oscillator belongs to the relaxation oscillators classification since its output is non sinusoidal.

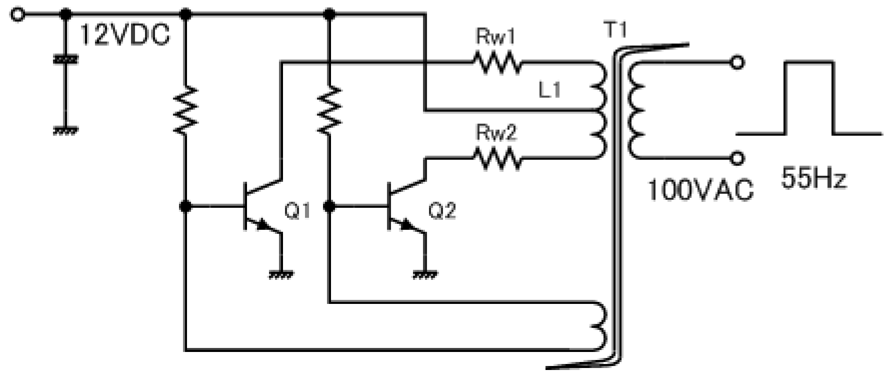


Fig. 5.2.5 Royer Oscillator

The capacitors turn the oscillator into a harmonic oscillator that outputs sine waves. This oscillator has two parts. The first part is a relaxation oscillator. It is connected as an astable multi vibrator which converts the dc power fed into it. It then converts the received dc power to a high frequency ac power. This part generates square waves which are the input of the second part which is the power amplifier. These waves are the input at the gate terminal of the power MOSFET. The second part is the power amplifier. The gate of the first MOSFET is driven by the signal generated at the oscillator part. This MOSFET provides the voltage and the current needed to drive the gate of the second MOSFET[5]. When the second MOSFET turns on it allows a large current from the dc signal to flow to the transmitting coil. The large current generates a large flux which then induces a high voltage to the receiving coil.

5.2.1.5 Microcontroller Unit

A simple definition of the microcontroller is a computer on a chip. The microcontroller enables the project to be a standalone system which is able to produce varied reactions to various situations according to preset controls. The microcontroller in this project is the AT mega 328 microcontroller. The system is required to alert the user if a load is in place, calculate and display the level of charge, start the charging if needed and finally cut the charging when the load is fully charged. To do these actions on its own, the microcontroller needs to be loaded with a program to enable it execute all these actions.

Types of Microcontrollers

There are several ways in which microcontrollers can be classified. The several aspects of classification lead to several types of microcontrollers. Classification based on internal bus width This classification results into three sub groups. Considering the length of the internal bus, a microcontroller can either be 8-bit, 16-bit or 32-bit.

8-bit microcontrollers

8-bit microcontrollers, as the name suggests have a bus width of 8 bits. Examples of such microcontrollers are Intel 8031/8051, PIC 1X and Motorola MC68HC11 families

16-bit microcontroller

Have greater precision than the 8-bit microcontroller. Has a range of 0X0000 – 0XFFFF (0- 65535) for every cycle. Examples of these microcontrollers are the extended 8051XA, PIC2X, Intel 8096 and the Motorola MC68HC12 families.

32-bit microcontroller

Used in automated devices, engine control systems, office machines and other embedded systems. From the name, the bus width is 32 bits and have even greater accuracy than the 16 bit types. Examples are Intel/Atmel 251 family and PIC3X families

Application of Microcontrollers

Microcontrollers have many applications across the technological fields' nowadays. Some of the most common applications are

In Day to day activities

- Light sensing & controlling devices
- Temperature sensing and controlling devices
- Fire detection & safety devices
- Industrial instrumentation devices
- Process control devices

- Industrial instrumentation devices

In Industries

- In Metering and measurement devices
- Measuring revolving objects
- Volt Meter
- Hand-held metering systems
- Current meter

AT mega 328

This is a single chip microcontroller created by the Atmel cooperation and it belongs to the megaAVR series. Typical features of this microcontroller are

- 28 pins (23 are I/O)
- 1kbyte EEPROM Data memory
- Works with an external oscillator of up to 20MHz
- Supports USART functionalities
- Two timers (one 8-bit and one 16-bit)

The I/O pins are responsible for connections of peripherals of the main system such as the LEDs and the LCD screen. The crystal is also connected to the microcontroller because the IC will not work properly without the crystal. The microcontroller was used to control the charging of the battery. One of the challenges with this microcontroller was that it has a voltage limit of 5V yet the battery being charged is a 9V battery. This means it can't measure the voltage of 9V. To solve this, a voltage divider circuit was introduced[20]. The range over which the microcontroller can measure voltage can be increased by using two resistors to create a voltage divider. The voltage divider decreases the voltage being measured to within the range of the microcontroller analog inputs. Code in the Arduino sketch is then used to calculate the actual voltage being measured. The microcontroller also sends a signal to the CD4066 switch to turn of the charging. The measured voltage is then displayed on the monitor.

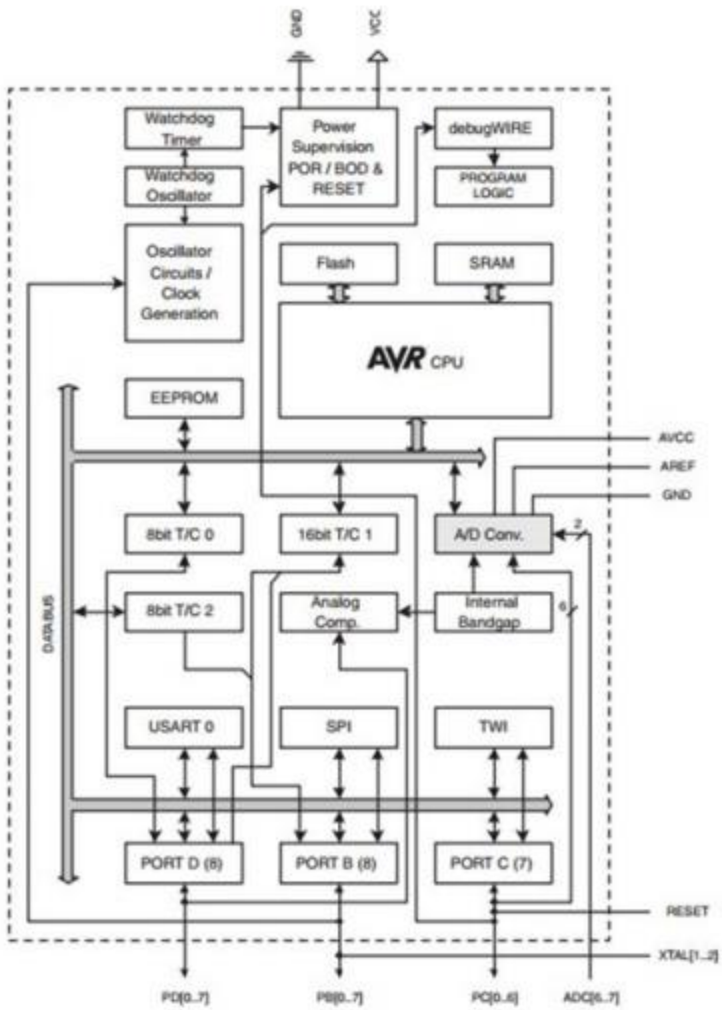


Fig. 5.2.6 AT mega 328

5.2.1.6 Switching Circuit

When the charging is complete, it is important to cut supply to the load so that power is conserved. The switching off of the circuit is achieved by the IC Cd 4066. Conventional switching circuit components such as the relay are not possible in this situation because of the lower power produced after transmission. Had a relay been used in the circuit, there would not have been enough power for the relay to work and therefore the switch will not work. The CD 4066 is a low power multiplexing switch circuit which is an ideal replacement for mechanical switches. The IC has a bandwidth of around 8MHz, current consumption of 1 mA but it requires a high level power supply voltage since the input impedance of the circuit drops with higher voltage levels[3]. The circuit cuts supply to the load once the batteries are full so that power is not lost unnecessarily.

The multiplexer switch diagram is shown below

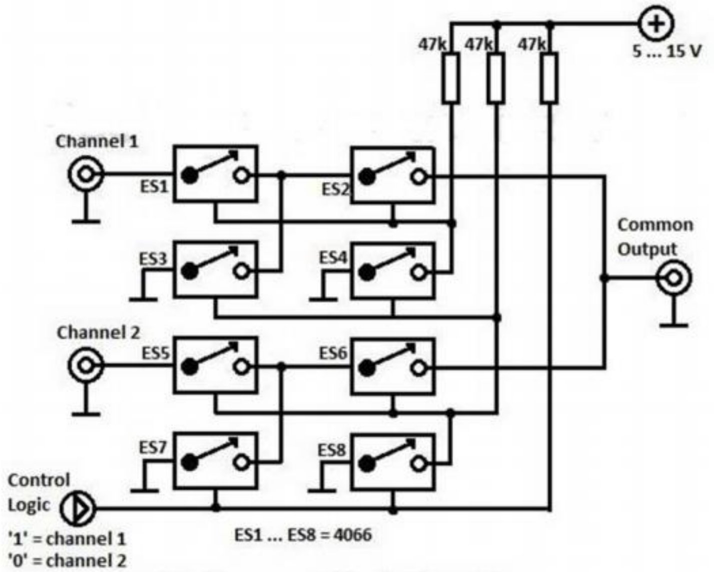


Fig. 5.2.7 Switching Circuit

5.2.1.7 Pulse Sensor

Principle

The principle behind the working of the Heartbeat Sensor is Photoplethysmograph. According to this principle, the changes in the volume of blood in an organ is measured by the changes in the intensity of the light passing through that organ.Usually, the source of light in a heartbeat sensor would be an IR LED and the detector would be any Photo Detector like a Photo Diode, an LDR (Light Dependent Resistor) or a Photo Transistor.With these two i.e. a light source and a detector, we can arrange them in two ways: A Transmissive Sensor and a Reflective Sensor.

In a Transmissive Sensor, the light source and the detector are place facing each other and the finger of the person must be placed in between the transmitter and receiver.Reflective Sensor, on the other hand, has the light source and the detector adjacent to each other and the finger of the person must be placed in front of the sensor[20]. A simple Heartbeat Sensor consists of a sensor and a control circuit. The sensor part of the Heartbeat Sensor consists of an IR LED and a Photo Diode placed in a clip.

The Control Circuit consists of an Op-Amp IC and few other components that help in connecting the signal to a Microcontroller.

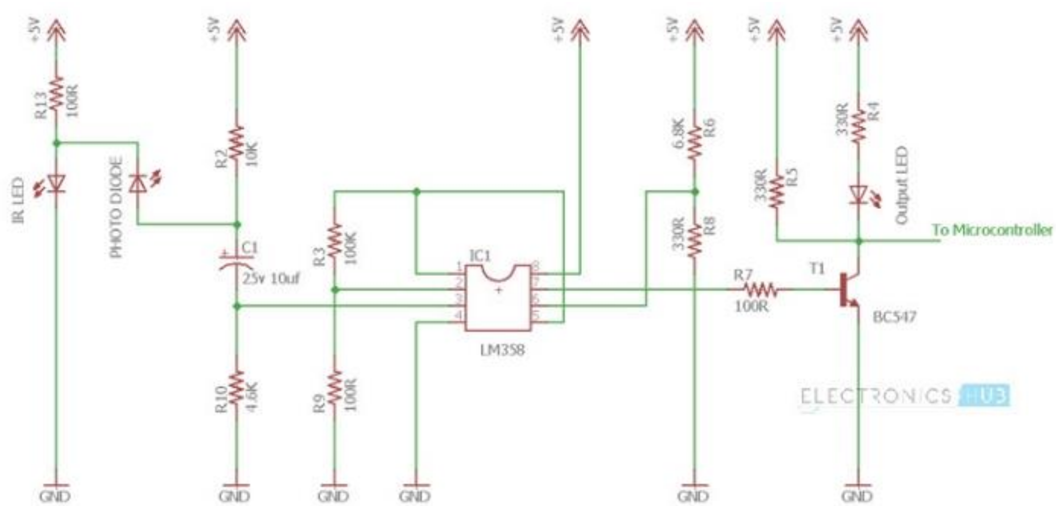


Fig. 5.2.8 Pulse Sensor

The above circuit shows the finger type heartbeat sensor, which works by detecting the pulses. Every heartbeat will alter the amount of blood in the finger and the light from the IR LED passing through the finger and thus detected by the Photo Diode will also vary.

The output of the photo diode is given to the non – inverting input of the first op – amp through a capacitor, which blocks the DC Components of the signal. The first op – amp cats as a non – inverting amplifier with an amplification factor of 1001.

The output of the first op – amp is given as one of the inputs to the second op – amp, which acts as a comparator. The output of the second op – amp triggers a transistor, from which, the signal is given to a Microcontroller like Arduino.

The Op – amp used in this circuit is LM358. It has two op – amps on the same chip. Also, the transistor used is a BC547. An LED, which is connected to transistor, will blink when the pulse is detected.

5.2.1.8 Flow Sensor

Accurate flow measurement is an essential step both in the terms of qualitative and economic points of view. Flow meters have proven excellent devices for measuring water flow, and now it is very easy to build a water management system using the renowned water flow sensor YF-S201. This sensor sits in line with the water line and contains a pinwheel sensor to measure how much water has moved through it. There is an integrated magnetic Hall-Effect sensor that outputs an electrical pulse with every revolution. The “YFS201 Hall Effect Water Flow Sensor” comes with three wires: Red/VCC (5-24V DC Input), Black/GND (0V) and Yellow/OUT (Pulse Output). By counting the pulses from the output of the sensor, we can easily calculate the water flow rate (in litre/hour – L/hr) using a suitable conversion formula.

Fig. 5.2.9 Flow Sensor

The basis relationship for determining the liquid's flow rate in such cases is **Q=VxA**, where **Q** is flow rate/total flow of water through the pipe, **V** is average velocity of the flow and **A** is the cross-sectional area of the pipe (viscosity, density and the friction of the liquid in contact with the pipe also influence the flow rate of water).

5.2.2 Software Components

5.2.2.1 USB Port

This is a USB based programmer for the microcontroller used for burning hex files into AVR microcontroller. In order to program any microcontroller you need the .HEX file or the sketch which is the machine code for the microcontroller. This file is generated by the corresponding assembler software, which converts programming code into machine code. Programming code can be produced by third party cross compiler software, we used arduino. To transfer program using it, one end is connected to the computer that has assembler software and code. The other end is then connected to a6-pin or a 10-pin cable. From this cable, female to female pins can be used which can then easily be hooked to a breadboard. Regardless of whether the 6-pin cable or 10-pin cable is used, only 6 pins will be in use, these are the MISO, SCK, RST, VTG, MOSI, and GND connections.

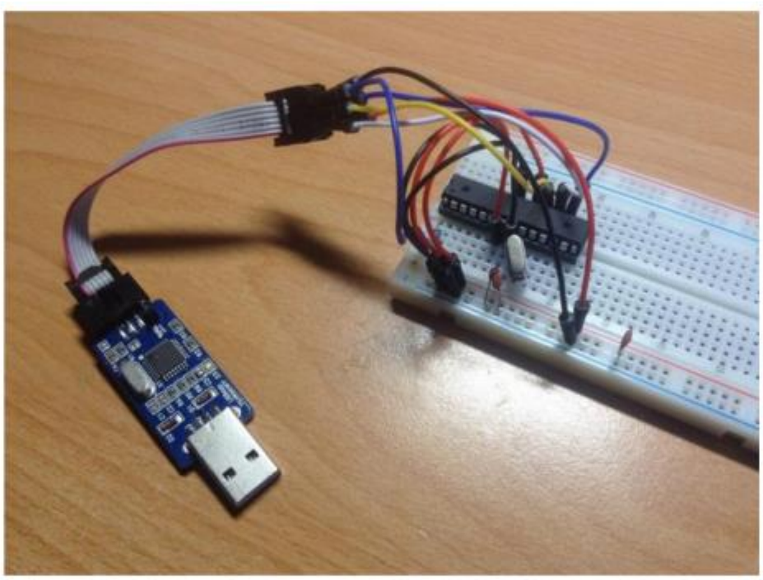


Fig. 5.2.10 USB Port

The pins function as follows:

MOSI- (Master Out Slave In) - it allows the master device to send data to slave or target device.

MISO- (Master in Slave Out) - it allows slave device/target to send information to master device.

SCK – (serial clock) - this mutual clock shared between master and slave device for synchronized communication.

Reset- (target AVR MCU Reset) - The reset pin for the AVR chip being programmed must be put in active low in order for programming to occur.

VCC- (Power) - The master and slave device both need power in order to operate.

GND- (Common Ground) - The master and slave device must share a common power ground data to the target AVR which is being programmed.

The SCK pin is the clock. It is essential because in order for the master and slave device to communicate, they need to have a time signal to communicate data in synchrony. The common clock signal shared between the master and slave device allow for efficient communication.

The RST pin is an essential connection because it must be put to an active low connection in order for programming to occur between the master and slave device. It is normally held high, but for programming to occur, it must be put low. It is an active low pin. When the RST pin is put low, the master slave can communicate on the SCK, MISO, and MOSI lines.

5.2.2.2 Programming Language

A programming language is a constructed language designed to communicate instructions to a machine. They are used to create programs that control how a machine functions in different circumstances.

This project is done in assembler language. This is a low level programming language for a microcontroller or other programmable device. The assembler language has a very strong association with the architecture of the microcontroller hence a good understanding of the microprocessor architecture is required when programming using assembler. Programming in assembler language has the following advantages:

- Suits time sensitive jobs
- Allows hardware specific complex jobs easier
- Requires less memory and execution time.

Pulse Sensor Algorithm

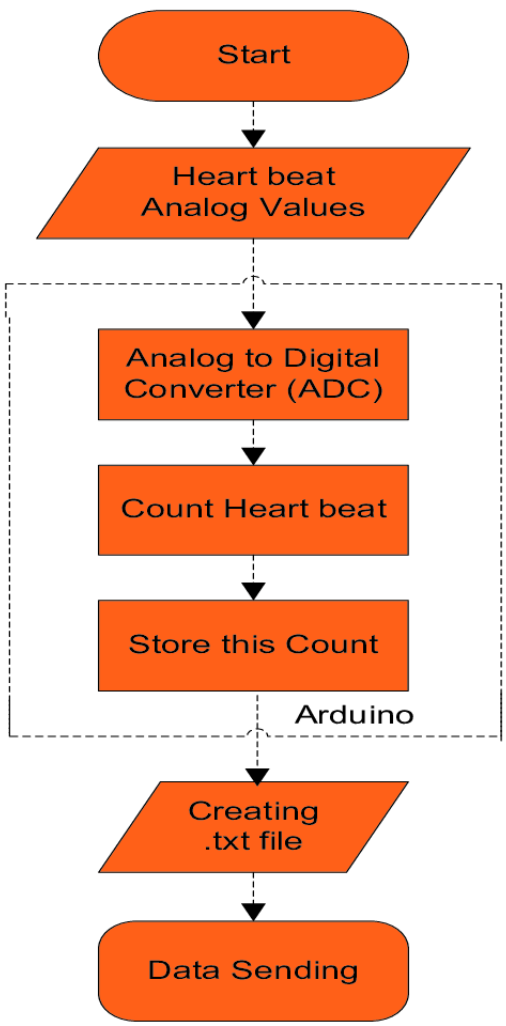


Fig. 5.2.11 Pulse sensor algorithm

Battery Charging Flow Chart

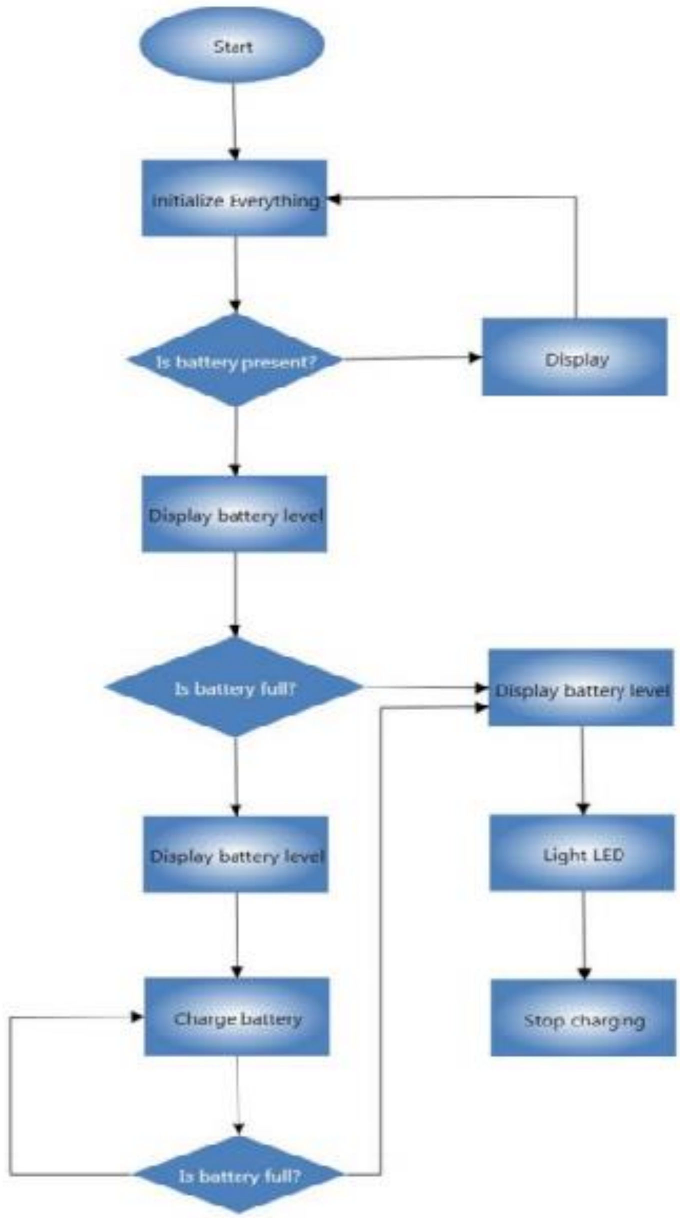


Fig. 5.2.12 Flow of current

CHAPTER 6

RESULTS AND DISCUSSION

6.1 Results

The main objective of the project was to develop a device for wireless power transfer. The device had to be an electronic circuit. The achievement of this objective was further broken down into specific objectives which all together aided the development of the device. The other objectives were as follows:

I. **Design and assemble a power supply unit**. The power supply was to step down 230V ac supplied by the mains to 12V ac high frequency. The 12V ac was then to be rectified to give 5V dc.

II**. Rectify and regulate the voltage.** 12V ac is rectified to dc supply and are filtered to remove any noise signals.

III. **Design and assemble an appropriate oscillator**. For the project, a royer oscillator was found to be most suitable.

The above three objectives formed the transmitter module. When assembled and fabricated it was as depicted in the figure below.

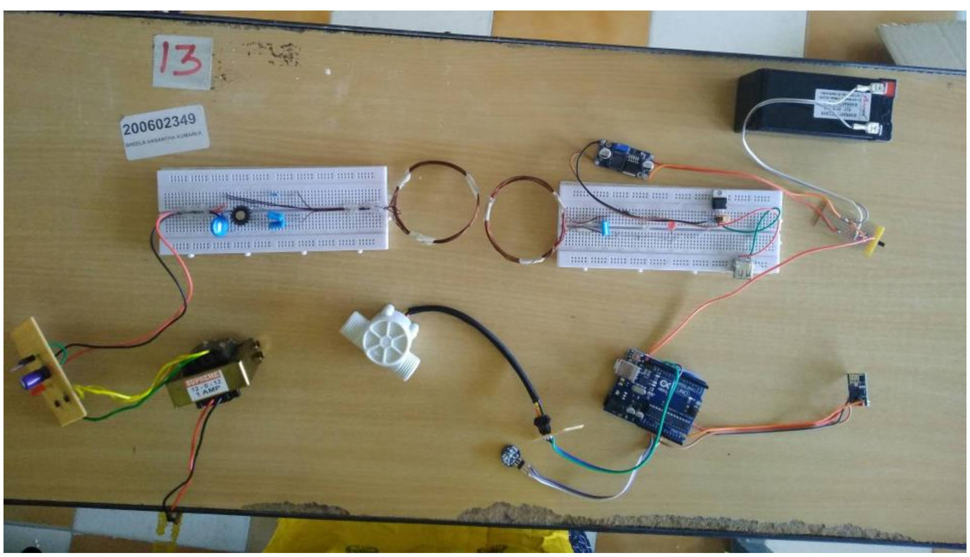


Fig 6.1.1 Experimental setup

IV**. Develop transmitter and receiver coils**. Electromagnetic induction occurs between these two coils and an emf generated on the TX coil that induces a current on the RX coil. The coils were embedded on the fabricated casing of the modules. However they are as in the figure below.

Fig 6.1.2 Transmitter & Receiver coil

V. **Design the receiver module and rectify the ac voltage received on the receiver coil.** A rectifier was needed to output dc power which would be used to power other components.

VI. **Designing a battery charging circuit.** The transmitted power was to be used to charge a battery so as to further demonstrate the application of wireless power transmission in the modern world.

VII**. Design a pulse and a flow sensor unit.** Pulse sensor and the flow sensor are connected to the microcontroller with their own software coding in order to check the vitals during the charging.

6.2 Analysis and Discussion

6.2.1 Coil Specifications

To test if power was transmitted we first soldered an LED to the receiver coil. The test was successful with only 5V dc powering the oscillator. However the power was too to energize the battery charging circuit that comprised of an LCD and microprocessor

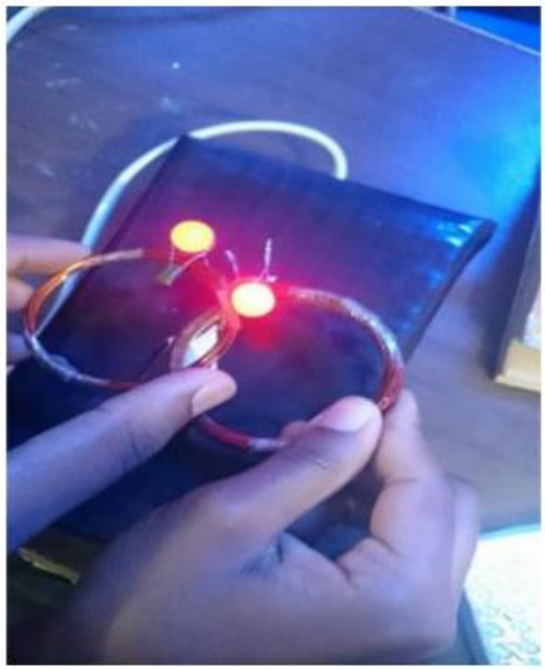


Fig 6.2.1 Power transmission testing

In the above figure, the receiving coils were not separated from the transmitter coil. However as the distance of separation increased the brightness reduced. This proved that indeed the distance of separation determines the current induced in the receiver coil. As distance increases, less current is induced from the change of flux. The test LED bulbs lit brightest up to a separation distance of 5cm between the two coils after which their brightness reduced significantly.

Coil	Diameter	Inductance	Quality factor @13.56MHz
Primary coil	3cm	2.07μH	89
Secondary coil	9.5mm	0.56μH	48

Table 6.1 Coil specifications

6.2.2 Royer Oscillator

The Royer oscillator was chosen because of its simplicity yet powerful design. It is capable of generating very high oscillating current which is necessary to increase the strength of the magnetic field. This is achieved by the semi-conductor used. In this case, the IR 540 power MOSFETs . However due to the large current, heating occurred in the MOSFETs thus heat sinks were attached to them.

Initially upon doing the test the transmitter circuit didn't oscillate yet the first MOSFET was rapidly heating up. It was discovered that due to voltage being fed rising too slowly on power up a short circuit occurred. To solve this issue, a reset switch was introduced between the power supply and the oscillator circuit. The switch also enabled the circuit to be reset once the MOSFETs heated up.

It was also observed that as much as the voltage to the oscillator had been stepped up, the power being received on the load coil wasn't enough to power the battery charging circuit. This was attributed to the receiver coil being slightly out of resonance thus it wasn't able to receive the power well. To solve this we ensured that the coils had the same number of turns and the capacitors used were identical so that both the transmitter and receiver circuits had the same resonant frequency.

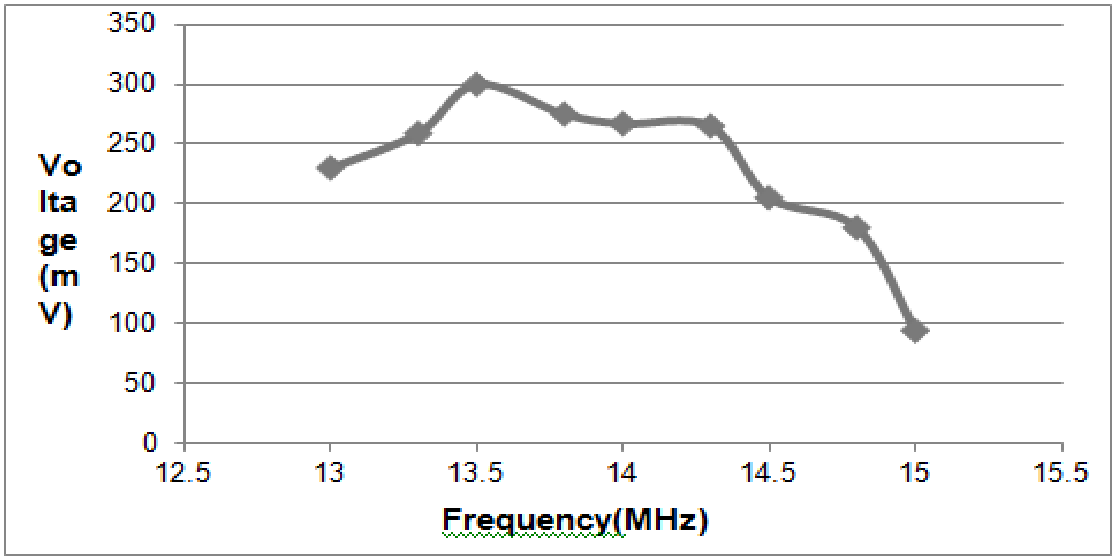


Fig 6.2.2 Represents the graphical representation of Voltage Vs Frequency

6.2.3 Distance Relationship

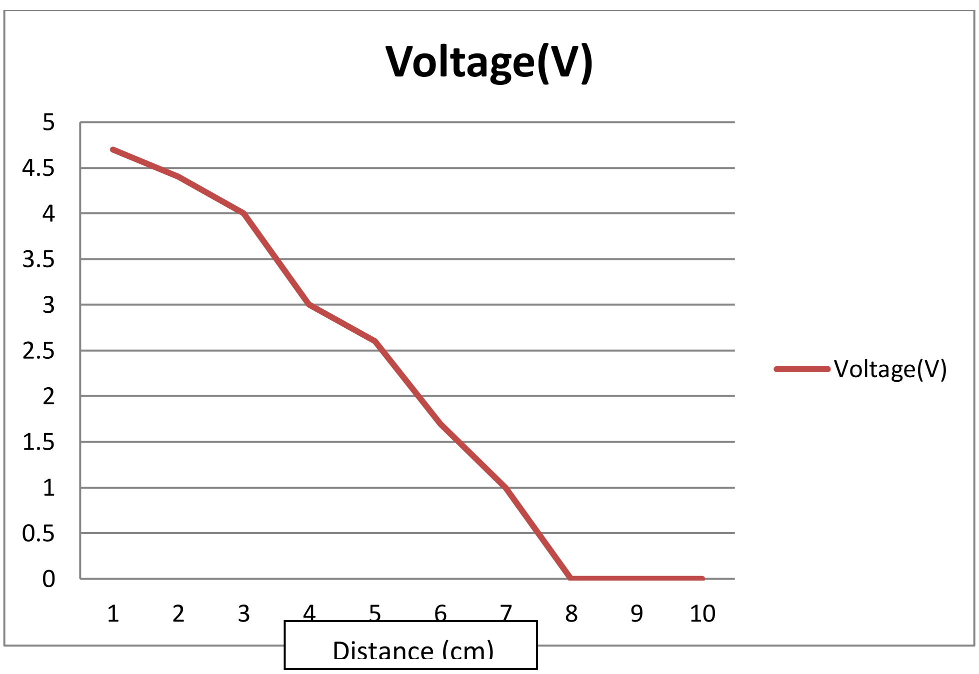


Fig 6.2.3 Represents the graphical representation of Distance Vs Voltage

6.2.4 Efficiency of the Voltage supplied

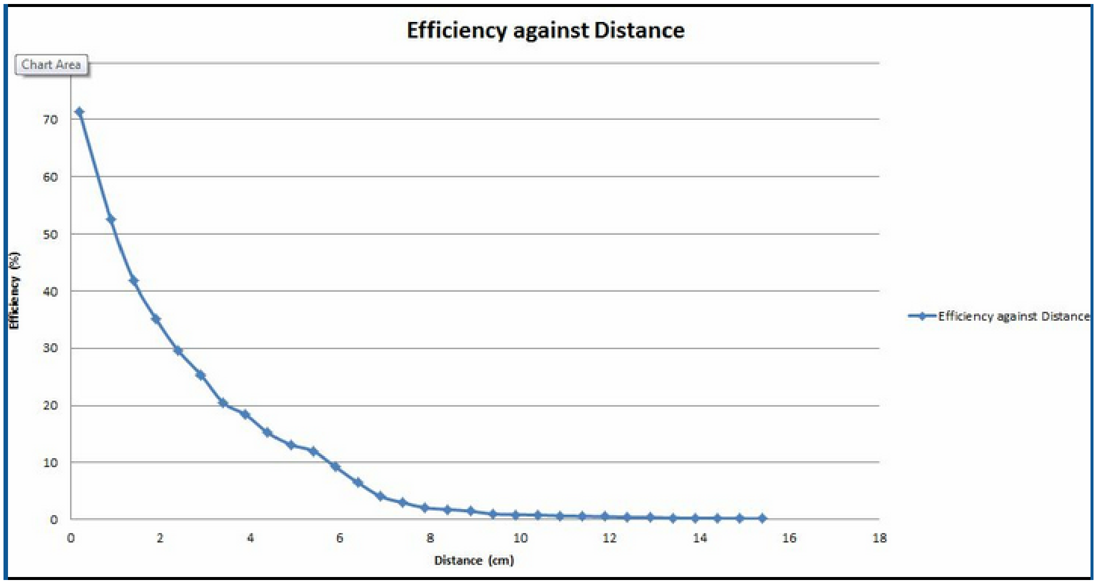


Fig 6.2.4 Represents the efficiency of the voltage applied

6.2.5 Pulse rate calculation

The Pulse Sensor can be connected to arduino, or plugged into a breadboard.The front of the sensor is the pretty side with the Heart logo. This is the side that makes contact with the skin. On the front you see a small round hole, which is where the LED shines through from the back, and there is also a little square just under the LED. The square is an ambient light sensor, exactly like the one used in cellphones , tablets, and laptops, to adjust the screen brightness in different light conditions. The LED shines light into the fingertip or earlobe, or other capillary tissue, and sensor reads the light that bounces back. The back of the sensor is where the rest of the parts are mounted.

The processing software will count and displays the pulse rate as shown in the image.

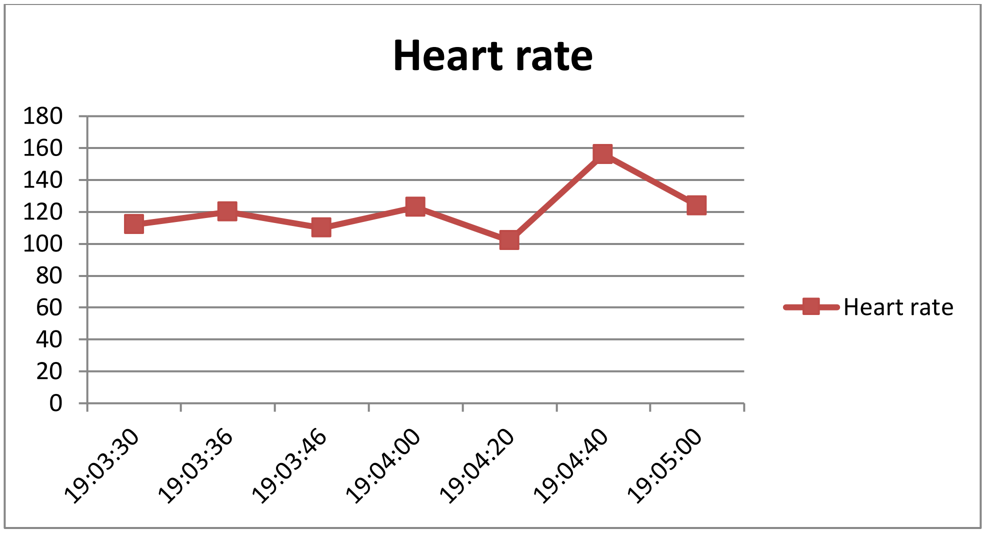


Fig 6.2.5 Pulse rate representation

6.2.6 Flow Sensor Graph

The blood flow measurement requires a minor surgery to insert the sensor into the blood which was not permitted for experimental purpose and hence we have calculated the air flow instead.

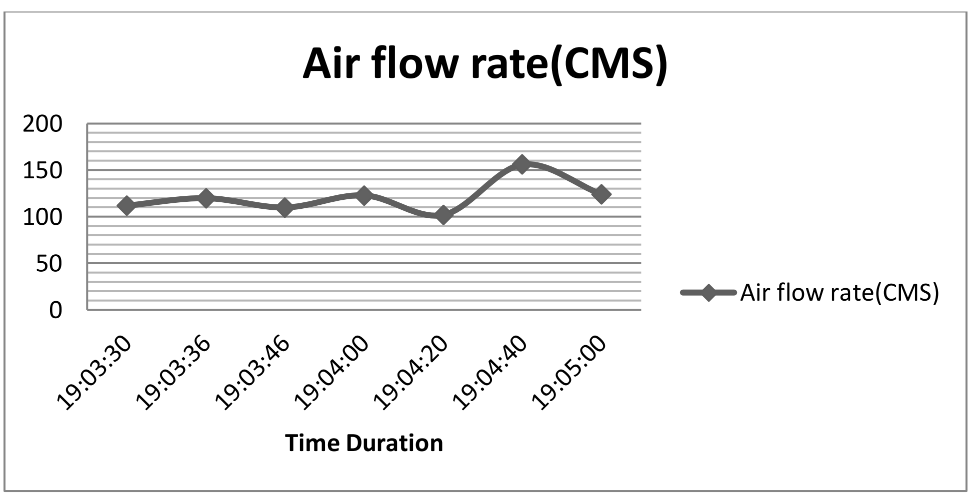


Fig 6.2.6 Air Flow rate representation

6.2.7 Charging Measurement

The battery charging circuit consisted of the rectifier which converted the ac power to dc, an Atmega 328 microcontroller, a monitor and a CD4066 switch. This part was largely controlled by the microcontroller. Initially a relay was used as the switch once the battery is full. However it was drawing more current and thus acted as load. The CD4066 became a better alternative as it consumed less current and also was less bulky as compared to the single channel relay.

One of the challenges with modern chargers is that once charging is complete; there is no notification to the user to stop the charging. To solve this, An RGB LED was used. Its operation was coded and loaded to the microcontroller.

It was observed that, once the battery started charging it heavily loaded the rectifier voltage and caused it to drop significantly. The battery internal resistance is suspected to be the major cause of this.

CHAPTER 7

CONCLUSION AND FUTURE SCOPES

7.1 Accomplishments

The proposed wireless power transfer showed a promising result as our main intention was to develop a wireless power transfer system. We got some output voltage to the receiver coil at a distance up to 7cm which drops at 8. We converted the output power from AC to DC and finally were able to charge the battery. We were able to obtain the desired pulse rate and flow rate during the charging process.

7.2 Observations

The oscillating circuit was the main part of this experience. We have to increase the frequency more than 50 kHz to make the coil work. The efficiency of wireless power transfer mostly depends on the capacitor values of the oscillating circuit. The simulation part shows that, if we change the capacitor value, the frequency changes and with higher frequency, we can transfer more power wirelessly to higher distances. This indicates that the efficiency and the range can be improved.

7.3 Limitations

The major problem of wireless power transfer using transmission coil is, the efficiency is inversely proportional to the distance. As a result, it can transfer very low power at higher distances. So, the overall efficiency is low.

Another major problem of wireless power transfer is, all devices, which are in the range of the coil, will act as a receiver and draw a load. Every device, which will be charged wirelessly, should have built in over current protection as the current in the air will be high enough to transfer power efficiently . The wireless system is easy and safe, comparing to the previous systems. But, it is costly. Our body can resist to low frequency voltages and hence this prototype does not cause any hazard to the health.

7.4 Scope of future work

For the future work, there are many ways to improve the wireless power transmission. To reduce the size of the coil, we can make a multilayer coil which can be made planar for easy integration with device platform. We can also load the antenna coil with ferrite to concentrate the magnetic field so that the transmission range can be increased. For maximum power transfer, a 50Ω impedance matching is needed. We can construct an impedance matching circuit by inserting discrete L and C elements between the band and the output of the final stage amplifier. To improve the transmission range, we can insert more RF power amplifiers and current amplifier after voltage regulator. For battery detection improvement, we can try to detect from the output battery level of cell phone's operating system.

7.5 Conclusion

The proposed thesis based project was to deliver power wirelessly. Our research and practical implementation showed positive results. We were able to transfer power wirelessly and the efficiency was 1.4% which is very low. But, from the research, we found that, the efficiency can be increased. As the output power is inversely proportional with the distance, it is very much challenging to improve the efficiency. Many research is going on to improve the efficiency.

This project shows many promises to the medical systems. But, to do so, we have to increase the efficiency first. If we can develop this design to get a high enough efficiency, we might be going for the large scale wireless power transmission for other implants.

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