WIRELESS ELECTRICITY

A SEMINAR REPORT

Submitted by

PATEL DHARMESH N. (090230111042)

PATEL SONESH R. (090230111044)

PATEL SHYAMAL B. (090230111118)

BHATT JIGNESH S. (090230111021)

In fulfillment for the award of the degree

of

BACHELOR OF ENGINEERING

in

Electronics and Communication Engineering

Government Engineering College of Surat

Gujarat Technological University, Ahmadabad

December,2012

Government Engineering College , Surat

Electronics and communication Engineering Department

2012

CERTIFICATE

Date: / /2012

This is to certify that the dissertation entitled "WIRELESS ELECTRICITY" has been carried out by PATEL DHARMESH N.(090230111042),PATEL SONESH R.(090230111044),PATEL SHYAMAL B.(090230111118),BHATT JIGNESH S.(090230111021) under my guidance in fulfillment of the degree of Bachelor of Engineering in ELECTRONICS AND COMMUNICATION ENGINEERING 7th semester of Gujarat Technological University, Ahmadabad during the academic year 2012-13.

Guide:

Prof. Avani A. Vithalani

Head of Department

Prof. P. S. GOSAI

ACKNOWLEDGEMENT

The present report is the work carried out during 4^{th} year under the supervision of Prof. Avani A. Vithalani in Electronics and communication engineering department at Government Engineering college, Surat.

Keeping in mind, first of all we want to thank our Government Engineering College (Electronics and communication Engineering Department) for providing us such a great atmosphere around us which encourages every student to work to their peak level. Special thanks to our H.O.D of Electronics and communication Engineering department

Prof. Avani A. Vithalani for their immense support, for their precious guidance and moral support which is beyond any comparison.

All our team members and our Professor have played significant role as moral boosters and have extended all possible help and co-operation. We expressed sincere gratitude to them. Last but not the least we are thankful to our parents who help us financially when Were quired and encourage us to get great achievements in our life.

Thank you all.

ABSTRACT

The objective of this technical report is to provide electrical energy to remote objects without wires. Wireless energy transfer also known as wireless energy transmission is the process that takes place in any system where electromagnetic energy is transmitted from a power source to an electrical load, without interconnecting wires. Wireless transmission is employed in cases where interconnecting wires are inconvenient, hazardous, or impossible.

The principle of wireless electricity works on the principle of using coupled resonant objects for the transfer of electricity to objects without the use of any wires. A witricity system consists of a witricity transmitter and another device called the receiver.

The receiver works on the same principle as radio receivers where the device has to be in the range of the transmitter. It is with the help of resonant magnetic fields that witricity produces electricity, while reducing the wastage of power. The present report on witricity aims at power transmissions in the range of 100 watts. May be the products using WiTricity in future might be called Witric or Witric's.

LIST OF FIGURES

Figure No	Figure Description	Page No
Figure 5.1	parallel configuration configuration.	21
Figure 5.2	characteristic of parallel configuration.	22
Figure 5.3	perpendicular configuration.	23
Figure 5.4	characteristic perpendicular configuration.	24
Figure 6.1	Schematic setup of the Standby saver. When the latching relay switches due to a power pulse received by the rectenna, the TV is connected to outlet power and turns on.	25

LIST OF TABLE

TABLE OF COTENTS

Chapter 1: Introduction

Wireless power transfer may seem like science fiction, but the idea is more than 100 years old. Around 1900 Nicola Tesla claimed to be able to radiate power over long distances with minimum loss of power, took a patent and even got some industrial finance for trials. These failed. Hundred years later, an electric toothbrush using Contactless inductive charging device is a common commodity in many households. Even more recently new breakthroughs are claimed to radiate enough energy from a power outlet to feed a nearby low-voltage lamp or electronic device using radio- frequency radiation over a distance of one meter. In this project, we came up with nine possible applications of wireless power transfer. They were analyzed based on a list of criteria, and based on this, the feasibility of the two best applications was investigated further. These criteria were:

- User-friendly, easy to use and easily standardized.
- Technologically possible to make.
- Economically feasible.
- Sustainable.

In chapter 2 of this report you will find the theory about the various ways of wireless power transfer. In chapter 3, all applications we came up with are mentioned, and these applications are analyzed and rated based on the criteria in chapter 4. Then in chapter 5 and 6, the two selected applications are investigated more thoroughly. In on these applications is drawn, and some recommendations are given.

Chapter 2: Theory

There are different ways to achieve wireless power transfer from a power source to a receiver. This chapter will discuss the basic theory behind several ways of wireless power transfer.

2.1 Induction

When the magnetic flux through a circuit changes, an electromotive force (emf) and a current are induced in the circuit. This effect is for example used in dynamos, electric motors and transformers. The central principle behind electromagnetic induction is Faraday's law, which relates to the induced electromotive force (emf) in any closed

Loop including a closed circuit 1.Induction can be used as a means of wireless power transfer. A changing current in one coil 1 creates an emf, which in turn induces a current in a coil 2, as shown in Figure 2.1.

The coils are not in contact and in this way energy can very simply be transported over short distances. This is used in for example an electric toothbrush charger. The short distance that is required for induction is the largest drawback of this way of wireless energy transfer, because it limits the applicability to very close-range situations 2.

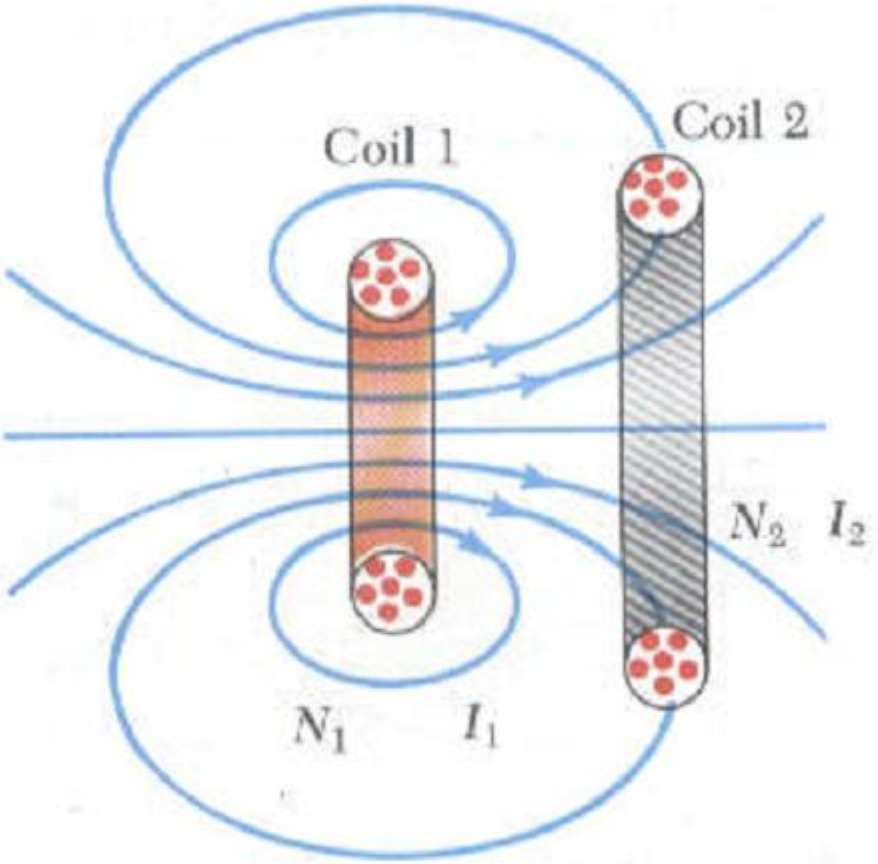


Figure 2.1: A time-changing current in coil 1 causes a time-changing magnetic flux through coil 2 which induces a time-changing current in that coil.

2.2 Radio Waves

The key component for wireless power transfer by radio waves is the rectenna. A rectenna is a combination of a rectifying circuit and an antenna. The antenna receives the electromagnetic power and the rectifying circuit converts it to DC electric power. A schematic rectenna design is shown in Figure 2.2.

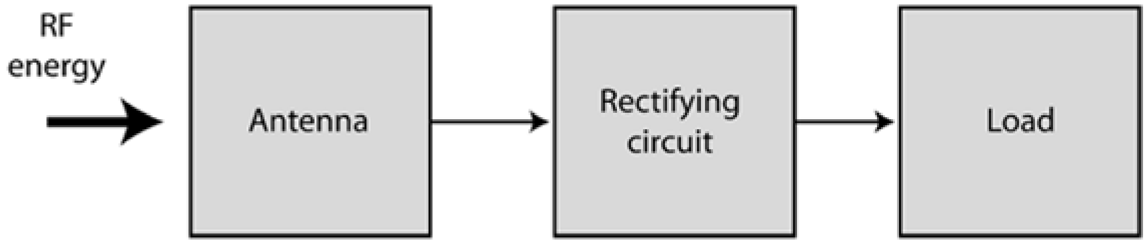


Figure 2.2: A schematic rectenna diagram.

A simple rectenna can be constructed from a Schottky diode 5 placed between the antenna dipoles. The diode rectifies the current induced in the antenna by the microwaves. Schottky diodes are used because they have the lowest voltage drop and highest speed and therefore waste the least amount of power due to conduction and switching.

The amount of power that can be transferred is limited. For safety reasons, the transmitted power is limited by regulations, for instance by the Federal Communications Commision (FCC), and the received power is attenuated, mainly due to free-space path loss. Furthermore, because portable devices have small dimensions, the rectenna should have small dimensions as well. This results in a small

antenna area and, consequently, a low amount of received power. Because of these limitations, wireless power transfer using radio waves is mainly suitable for low-power applications, e.g. a low-power wireless sensor.

2.3 Light

Power delivery that starts with sunlight has many advantages such as sustainability and the fact that the sun is present every day. However solar cells have limited efficiency and sunlight is not available at night. An alternative is to generate artificial light, from a laser, transmit it through air, and then convert it into electricity. New refinements are making this alternative more attractive. NASA has demonstrated flight of a lightweight model plane powered by laser beam, directed at a panel of infrared-sensitive photovoltaic cells mounted on the bottom of the aircraft.

A theoretical setup consists of a laser (Light Amplification by Stimulated Emission of Radiation) and a photovoltaic, or solar cell. First electricity is converted by the laser into a laser beam, which consists of coherent radiation. Next this beam is pointed towards a photovoltaic cell receiver, which in turn converts the received light energy back into electricity. This is generally called “power beaming”. Both steps are not highly efficient and also a direct line of sight between laser and the photovoltaic cells is required.

2.4 Electrical Conduction

Power is normally supplied by means of a conducting wire, where the conductive material is a metal. In the case of wireless power supply through conduction, this conducting wire is replaced by ionized air. Air is a good insulator and a high potential difference, called the breakdown voltage, is required to generate a current. In the case of lightning this can easily be 10.000 volts.

In order to lower this breakdown voltage one can ionize the air by means of a high-power ultraviolet beam. This concept works as follows: The high-power ultraviolet beam strikes the air molecules thus exciting the electrons. The electron that formerly occupied the HOMO (Highest Occupied Molecular Orbital) level of the molecule is no longer bound to the molecule and the oxidation state of the molecule is increased thus generating an ion (Figure 2.3). This way, the laser beam creates a plasma Channel in the air which contains free charge carriers (Figure 2.4). The air has been made conductive and can now serve as a conducting medium just like a metal wire**.**

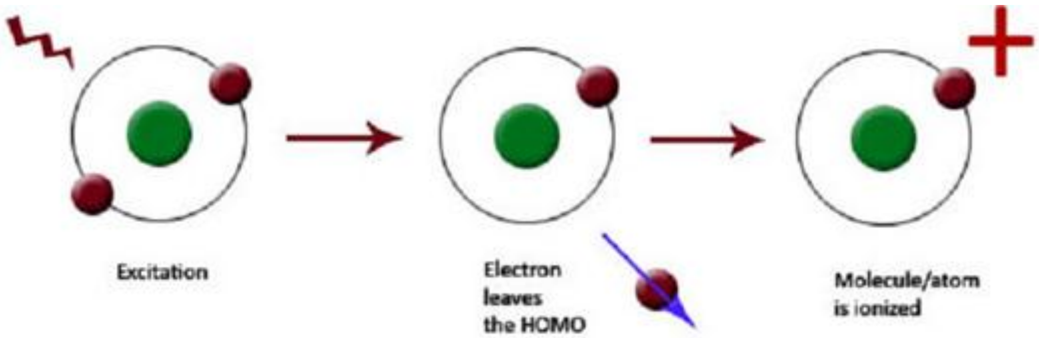


Figure 2.3: In electron in the HOMO is excited by a photon .The electron leaves the molecule thus generating an ion.

In order to actually transmit power, it is necessary to create a loop, so in the case of supplying power through ionized air, actually two paths of ionized air have to be made. It is also possible to connect both sender and receiver to the ground.

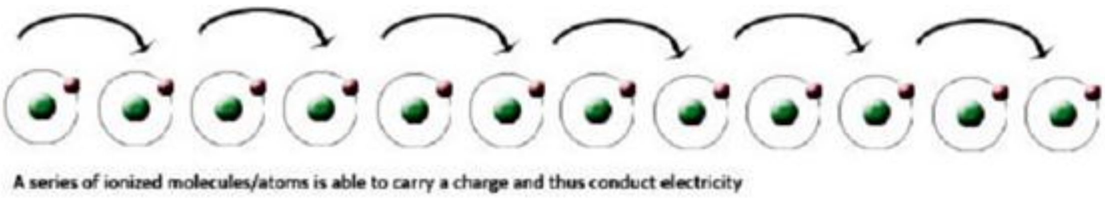


Figure 2.4: Conduction by means of ionized air molecules.

2.5 Evanescent Wave Coupling

Evanescent wave coupling (or "WiTricity"18) is a technique that has recently been investigated by researchers at MIT. The physics behind this technique is rather complicated. At a glance, it basically extends the principle of magnetic induction to mid-range applications up to a few meters. The main difference is the use of resonance; if sender and receiver have the same magnetic resonance frequency, energy can efficiently be transported, while losses to the non-resonant environment are small. Using resonance, for the same geometry, power can be transported approximately 106 times more efficiently than without resonance.

The experimental setup used by the MIT researchers is shown in Figure 5. The coils can be compared to antennas; the electric and magnetic fields produced by antennas can generally be divided into the near field, which is dominant at close ranges, and the far field. The far field, responsible for electromagnetic waves, radiates energy into the environment. The near field does not radiate, so no energy is lost, except when the sender and receiver have the same resonance frequency. In that case energy is transported from the sender to the receiver. The main achievement of the MIT team is to have figured out

how to fine tune the system so that the near field extends to distances of a few meters, simultaneously limiting the power radiated through the far field.

Figure 2.5: A demonstration of power transmission through evanescent wave coupling.

One of the benefits is that most common materials do not interact with magnetic fields, so obstructing objects do not have much influence. This also goes for human tissue and therefore health risks are low. The coils shown above are too large for applications in i.e. a cell phone, but the receiving coil can be made smaller. The researchers state that the transmitted power can be kept constant, if the size of the sending coil is increased to keep the product of the sizes of both coils equal. The efficiency of the above setup is around 40 to 50% for wireless power transfer over 2 meters. However, the efficiency from power outlet to light bulb was 15%, because a ery inefficient component (Colpitts oscillator) was used.

Chapter 3: SYSTEM DESIGN

With all the necessary background research completed it became clear what basic design components the entire system would require. First we needed a method to design an oscillator, which would provide the carrier signal with which to transmit the power. Oscillators are not generally designed to deliver power, thus it was necessary to create a power amplifier to amplify the oscillating signal. The power amplifier would then transfer the output power to the transmission coil. Next, a receiver coil would be constructed to receive the transmitted power. However, the received power would have an alternating current, which is undesirable for powering a DC load. Thus, a rectifier would be needed to rectify The AC voltage to output a clean DC voltage. Finally, an electric load would be added to complete the circuit design.

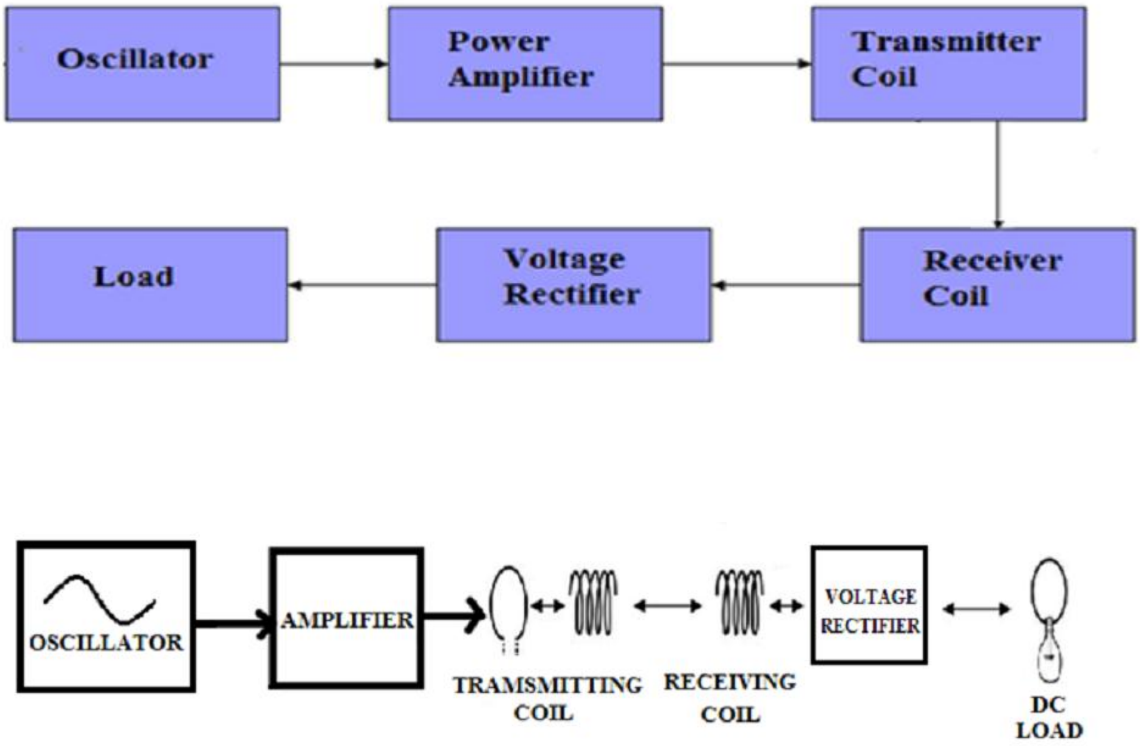


Figure 3.1 block diagram

3.1 OSCILLATOR

There are two general classes of oscillators: sinusoidal and relaxation. Op-Amp sinusoidal oscillators operate with some combination of positive and negative feedback to drive the op-amp into an unstable state, causing the output to transition back and forth at a continuous rate. Relaxation Op-Amp oscillators operate with a capacitor, a resistor or a current source to charge/discharge the capacitor, and a threshold device to induce oscillation. The oscillator design that we utilized was a relaxation oscillator using a single Operational amplifier. This oscillator was a Square Wave Generator and could be classified in the category as an astable multivibrator.

3.1.1 DESIGN

In the design of a Relaxation oscillator, as shown in the figure below, we used a high speed Operational amplifier, AD829, which had a very high frequency response of 120 MHz. The operational amplifier was connected in a Schmitt-trigger configuration with positive feedback through a resistor of 500 Ohms and a variable resistor of 1K.The inverting input for the Op-Amp was biased with a capacitor of 20pF and a resistor of 200 Ohms.

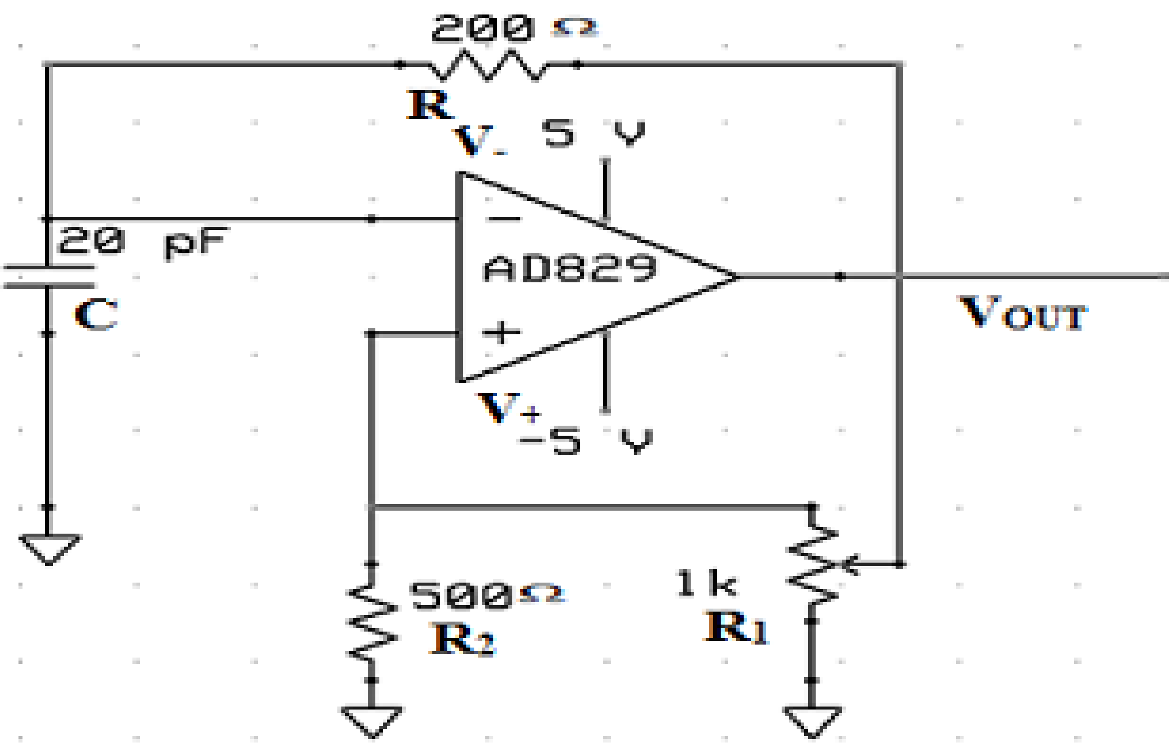


Figure 3.2: Amplifier

WORKING PRINCIPLE:

Initially, the non-inverting input at the Op-Amp is biased at a voltage of VOUT * R2 / (R2 + R1) and the op-amp's output is saturated at that particular voltage level. Since the op-amp always attempts to keep both its inverting and the non-inverting inputs, V+ and V- equal to each other, the feedback causes the 20pFcapacitor to charge and make the value of V- equal to V+. When V- reaches the value of V+, a switch to negative saturation at the output occurs and the capacitor begins to discharge. The charging and discharging of the oscillator effectively causes an oscillating signal to the output.

The general equation for charging a capacitor is given by:

$$q = CV\,(1 - e^{-t/RC}) + q_0 e^{-t/RC}$$

In this case, V is -VOUT, and if the voltage at V+ is called VOUT, q0 becomes CVOUT. The charging equation then becomes

$$q = -CV_{OUT}(1 - e^{-t/RC}) + \lambda CV_{OUT} e^{-t/RC}$$

When q gets to -VOUT, another switch will occur. This time it is half the period of the square wave. Therefore:

$$-\lambda CV_{OUT} = -CV_{OUT}\,(1 - e^{-t/RC}) + \lambda CV_{OUT} e^{-t/RC}$$

Solving for T gives:

$$T = 2RC * \ln[\,\frac{1+\lambda}{1-\lambda}] \quad \text{where} \quad \lambda = \frac{R_2}{R_2+R_1}$$

The frequency of oscillation can be determined by. In our case, the variable resistor R1 could be varied using a 1K pot which was able to tune the frequency from 1.6 MHz to 10.3 MHz.

3.1.2 DESIGN DETAILS

The challenges encountered during the design of the oscillator were the selection of the oscillator design and the Op-Amp chip required to produce a stable and symmetrical oscillating signal. We had experimented with IC Logic chips and low frequency response Op-Amp chips for the design of the oscillator. However, the oscillation signal output from these circuit configurations was not stable or symmetrical. We also initially had problems with distortion of the signal by the unstable power supply from the PCB board and other extraneous noise at high frequencies. We dealt with this problem by neatly laying out the relaxation oscillator circuit using shorter wires and the placing two decoupling capacitors of one microfarads each between the positive and negative power supply to the ground.

3.2 POWER AMPLIFIER

In order to generate the maximum amount of flux which would induce the largest voltage on the receiving coil, a large amount of current must be transferred into the transmitting coil. The oscillator was not capable of supplying the necessary current, thus the output signal from the oscillator was passed through a power amplifier to produce the necessary current. The key design aspect of the power amplifier was to generate enough current while producing a clean output signal without large harmonic distortions. For this purpose, we utilized a simple switch-mode amplifier design whose design aspects are described below.

3.2.1 DESIGN

The main idea behind the switch-mode Power Amplifier technology is to operate a MOSFET in saturation so that either voltage or current is switched on and off. The figure below shows the circuit diagram of the switch-mode power amplifier.

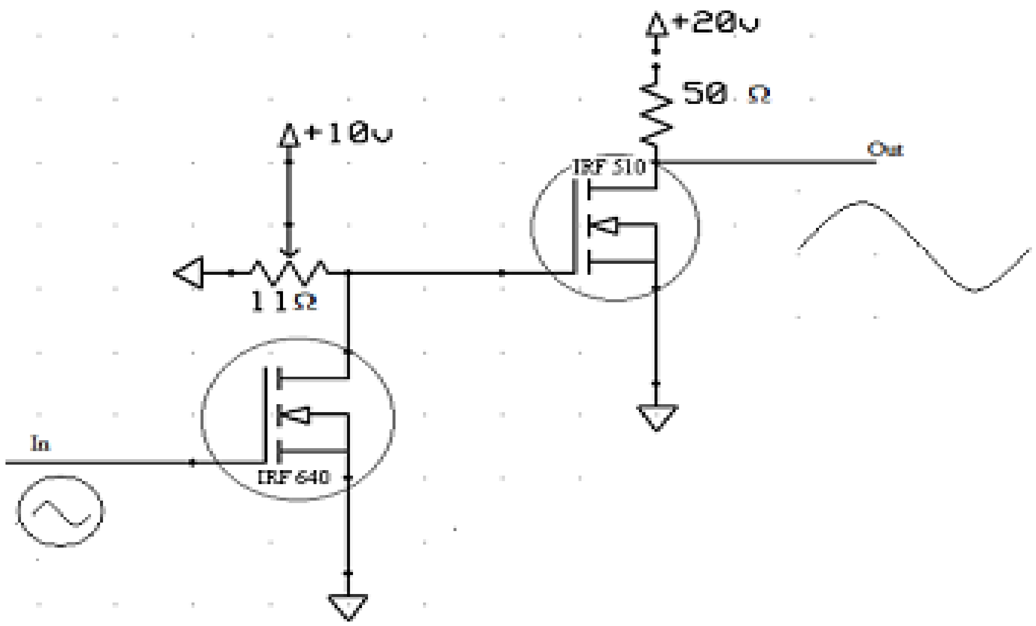


Figure 3.3:oscillator

Our switch-mode design consisted of a MOSFET IRF 510, which when turned on allowed large current from the DC power supply to flow through the resistor of 50 Ohms and through the transmitting antenna to transfer current from the power supply through the transmitting coil. The large current from the transmitting coil was able to generate a large flux to induce a high voltage in the receiving coil. The current and voltage required to drive the gate of the MOSFET IRF 510 was supplied by the MOSFET IRF 640 whose gate was driven by the input signal from a Hewlett Packard signal generator. The maximum voltage when the coils were tuned at resonance was recorded to be around 102.3V.

3.2.2 DESIGN DETAILS

Since our single op-amp relaxation oscillator was using an AD 829 chip, it was not able to source enough current to drive the Mosfet IRF 510 or control the amplitude of the output signal. For this reason, we employed the Hewlett Packard 3310A Function Generator as our oscillator. The signal generator was capable of supplying current and voltage required for driving the gate of the IRF640. Furthermore, using the signal generator, we were also able to set the DC bias voltage and tune the output voltage to get maximum voltage out.

The major challenge while designing the power amplifier circuit was to drive the gate of the Mosfet IRF 510 to switch the Mosfet on. Our initial approach was to design a class D amplifier to drive a H-Bridge3 configuration (which meant driving 4 IRF 510 Mosfet) for an efficient power amplification using a single positive power supply. The H-Bridge 4 required two digital signals that were 180 degrees out of phase with a small dead-time in between the signals. The whole second week we were working on trying to generate these signals as inputs to the H-bridge. In generating these signals, we encountered problems with our comparator chips to output noise free digital signals at high frequency (5 MHz range). Using 2 high speed comparators, LT1016, and introducing terminating resistances (68 Ohm) in series to the output, we were able to output digital signals 180 out of phase with a small dead time for the input to the H-Bridge.

However, the signal output from the comparators as can be seen from the image above was unable to turn the Mosfet IRF 510 on. The comparator could not source enough current to drive the gate of the Mosfet to turn on at a frequency range of around 5 MHz.

3.3 TRANSMITTER AND RECEIVER COILS

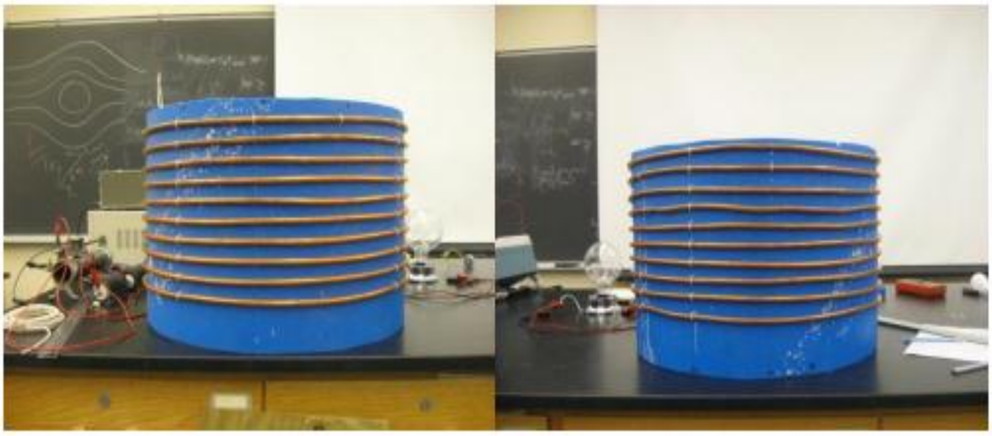
The transmitter and receiver circuit combined is called the coupling circuit. It is the heart of the entire system as the actual wireless power transfer is carried out here. The efficiency of the coupling circuit determines the amount of power available for the receiver system.

3.3.1. DESIGN

The transmitter and receiver coils were designed by former Cornell students, Lucas Jorgensen and Adam Culberson. The coils had a resonant frequency of 4.8 – 5.3 MHz, which could be tuned with our oscillator (later a signal generator) to get to the resonance frequency of the coils. The basic configuration of the design can be seen from the table and the image below.

Transmitting Coil	No of turns	10
	Diameter of each turn	60.32 cm
	Diameter of copper tube	0.95 cm
Receiving Coil	No of turns	10
	Diameter of each turn	60.32 cm
	Diameter of copper tube	0.95 cm
Transmitting Antenna	No of turns	1
	Diameter of each turn	56.1 cm
	Diameter of copper wire	0.23 cm
Receiving Antenna	No of turns	2
	Diameter of each turn	44.6 cm
	Diameter of copper wire	0.23 cm

Table 3.1 : transmitting and receiving elements



Transmitting Coil (with a loop antenna) **Receiving Coil (with 2 loops of antenna)**

Figure.3.4: Transmitting and receiving coil.

3.4 VOLTAGE RECTIFIER:

A rectifier would be needed to rectify the AC voltage received from the receiver coil to drive a DC load. it has some specified DC component is a Full Wave Bridge Rectifier. This type of single phase rectifier uses four individual rectifying diodes connected in a closed loop "bridge" configuration to produce the desired output. The smoothing capacitor connected to the bridge circuit converts the full-wave rippled output of the rectifier into a smooth DC output voltage.

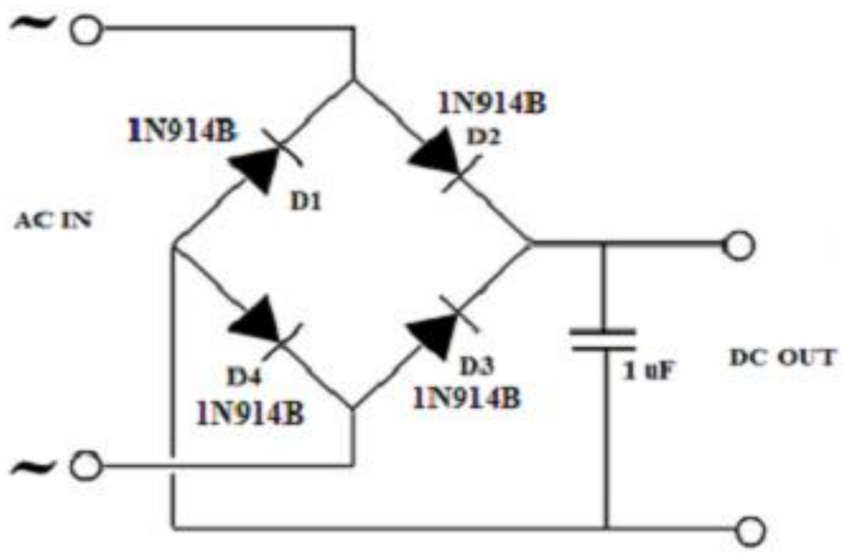


Figure 3.5: voltage rectifier

Since the diodes had to rectify AC signals of Megahertz frequencies, fast signal diodes, 1N914B, had to be used for the bridge circuit. However we did not implement this circuit with our final setup as we did not drive a DC load with our setup.

Chapter 4. All applications

In this chapter, possible applications using wireless power supply are introduced. The applications came up during a brainstorm session. Powercast is an application that is already being developed commercially. The contactless energy desktop application of is based on research currently conducted at Eindhoven University of Technology. All other applications are ideas of our own.

4.1 Combination of wireless power and network

Wireless networks eliminate cables by using radio waves to transfer the data from computer to router. However, the battery life of a laptop is still limited, so there still is the need of carrying a cable for powering the laptop itself. It would be nice to combine these two into one: using the radio waves of a wireless network, not only for internet but also for powering the laptop itself.

4.2 Contactless Energy Transfer Desktop Application

Contactless Energy Transfer (CET) is the process in which electrical energy is transferred between two or more electrical devices through inductive coupling. The CET desktop application is a new development in the area of wireless power transmission, where a table with embedded “power transmitting coils” powers and recharges different electronic devices, which normally need to be charged by Plug & Socket connectors, like cellular phones, music players and laptops . This is done by simply placing them on top of the desk.

The CET desktop uses a matrix of hexagon spiral windings embedded underneath its surface, to transfer power to CET enabled consumer electronics devices placed on the wooden or plastic table. When electronic devices fitted with power receiving coils are placed on the table, the increase in electromagnetic coupling between primary and secondary coils, allows power to be transmitted from the desktop to the devices. To improve efficiency and limit stray magnetic fields, clusters of only three primary coils, located closest to the receiving devices, are excited. The coils are excited with out-of-phase currents to further reduce stray magnetic fields. The power transfer efficiency is not constant but varies throughout the surface of the table, because the magnetic field of a coil is not homogeneous.

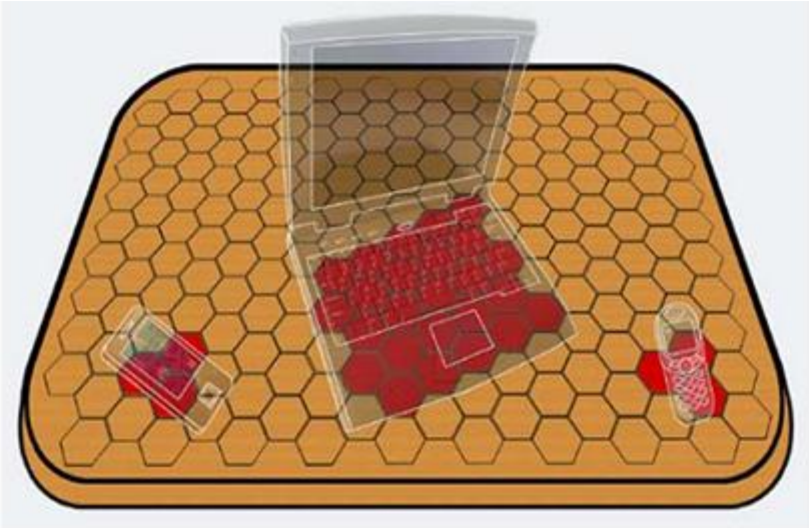


Figure 4.1: The CET desktop application showing activated coils powering the devices placed on table

4.3 Wireless powered LED bicycle lights

Removable LED lights are used worldwide on bicycles that do not have wired lighting. The advantage of these lights is that they do not require a dynamo to power them, because they use batteries. However, the batteries can unexpectedly run out of power and need to be replaced often which is not environmentally friendly. As an alternative a new application, using a dynamo to wirelessly power LED lights using radio waves, is introduced. Because this is one of the applications that were chosen for further research, more information can be found in chapter 6: Wireless Bicycle Lights.

4.4 Wireless powered and controlled laptop screen

A common defect in laptops is that the cable that connects the display is damaged causing the screen to flicker or to go black. Normally this is caused by wear and tear and it has the tendency to occur outside the laptop's warranty. One way to avoid the cable to break is to have no cable at all. As a new application the wireless powering and controlling of a laptop screen is introduced.

Figure 4.2: wireless powered and controlled laptop screen

Since the display is attached to the rest of the laptop via a hinge, it is very close to the bottom part of the laptop. Powering of the display can be easily achieved using mutual induction, a principle that has been very well proven to work for all kind of applications. Controlling the contents on the screen can be achieved using a radio signal. This can be done just like with wireless internet on for instance the 2.45 GHz band.

The application would work the same way as a power transformer: a changing current in the first circuit creates a changing magnetic field; in turn, this magnetic field induces a changing voltage in the second circuit   If the primary circuit (in the laptop bottom part) and secondary circuit (in the display) are very close, which will be the case for this application, a very high efficiency can be achieved. Everything inside a laptop is DC powered. To be able to use mutual inductance, this DC must be inverted to AC first. There are already small inverters around to be able to cope with the 8-10 Watts power requirement 25 of a laptop display26, 27. Depending on the efficiency of the inverter, it could be so that not much extra power is consumed powering a wireless display, compared to powering a wired display.

4.5 Applications using Powercast technology

Powercast is a company that has invented a way to wirelessly transfer energy using radio waves to a so called harvester module. The modules are made to power small devices such as cell phones, lighting, remote controls, sensors and toys. Recently, the first commercial product using Powercast was released, a Christmas tree with wirelessly powered lights. While it is presented as wireless power, Powercast isn't just a replacement for a universal charger. Instead, it is meant to either continuously charge a battery or replace the need for them altogether. It works like this: a transmitter can be placed anywhere. This transmitter sends out a continuous, low radio frequent (RF) signal. Anything with batteries set within its range (and equipped with a Powercast receiver, which is the size of your fingernail) will be continuously charged.

4.6 Solar powered recharging backpack

Currently existing models of backpacks that have flexible solar panels on them use batteries and wires to charge the equipment in them. Wireless power supply could be a nice alternative to charge these electrical devices without the necessity of plugging them in. Just by placing the device inside the backpack, it will be charged.

The distance from the transmitter to the receiver is quite short, therefore mutual induction can be used, but it is also possible to use evanescent wave coupling. It is even possible that energy is shared among various people wearing these backpacks. If for instance a person has excess power, because his devices are already charged, he can share this surplus power with other persons in his vicinity, thus making efficient use of the solar energy harvest.

4.7 Wireless audio speakers

One interesting application is wireless powering of speakers. For example, a typical home cinema set has five speakers, each with its own cable. Installing these cables is quite a hassle, and it often looks very ugly, especially for the rear speakers far away from the receiver unit. Already, a lot of wireless audio sets are available on the market, but these all use batteries for the power. Usually only the two rear speakers are wireless, but even changing only these batteries can be frustrating when the speakers are placed high on the wall. Furthermore you don’t want your system to stop functioning when you are out of batteries, and batteries are quite expensive compared to normal electricity and hazardous to the environment.

The most suitable method of wireless power supply for this application seems to be evanescent wave coupling (WiTricity). It is suitable for distances to a few meters, and has a high efficiency compared to, for example, RF energy that is radiated in all directions. Methods requiring an interrupted line of sight such as laser light are not suitable in a living room setting.

4.8 Wireless powered vacuum cleaner

Vacuum cleaning your floor can be a tedious job, but this can be automated using robotic vacuum cleaners. Current models (Figure 12) use an internal battery and a loading station for power supply. It is however possible to implement a power grid into the floor (Figure 13), similar to the power grid in the CET desktop. At the exact spot where the vacuum cleaner is cleaning, this power grid can be turned on, thus providing power to the cleaner by means of mutual induction.

The contact distance between the floor and the vacuum cleaner is quite short, so a relatively high efficiency is possible. The power level supplied to the cleaner can also be higher than with batteries, thus increasing its cleaning capacity which is of interest for companies (for instance workshops and bakeries) where the floors tend to be filthier as compared to normal households.

4.9 Wireless power-on function

A lot of in-home applications are constantly in standby-mode, waiting for the user to press the power button on the remote control. This consumes a significant amount of power. Also, standby modes increase fire risks. It would be great to let devices have a “passive” standby mode, which uses no power at all but still makes sure the device can be powered on by the remote control. Perhaps, it could be achieved by using the power of the signal sent by the remote control to turn on the device.

Probably the most convenient way of doing this is by installing a RF transmitter in the remote control, and a receiving rectenna in the device. When the signal reaches the rectenna, it induces a current which can be used to change the state of a latching relay. A relay is an electrical switch that opens and closes under the control of another electrical circuit, in this case the rectenna. A latching relay differs from a normal relay in that it has two relaxed states, so that you don’t need a constant current to keep the switch turned on. This way, a single pulse is enough to turn the device on or off.

Chapter 5. : RESULTS AND MEASUREMENTS:

At a distance of 0.18 cm between the two coils, we were able to transmit enough power to power a 40 W light bulb. As the distance of separation between the coils was increased, the bulb got dimmer. It was evident from this simple experiment itself that the power ransmitted was related to the distance of separation between the coils.

To demonstrate the presence of evanescent waves being produced which transferred power from the transmitter coil to the receiver coil, we measured the voltage across the 40 Watt light bulb at varying distances and orientations. We took measurements starting at a distance of 0.5 m between the coils in 10 cm increments up to a distance of 2 m of separation. We found that the resonant frequency changed with distance due to the imperfect match in the resonant frequencies of our coils. The frequency was then adjusted to find the maximum output voltage at every measurement.

PARALLEL CONFIGURATION:

The coils were arranged in the configuration as shown below and voltage measurements were taken as a function of distance between the coils.

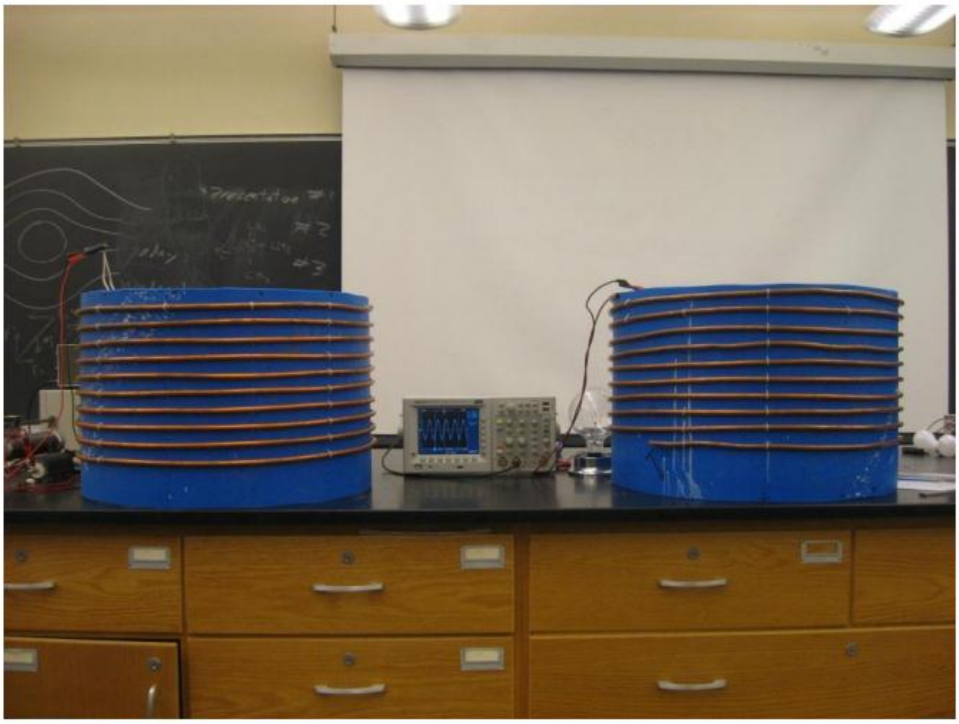


Figure 5.1: parallel configuration configuration.

Based upon the data we collected, the following graph shows voltage as a function of distance between the coils.

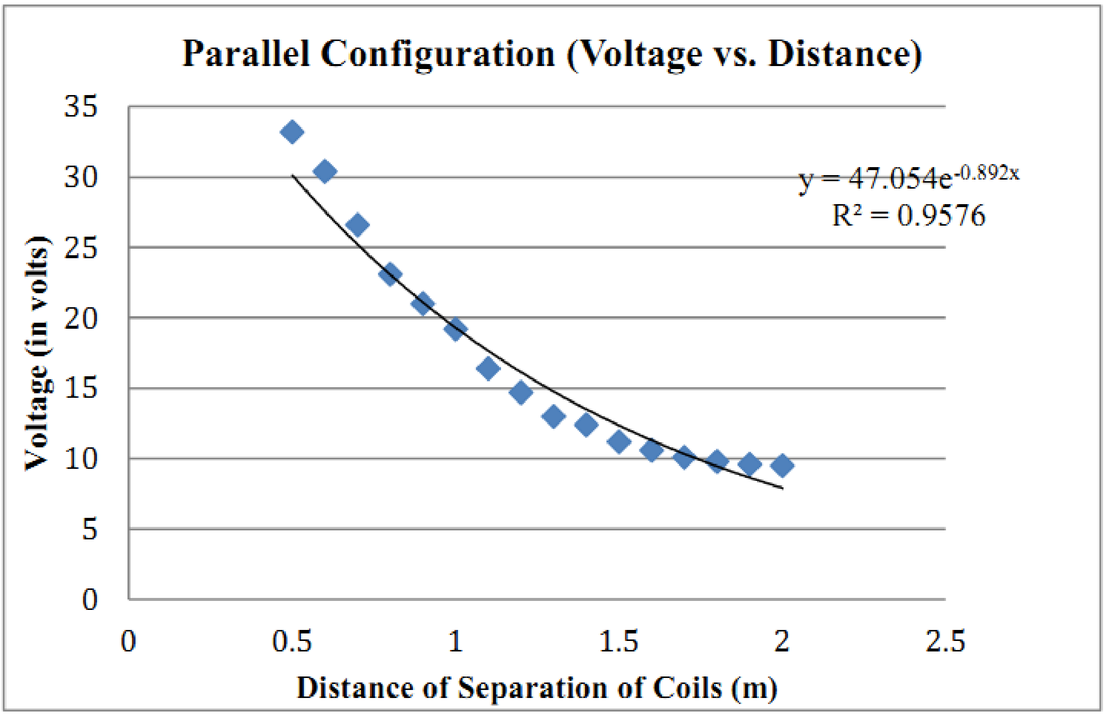


Figure 5.2: characteristic of parallel configuration.

Since the coefficient of determination (R2) has a value close to 1 for the exponential fit, the data points were strongly exponentially correlated. In other words, the voltage decayed exponentially as the distance of separation between the coils was increased. This illustrates the theory of power transmitted through evanescent waves that decay exponentially as the distance between the coils was increased.

Similar observation of exponential fit was observed when the coils were faced perpendicular to each other as shown below.

PERPENDICULAR CONFIGURATION:

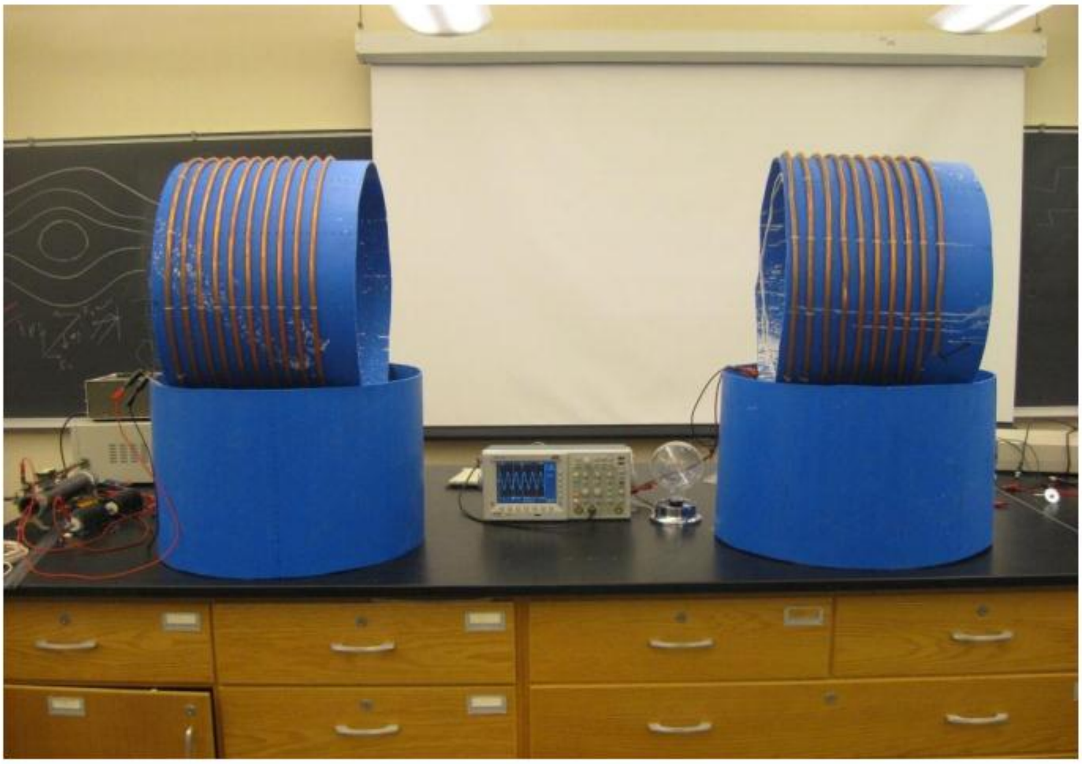


Figure: 5.3: perpendicular configuration.

Based upon the data we collected, the following graph shows voltage as a function of distance between the coils.

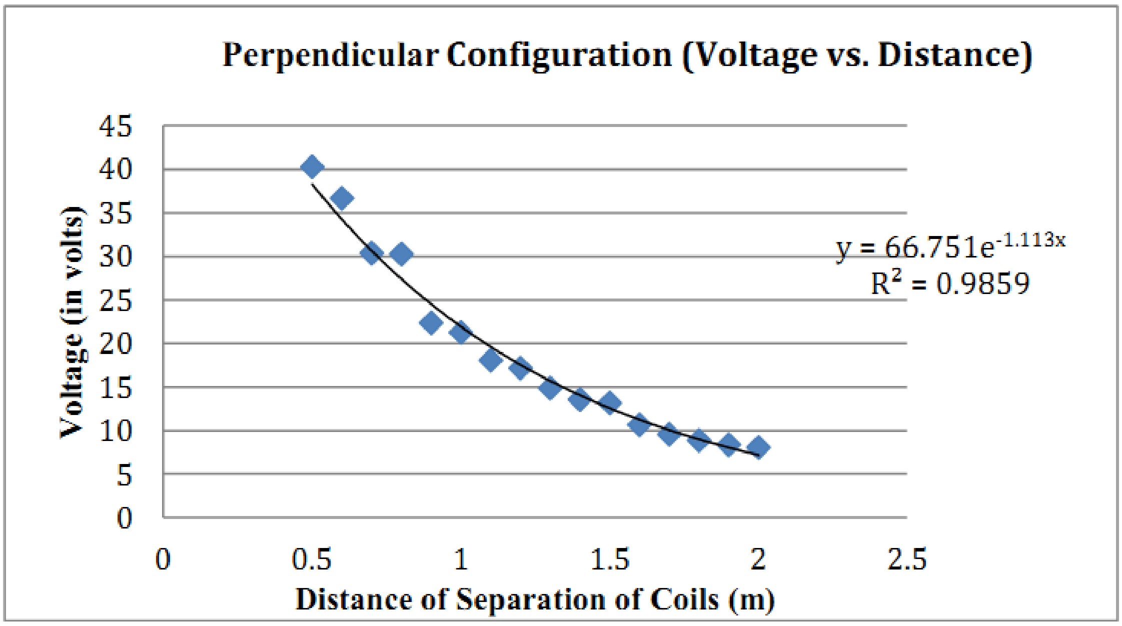


Figure 5.4: characteristic perpendicular configuration.

In this case, the value of the coefficient of determination (R2) is closer to 1 than when the coils were placed parallel to each other. The strong exponential correlation in this case also illustrates the exponential decay of evanescent waves propagating from the transmitting coil to the receiving coil.

Chapter : 6 Standby Saver

The Standby Saver application eliminates the need for standby power of devices like televisions. The idea is to use the energy contained in an RF pulse, sent by the remote control, to power a switch that turns the device on.

6.1 Technological design

The basic design includes a transmitting antenna in the remote control, a receiving rectenna, and a latching relay connected to the latter. This is pictured in Figure 14. Instead of pressing the “hard” power button, one can now use the remote to completely turn the device on or off and save power this way. This is a slight improvement of user-friendliness.

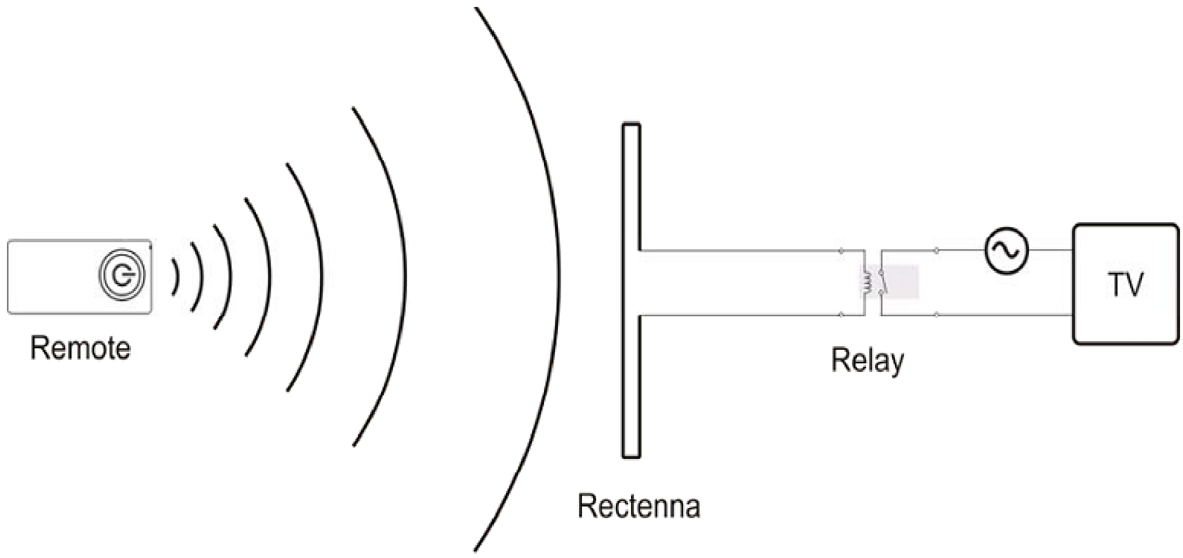


Figure 6.1: Schematic setup of the Standby saver. When the latching relay switches due to a power pulse received by the rectenna, the TV is connected to outlet power and turns on.

It is of course important that the amount of power that is received by the rectenna, is enough to switch the relay. In order to switch, a typical latching relay needs at least 90 mW of power, during a pulse period of 3 ms. The power transferred from one antenna to the other is given by the Friis transmission equation:

$$P_r = P_t \frac{G_t G_r \lambda^2}{(4\pi r)^2}.$$

In this equation, Pr is the received power, Pt is the transmitted power, r is the distance between transmitter and receiver, λ is the wavelength and Gt and Gr are the antenna gains of the transmitter and receiver, respectively. This equation assumes optimal alignment of the transmitter and receiver. The antenna gain says something about the directivity of the antenna. A gain equal to 1 means isotropic radiation in all directions (or reception from all directions for receiving antennas), a higher gain means the power distribution is more focused. The antenna gain is given by:

$$G = \frac{4\pi}{\lambda^2} A_e = \frac{4\pi}{\lambda^2} \varepsilon_{ap} A_p .$$

Here, Ae is the effective aperture of the antenna, which is equal to the aperture efficiency times the physical area of the antenna Ap. The directivity of an antenna a thus increases with frequency (decreases with wavelength). The aperture efficiency of a typical antenna is approximately 0.5. Equation (1) can now be written as:

$$P_r = \eta P_t \frac{A_{p,t} A_{p,r}}{4r^2\lambda^2},$$

where the extra η factor accounts for the conversion efficiency of the rectenna. Thus, to optimize power transfer, the antennas should be made as large as possible, and the frequency as high as possible. However, when the frequency becomes too high, the antenna becomes too directive, making it harder for the user to point the remote control correctly. A reasonable size for the antenna in the remote control could be 3cm x 1cm. The one in the television could be larger, say 10cm x 50cm. A reasonable frequency is 5.8 GHz, which is a license-free ISM-band. If we assume 5 meter distance between sender and receiver, and incorporate the limited conversion efficiency of the receiving antenna (η = 83% for printed dipole rectennas, it can be calculated that the following power is required at the transmitter:

$$P_t = \frac{4P_r r^2 c^2}{\eta A_{p,t} A_{p,r} f^2} = \frac{4\cdot 90\cdot 10^{-3}\cdot 5^2\cdot \left(3\cdot 10^8\right)^2}{0.83\cdot 0.03\cdot 0.01\cdot 0.1\cdot 0.5\cdot \left(5.8\cdot 10^9\right)^2} = 1934\text{W} .$$

This is a very high power level for a battery-powered device. But this amount of power is only required for 3 milliseconds. A solution could therefore be to divide the radiated energy over a larger amount of time. For example, 500 milliseconds at 11.6 watts yields the same energy as 3 milliseconds at 1934 watts. A capacitive element between rectenna and relay, could accumulate this energy and discharge with a 3 millisecond pulse. This could however lead to additional losses. Summarizing, this application could be possible at 5.8 Ghz, with pulses of 500

milliseconds at about 12 watt input power. However, in practice the power requirement may be higher because of additional losses which are not accounted for in the above discussion. Also, the user has to point the remote control correctly for half a second. On the other hand, it may be possible to optimize relays to have minimal power requirements, which could again decrease the power needed.

6.2 Environmental analysis

The power saved by the Standby Saver will of course be an improvement to the environment. Currently standby-leakages contribute to 5% of the total domestic power use in developed countries, thereby using 45 billion kWh of electricity per year in the United States alone. Leaking electricity will account for 90% of the increase of CO_2 emissions from offices and households between 1990 and 2010. Strong reduction of this type of energy wastage will both save the environment as well as reduce the operating costs of various domestic electric devices.

The standby power used, varies widely among different modern TV's, from a modest 0.31 Watt to an astonishing 76.11 Watt. Average standby power of a TV is estimated at 1.9 Watt. The average standby energy consumption of TV's in households is 21.1 kWh/year. This is not much for a single household, but summed over all households and all other devices, it does become significant.

However, the Standby Saver will draw more power from batteries than a regular remote control. By still using infrared signals, or low power RF signals, for the functions to be performed when the device is on, this extra power is limited. The energy needed for one on/off switch is 0.5 Joule. The energy contained in two alkaline AA batteries (typical for a remote control) is 30.8 kJ s 12W=6 × 52. Hence, ideally, one could turn a TV on or off more than 5 thousand times before replacing batteries. So, because the on/off button is used much less frequent than the other buttons, the extra battery use is negligible.

One must however keep in mind that the Standby Saver is not suitable for all electronics that have a standby mode, but only for ones with a remote control. Also, some devices can lose some functionality when not used in standby mode, like VCRs that use a timer. So relative to the total standby power consumption, only a small fraction is removed.

Furthermore, implementing this technology in current electronic household devices is probably not possible since it requires the replacement of current circuitry, which is too expensive to be beneficial. Hence, only new products can be equipped with this feature. Summarizing, we have to realize that if this application would become common in new televisions, only a very slight reduction in domestic power use will probably be noticeable, over several years of time.

6.3 Health hazards

In the past, numerous studies have been carried out on the possible health hazards of RF radiation. There are a few different ways by which non-iozing electromagnetic radiation can be hazardous.

The predominant effect of exposure to RF fields is the heating of body tissue as energy is absorbed by the body. Prolonged exposure to strong RF fields may increase the body temperature, producing symptoms similar to those of physical activity. In extreme cases, or when exposed to other sources of heat at the same time, the body's cooling system may be unable to cope with the heat load.

Thermal effects include heat damage to organs which have poor temperature control, such as the lens of the eye and the testes, skin burns, deep burns, tissue damage, heat exhaustion, heat stroke, decreased ability to perform mental or physical tasks and even birth defects.

Besides thermal effects, one of the most important issues to be considered is the possibly increased risk of cancer by exposure to radiofrequencies. Most epidemiological studies have found no significant correlation between exposure to radio frequency radiation and an increased risk of cancer. There is also no replicated evidence of DNA or repair damage due to RF exposure. Most of RF studies concluded that RF exposure is not genotoxic or mutagenic.

The nature and the degree of the health effects of overexposure to RF fields depend on frequency, intensity of the fields, duration of exposure and distance from the source.

As mentioned before, the most problematic effect of RF radiation on the body is the heating effect. A measure that is often used in this context is the Specific Absorption Rate (SAR), which is the power absorbed by the body per unit mass. At an exposure to electromagnetic radiation in the frequency range 10 MHz to a few GHz at a SAR value of 4 W/kg for 30 minutes, the body temperature can increase with almost 1 degree Celsius. This result was found from a study with volunteers.

In terms of tissue properties, the SAR value can be defined as:

$$SAR = \frac{\sigma E_{\mathrm{rms}}^2}{\rho} = \frac{\sigma E_{\max}^2}{2\rho} .$$

In this formula, SAR has units W/kg, σ (S/m) is the electrical conductivity of the absorbing tissue per meter, ρ (kg/m) is the mass density and Erms is the root-mean-square value of the electric field, which is equal to ½ 2 Emax, where Emax is the amplitude of the electric field.

From the intensity of an isotropic radiating source:

$$I = \frac{c\varepsilon_0\varepsilon_r E_{\max}^2}{2} = \frac{P}{4\pi r^2},$$

The amplitude of the electric field can be calculated:

$$E_{\max} = \sqrt{\frac{P}{2\pi c\varepsilon_0\varepsilon_r r^2}}.$$

Here, I is the intensity, c is the speed of light, ε0 is the permittivity of free space, εr is the relative permittivity, Emax the amplitude of the electric field, P the power of the source and the distance to the source. So the SAR value can also be written as:

$$SAR = \frac{\sigma P}{4\pi\rho c\varepsilon_r\varepsilon_0 r^2}.$$

For a male human, the average density ρ is approximately 1070 kg/m3. The speed of light c =3·108 m/s and the permittivity of free space is ε0 = 8.85 · 10−12F/m. The parameters σ and εr depend strongly on the type of tissue, and the frequency. To determine the SAR value for the entire human body, an average has to be found for these parameters. In Appendix A, we have made a calculation of the average σ and εr; the results are σ = 3.87 S/m and εr = 36.9.

	ACA (Australia)	FCC (USA)	ICNIRP (Europe)	MPTC (Japan)
	ARPANSA	C95.1	EN50361	ARIB
Whole body exposure, (W/kg)	0.08	0.08	0.08	0.08
Partial body exposure, (W/kg)	2	1.6	2	2
Average time (m)	6	30	6	6

Table 6.1: SAR limits for unaware exposure of the general public, according to several international organizations.

In Table 2, a distinction is made between the limits of average exposure of the entire body, and the exposure of only a part of the body. For the remote control application, we estimate that on average, the body is 0.4 m, and the part closest to the transmitter (the thumb) at 0.02 m. Using the input power of 12 Watts proposed in section 5.1, the whole body and partial body SAR during the transmission of the pulse would become 0.22 W/kg and 88 W/kg, respectively. However, the SAR limits are defined as an average over 6 minutes (in Europe).

Assuming that you will not press the power more than once in six minutes, the SAR values have to multiplied by (0.5 seconds / 6*60 seconds). This yields 0.00031 and 0.12 W/kg, respectively, which is well below the allowed values. The SAR will still be in compliance with regulations if used up to 16 times in the six minutes averaging time.

In the above calculation, the transmitter is assumed to be a perfectly isotropic source. This is obviously not the case in our application, because the beam is made more directive. If the user is outside the directive beam, the SAR value will be lower than calculated. Only if the user is in the course of the directive beam, the SAR will be higher. Based on this, we can conclude that there are no health hazards caused by this application, because the SAR value is below allowed safety values. As said before, effects other than body heating have never been consistently proven, so that is not something to worry about either.

6.4 Economic aspects

Batteries are more expensive than electricity from the power grid. This is mainly because of the cost of producing batteries and the materials involved. Even though they can be two thousand times more expensive, consumers still use them in cases where it is impossible or very inconvenient to use the power grid. This influences both our applications, as in the bicycle lights we are replacing batteries, while in the power-on function there will be a bigger drain on the batteries in the remote control.

The standby function on electrical devices, such as TVs, computers and video and DVD players uses a lot of electric energy. As mentioned before the average standby energy consumption just for TV's in households is 21.1 kWh/year. At an energy cost of € 0.20 per kWh, this means that just € 4.20 is lost. As there are seven million households in the Netherlands, this is still almost thirty million euros in the Netherlands. An earlier calculation shows that on normal batteries, the application can be used 5000 times before the batteries run out. This puts very little extra drain on the batteries. It can be concluded that though the price of batteries is approximately two thousand times the power grid price, battery use will not stop customers using this application.

The antenna in the remote control will take up physical space. This will make the remote bigger and more expensive to make also increasing the price at which consumers buy the TV. This is even more true for the receiving antenna circuit in the TV. Compared to the total price of a TV, the extra costs for antennas will not have a large influence.

In conclusion, the TV will become more expensive because of more materials that are used and using the Standby Saver will save also a little money. But this will not be the deciding factor in buying one; the environmental aspects will be of more in

Chapter 7. : CONCLUSION AND FUTURE WORK:

At the end of the research, we were able to design a system for transmitting watts of power wirelessly from the transmitting coil to the receiving coil that was enough to light a 40W bulb. We were able to design discrete components such as the relaxation oscillator, switch mode-power amplifier and a full bridge voltage rectifier for the system design process. We also managed to demonstrate evanescent waves by measuring exponential decay of voltage as an increase in distance between the transmitter and the receiver coils.

There can be significant research work that can be done in the future of this research. Future work includes connecting the relaxation oscillator with the power amplifier using current amplifier chip for providing enough current to drive the gate of the MOSFET to drive the efficient class D H-Bridge power amplifier. Also, reduction in the size of the transmitting and receiving coils and utilizing the regulated signal to power a DC load could be something that could be worked in the future as a means to make this system feasible for practical applications.

CHAPTER 8: REFERENCES:

8.1 ORIGINAL MIT PAPER:

[1]Andre Kurs, Aristeidis Karalis, Robert Moffatt, J. D. Joannopoulos, Peter Fisher, Marin Soljacic. 2008. Wireless Power Transfer via Strongly Coupled Magnetic Resonances.Science.

http://www.sciencemag.org/cgi/rapidpdf/1143254?ijkey=94ff.Ay4jRMqU&keytype=ref&siteid=sci (accessed December 5, 2011).

8.2 LINK TO THE PROJECT BY ADAM AND LUCAS:

[2]http://www.cornellcollege.edu/physics/courses/phy312/Student-Projects/Magnetic-Resonance/Magnetic-Resonance.html

8.3 THEORY AND COMPONENTS DESIGN:

[3] G. L. Peterson, "THE WIRELESS TRANSMISSION OF ELECTRICAL ENERGY," [online document], 2004, [cited 12/10/04], http://www.tfcbooks.com/articles/tws8c.htm

[4] U.S. Department of Energy, "Energy Savers: Solar Power Satellites," [online document] rev 2004 June 17, [cited 12/10/04], http://www.eere.energy.gov/consumerinfo/factsheets/l123.html

[5] S. Kopparthi, Pratul K. Ajmera, "Power delivery for remotely located Microsystems," Proc. Of IEEE Region 5, 2004 Annual Tech. Conference, 2004 April 2, pp. 31-39.

[6] Tomohiro Yamada, Hirotaka Sugawara, Kenichi Okada, Kazuya Masu, Akio Oki and Yasuhiro Horiike,"Battery-less Wireless Communication System through Human Body for in-vivo Healthcare Chip,"IEEE Topical Meeting on Silicon Monolithic Integrated Circuits in RF Systems, pp. 322-325, Sept. 2004.

[7] "Category: Radio spectrum -Wikipedia, the free encyclopedia," [online document], 2004 Aug 26 [cited 12/11/04], http://en.wikipedia.org/wiki/Category:Radio_spectrum.

[8] Zia A. Yamayee and Juan L. Bala, Jr., Electromechanical Energy Devices and Power Systems, John Wiley and Sons, 1947

[9] "The Spark Transmitter. 2. Maximizing Power, part 1. " November 2004,http://home.freeuk.net/dunckx/wireless/maxpower1/maxpower1.html.

[10] R. Victor Jones, "Diode Applications," [Online Document], 2001 Oct 25, [cited 2004 Dec 11], http://people.deas.harvard.edu/~jones/es154/lectures/lecture_2/diode_circuits/diode_appl.html.

[11] Central Semiconductor Corp, “PNP Silicon Transistor”, November 2004,http://www.semiconductors.philips.com/acrobat_download/datasheets/2N2222_CNV_2.pdf.

[12] Neha Bagga, Joshua Gruntmeir, Samuel Lewis, “Wireless Power Transmission”, Dec.2004.