Acknowledgements

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Lastly,and most importantly,we wish to thank our parents,they raised us,supported us,taught us and loved us.To them we dedicate this thesis.

Abstract

Different aspects of Wireless Power Transmission(WPT) is the prime subjects in this thesis.In this thesis various means and ways of wireless power transfer are described.

The main difficulty of wireless power transfer is it's low range and low efficiency.The factors that are responsible for low range and low efficiency are analyzed in this thesis and probable solution to these problems are proposed with mathematical analysis.The necessity and advantage of wireless power transfer are also mentioned in this thesis.The Solar Power Satellites (SPS) system which is a probable solution to future energy crisis is also described briefly in this thesis.The bio-effect of wireless power transfer is also mentioned.

Based on mathematical treatment a simple project is done.In this project LED is lighted wirelessly with a few distance from source.

Finally a mobile phone charger is designed that can charge a mobile phone without direct contact with the source.

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Chapter 1

Introduction

The definition of Wireless Power Transmission (WPT) is: efficient transmission of electric power from one point to another trough vacuum or an atmosphere without the use of wire or any other substance. This can be used for applications where either an instantaneous amount or a continuous delivery of energy is needed, but where conventional wires are unaffordable, inconvenient, expensive, hazardous, unwanted or impossible. The power can be transmitted using microwaves, millimeter waves or lasers. WPT is a technology that can transport power to locations, which are otherwise not possible or impractical to reach.

There are 3 major types , each with different ranges, methods of transfer, and pros and cons:

– Short range; Inductive Coupling
– Medium range; Resonant Induction
– Long range; Electromagnetic Wave Power Transfer

The efficiency of an energy transferring system is the percentage of energy sent which reaches the destination. Sending energy through wires is often more efficient because wires represent a low loss way to confine and guide the energy to where it is needed. Still, generally, wireless energy transfer works very well at short range; and efficient long-distance transfer is possible if the transmitters and receivers are physically large, or if the energy can be formed into a tight beam.

A great concern has been voiced in recent years over the extensive use of energy, the limited supply of resources, and the pollution of the environment from the use of present energy conversion systems. Electrical power accounts for much of the energy consumed. Much of this power is wasted during transmission from power plant generators to the consumer. The resistance of the wire used in the electrical grid distribution system causes a loss of 26-30% of the energy generated. This loss implies that our present system of electrical distribution is only 70-74% efficient. There are areas of the World where the need for electrical power exists. Yet there is no method for delivering power. Africa is in need of power to run pumps to tap into the vast resources of water under the Sahara Desert. Rural areas such as those in China require the electrical power necessary to bring them into the 20th Century and to equal standing with Western nations.

Space Solar Station can provide a great advantage in minimizing the future energy crisis.Here solar plant will be set at satellite and electrical energy will be transmitted wirelessly,in ground receiving station will receive power.In limited range application mobile phone,laptop etc can be charged without plugged in.This eliminate extra wire.

The main problem of WPT system now is it’s limited range and system efficiency.The power diminishes tremendously at a short distance and efficiency is also very low.So the main problem is to increase range range and efficiency and also reduce overall cost.

1.1 Review of Previous Work

Maxwell's theory of electromagnetism, published in 1865 mentions electromagnetic waves moving at the speed of light, and the conclusion that light itself was just such a wave. In 1886 Hertz performed a successful experiment with pulsed wireless energy transfer. He produced an apparatus that produced and detected microwaves in the UHF region. Also Tesla did experiments in the field of pulsed wireless energy transfer in 1899. Tesla's Magnifying Transmitter, an early type of Tesla Coil that measured 16 meters in diameter, could transmit tens of thousands of watts without wires.

Tesla supposedly managed to light 200 lamps, without wires, from 40 kilometers away. No documentation from Tesla's own records has been published validating that this actually happened. In 1897, he filed his first patents dealing with Wardenclyffe tower. This aerial tower was meant to be a pilot plant for his “World Wireless System” to broadcast energy around the globe. The core facility was never fully operational and was not completed due to economic problems . The Raytheon Company did the first successful WPT experiment in 1963.

In this experiment energy was transmitted with a DC-to-DC efficiency of 13%. This company also demonstrated a microwave-powered helicopter in 1964 . The Jet propulsion lab of NASA carried out an experiment and demonstrated the transfer of 30 kW over a distance of 1 mile in 1975. They used an antenna array erected at the Goldstone facility. This test demonstrated the possibilities of wireless power outside the laboratory. Rockwell International and David Sarnoff Laboratory operated in 1991 a microwave powered rover at 5.86 GHz. Three kilowatts of power was transmitted and 500 watts was received .

In 2006, exactly 100 years after Tesla laid off his employees on Long Island, another immigrant from Croatia surprised America with a proposal for sending power through the air. Physicist Marin Soljacic, along with several of his colleagues at MIT, performed a theoretical analysis of a system for projecting useful amounts of power wirelessly using electromagnetic induction, a phenomenon that's been well known since Michael Faraday first described it in the early 19th century.

In 2007, Marin Soljacic led a five member team of researchers at MIT (funded by Army Research Office, National Science Foundation and the Department of Energy) and experimentally demonstrated transfer of electricity without the use of wires. These researchers were able to light a 60W bulb from a source placed seven feet away, with absolutely no physical contact between the bulb and the power source.

The first copper coil (24 inches in diameter) was connected to the power source and the second was connected to the bulb, and were made to resonate at a frequency of 10 MHz. The bulb glowed even when different objects (like a wooden panel) were placed between the two coils. The system worked with 40% efficiency and the power that wasn't utilized remained in the vicinity of the transmitter itself, and did not radiate to the surrounding environment.

1.2 Thesis Objective

Study of different theories and strategies of electromagnetic fields and waves and apply these theories and strategies to the implementation of wireless power transfer is the main objective of our thesis.

The main problem of WPT system now is it's limited range and system efficiency.The power diminishes tremendously at a short distance and efficiency is also very low.Observation of different facts that are responsible for attenuation of electromagnetic fields and low efficiency of wireless power transfer is also an objective of our thesis.

Finally our objective is to design an wireless mobile phone charger.

Chapter 2

Inductive Coupling

Inductive Coupling is a method for short range wireless energy transfer. Its range can vary, but it’s often very short. Because of its short range it usually is used when the device containing the receiver and the device containing the transmitter are touching.

Inductive coupling works on the principles of electromagnetism :When a current (electricity) passes through a wire, it generates a magnetic field perpendicular to the wire. This effect can be magnified through coiling the wire When a wire is in proximity to a magnetic field, it generates a current in that wire.Transferring energy between wires through magnetic fields is inductive coupling Magnetic fields decay quickly , making inductive coupling effective only at very short ranges.

2.1 Basic Concept

The contactless coupling induction system is based on the electromagnetic induction coupling concept in which current and electromagnetic field transmission of primary side coil to independently isolated equipments. The theories are based on Faraday’s Law and Ampere’s Circuital Law. This type of transmission power and energy from the electromagnetic field is similar to theoretic basis as wireless microwave transmission. The only difference in wireless microwave transmission is higher frequency and lower energy while in the contactless power transmission system.

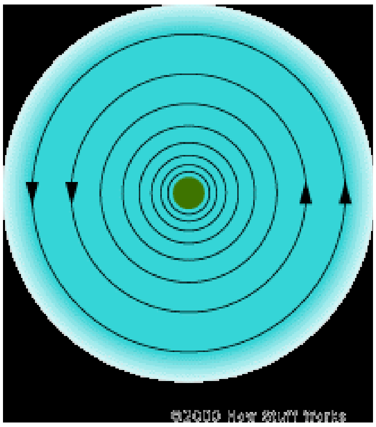

Figure 2.1: Magnetic field around a current carrying conductor

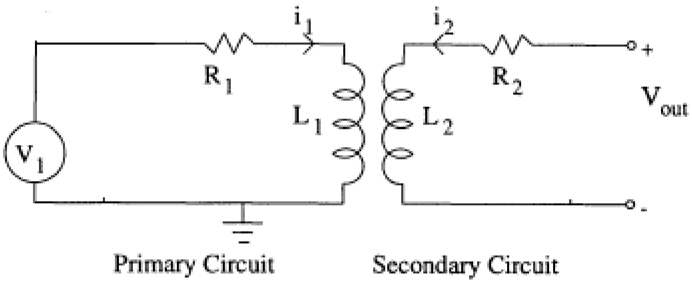

Figure 2.2:Two coil with inductive coupling

2.2 System Design

The structure of the primary side and the secondary side of the contactless power transmission system is shown in Fig. 2.2. The primary side includes three parts: power source, controller, and converter. The converter frequency design is set such that it ensures maximum transmission power. The controller offers detection and protection functions during abnormal conditions such as over-current and circuit shortage. The current of the primary input passes through track transmission to produce litz wire and secondary side induction. According to Ampere's Law, a litz wire is produced in the peripheral of the conductor. If the iron core of secondary output is setup nearby the conductor and also according to Faraday's Law, voltage will be induced by secondary output.Voltage induced by secondary winding is converted to DC voltage by the converter. Finally, it is added to load output.

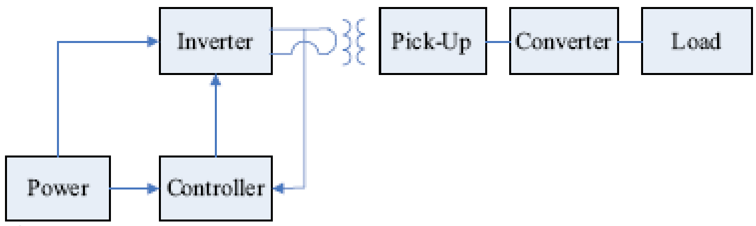

Figure 2.3: Contactless power transmission system using Inductive coupling

Contactless power transmission system design steps and processes are conducted based on the flowchart in Fig. 2.3.

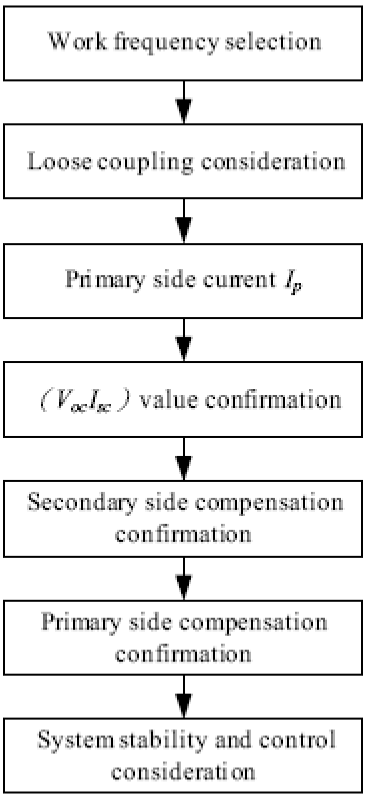

Fig.2.4: Design flowchart of the contactless power transmission system

Designs of respective processes are described below :

A. *Selection of frequency*

System working frequency selection is the first step in contactless power transmission design. Therefore, work frequency is selected based on present power electronic technique standards, power components and related system design experiences. In terms of the presents power electronic technique standards and system costs, selection of frequency between 10 kHz ~ 100 kHz is more reasonable.

B. *Loose* coupling consideration

At present, the widely adopted transformer is tight coupling model since it is likely to be limited by existing iron core material and structure. However, the contactless power transmissions system adopts loose coupling inductance. It is less likely to be limited by iron core structure. Since loose coupling inductance is selected based on related design experiences. After confirming the structure of loose coupling inductance device, basic parameters should be set such as primary input and secondary output coil inductance volume, coupling coefficient, mutual inductance and so on.

C. *Primary side current Ip selection*

In the contactless power transmission system, transmission electrical energy size, and primary input power source transformer structure are closely related to current Ip. Generally, Ip selection begins from smaller value of currents. After calculation, when Ip value of current fails to meet system electrical energy transmission requirements, value of current can be further increased.

D. *Voc and Isc value confirmation*

Based on electromagnetic device selected, when using Ip selected from primary side current, the open circuit voltage Voc and short circuit Isc are tested. During experiment conduction, avoid inadequate rated current of pickup coil which might cause the instability to perform action.

E. *Second side compensation confirmation*

When secondary side circuit is not compensated, load is able to attain the maximum power transmission which is equal to VocIsc/2. If load required power value is exceeded, the secondary side needs to adopt compensated circuit. The quality factor of the compensated circuit is calculated as shown below.

$$Q_s = \frac{P}{V_{oc} I_{sc}}$$

where P is the transmission power at the load end. The secondary side required V.A rate is shown below.

$$S_s = P\sqrt{Q_s^2 + 1}$$

If the rate of the secondary side, V. A, is higher than the value of quality factor; the system will be able to transmit the required power. If the opposite is true, the design will not be able to transmit required power P. In that case, the design has to be adjusted to enhance the power transmission capability. After secondary side coil rated meets design requirements,the next step is to confirm secondary side compensated circuit and topology adopted. The selection of compensated circuit topology is determined by application. Parallel compensation current source features are suitable for battery charging site;

series compensation voltage source features are more suitable for electrically-driven power supply sites.

F. Primary side compensation confirmation

The transmission power is divided by the V.A rated to derive the quality factor Qp of primary side coil. As mentioned, the primary coil compensated circuit is also determined by application. When primary side coil adopts longer cables, series compensation adoption is preferable; when primary side coil is in concentrated winding, parallel compensation adoption is preferable.

G. System stability and control consideration

If Qp < Qs, stability analysis should be conducted on the system. If system cannot guarantee stability control under all work conductions, the system parameters must be adjusted. Common methods include increasing primary side coil current, improving loose coupling inductance device structure or changing system work frequency etc.

2.3 Applications for Inductive Coupling

Radio-Frequency Identification (RFID) tags are a widespread use for inductive coupling. These tags are used for everything from identifying livestock to anti-theft mechanisms on products in stores.

Inductive coupling is also used for wireless charging of electronic devices. Although its short range is limiting, several products use inductive coupling to charge, such as electric toothbrushes , and charging mats such as Splash power .

2.4 Limitation of Inductive Coupling

Magnetic fields decay quickly , making inductive coupling effective only at very short ranges.

Chapter 3

Resonant Induction

Resonant induction still uses the same principles as magnetic induction (magnetic fields to transfer current) , but it uses resonance to increase the range at which the transfer can efficiently take place . Everything resonates at a certain frequency, based on its shape and material. Two resonant objects of the same resonant frequency tend to exchange energy efficiently, while interacting weakly with extraneous off-resonant objects. Imagine a room with 100 identical wine glasses, each filled with wine up to a different level, so they all have different resonant frequencies. If an opera singer sings a sufficiently loud single note inside the room, a glass of the corresponding frequency might accumulate sufficient energy to even explode, while not influencing the other glasses.With resonant induction, power is transmitted between two resonating coils.

Magnetic coupling is particularly suitable for everyday applications because most common materials interact only very weakly with magnetic fields, so interactions with extraneous environmental objects are suppressed even further. The fact that magnetic fields interact so weakly with biological organisms is also important for safety considerations..Efficiency can be increased with time, most of the 60% lost is from heat radiated from the coils. In any system of coupled resonators there often exists a so-called “strongly coupled” regime of operation. If one ensuresto operate in that regime in a given system, the energy transfer can be very efficient.

Theoretically one stationary coil in a room could power multiple devices with receiving coils.No more messy wires, and with widespread enough use it could even eliminate costly batteries.

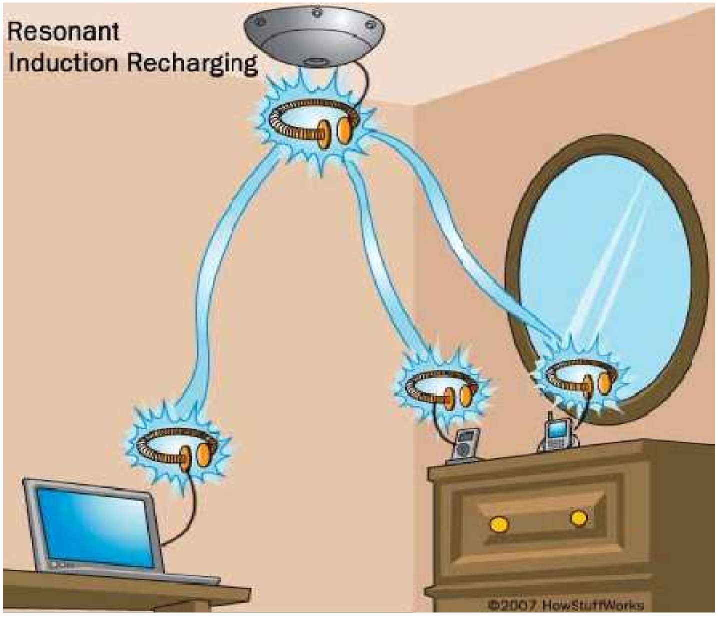

Figure 3.1:Resonant induction recharging

3.1 Basic Idea About Resonant Coupling

The basic principle of this technology is that two separate coils with same resonance frequency are possible to form a resonant system based on high frequency magnetic coupling and exchange energy in a high efficiency, while the coupling effect is weak between those objects with different resonance frequency. The medium of energy transfer is an alternating magnetic field. This technology can be used to provide energy for electricity equipments wirelessly in a certain distance.

The investigated design consists of two copper coils, each a self-resonant system. One of the coils, attached to the power source, is the sending unit. Instead of irradiating the environment with electromagnetic waves, it fills the space around it with a non-radiative magnetic field oscillating at MHz frequencies. The non-radiative field mediates the power exchange with the other coil (the receiving unit), which is specially designed to resonate with the field. The resonant nature of the process ensures the strong interaction between the sending unit and the receiving unit, while the interaction with the rest of the environment is weak. The crucial advantage of using the non-radiative field lies in the fact that most of the power not picked up by the receiving coil remains bound to the vicinity of the sending unit, instead of being radiated into the environment and lost.

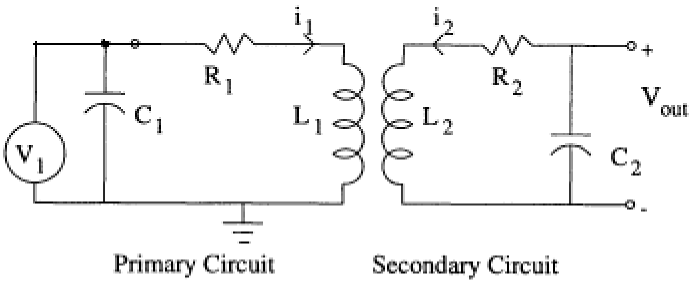

Figure 3.2: Resonant coupling of two coil

For the above circuit maximum energy will be transferred if $\frac{1}{2\pi\sqrt{L_1C_1}} = \frac{1}{2\pi\sqrt{L_2C_2}}$

3.2 Structure Of Energy Transfer System Via Coupled Magnetic Resonance

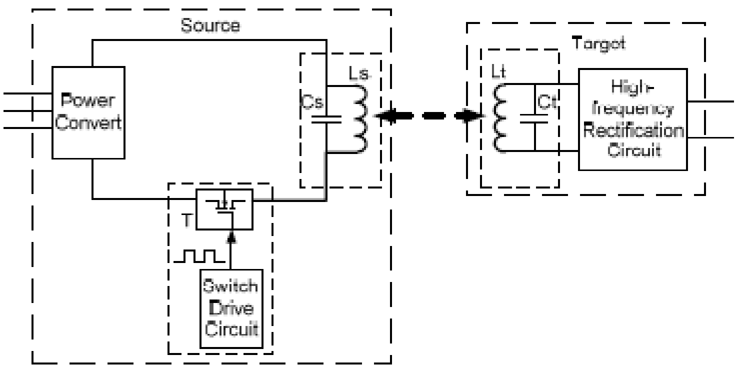

Figure 3.3: Schematic diagram of energy transfer system via coupled magnetic resonance.

As shown in figure 3.3, a simple structure of energy transfer system via coupled magnetic resonance is proposed. The energy supply of source is provided by power convert module, inductor L_s and capacitor C_s constitute a resonance source circuit to

generate an alternative non-radiative magnetic field. The resonance frequency of LC circuit is f_s . The control signal for power switch tube T is generated by switch drive circuit, and its frequency is f_k . In theory, when f_t is close or equal to f_s , the oscillation of source resonance circuit is strongest, the value of resonance current is highest, and the magnetic field intensity is also strongest. Inductor L_t and capacitor C_t constitute the receiving resonance circuit to produce resonance with the magnetic field which generated by source resonance circuit to receive energy. The frequency of receiving resonance circuit is f_t , the parameters of L_t and C_t needn't be in full accord with the source resonance circuit. What the receiving resonance circuit must need is to ensure $f_t = f_s$, that is the necessary condition for energy transfer. In figure 3.2, C_s and C_t are capacitors in resonance circuit. If there are more than 2 capacitors, the equivalent capacitance should be calculated according to the specific circuit and the relationship between the capacitors (series or parallel). L_s and L_t are the values of coil inductance in resonance circuits. For different shape and structure of coils, the formula to calculate the coil inductance is also different. The circular loop coil is used in this resonance system proposed in this paper, and the coil inductance can
be calculated from

$$L = N^2 R \mu_0 [\ln(\frac{8R}{a}) - 1.75]$$

Where, N —coil turn;

μ = 4π ×10− —permeability of vacuum , (H/m);

R —radius of coil (m);

a—radius of conductor section (m).

If the inductor L and capacitor C in resonance circuit is determined, the circuit resonance frequency f could be calculated from

$$f = \frac{1}{2\pi\sqrt{LC}}$$

The frequency f_k of driving signal for power switch tube T can be called driving frequency. It can be determined according to f_s . The driving signal can be generated by signal generation circuit or device. The closer f_k to f_s , the stronger is the magnetic field. The stronger is the magnetic fields, the longer is the energy transfer distance and also higher is the transfer efficiency. Through the on–off control of power switch tube by driving signal, resonance current is emerging in the source resonance coil. Then this resonance current generates the alternating non-radiative magnetic field. The working frequency of energy receiver f_t is also determined by f_s . When the receiving resonance coil enters into the alternating magnetic field produced by the energy transmitting source, it begins to oscillate because it has the same resonance frequency with the alternating magnetic field. As have been said before, energy in the inductance coil continues gathering, the voltage is increasing, and the receiving energy can be used by the load after being converted by follow-up high-frequency rectifier circuit.

3.3 Finite Element Simulation Analysis

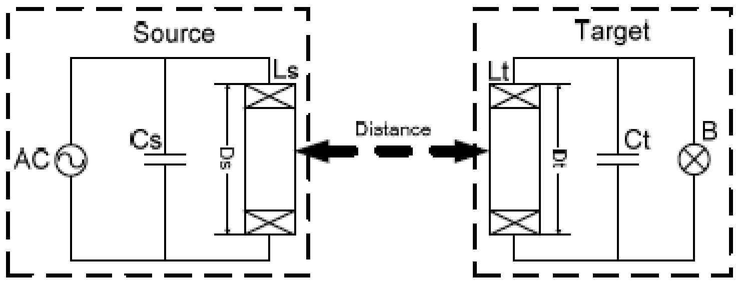

Figure 3.4: Model of the finite simulation analysis

As shown in figure 3.4, a model of finite element simulation for magnetic resonances energy transfer system is established. An ideal AC voltage source is used in simulation as the power supply of energy source, its can be expressed by formula $V=V_0 Sin(\omega t+\varphi)$. The voltage amplitude V_0 and frequency ω can be adjusted according to different simulation conditions. The frequency ω equivalent to the driving frequency f_k . The supply power can be loaded to source resonance circuit which constituted by the inductor L_s and capacitor C_s . The simulation model of inductance coil is established by the experiment parameters. By using the circuit function of finite element analysis software, the capacitor and inductance coil are connected to form the LC resonance circuits. The simulation of energy transferred according to different distance between L_s and L_t can be done. In this paper, the back electromotive force (back-EMF) in the receiving coil related with different transfer distance and with driving frequency is simulated and analyzed. Curves in figure 3.5 show the impact on the back-EMFcaused by different transfer distance. It is obvious that the longer is the distance between the two coils, the lower the back-EMF of the receiving coil is.

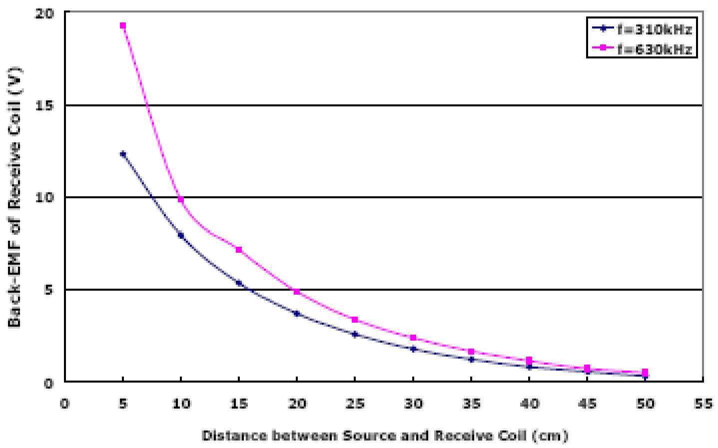

Figure 3.5: Relationship between the transfer distance and back-EMF of the receiving coil

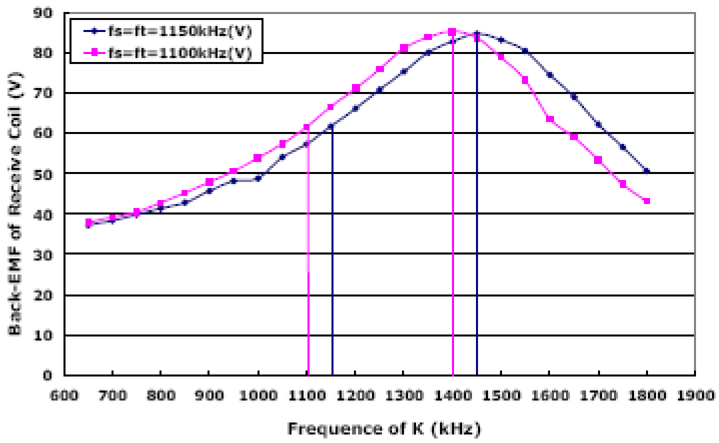

Figure 3.6: Relationship between different driving frequency f_k and back-EMF of the receiving coil.

When LC circuit has been set, its inherent resonance frequency can be calculated by formula above. Changing the frequency of AC source equivalent to changing the driving frequency f_k , which change the magnetic field generated by LC circuit. The curves in Figure 3.6 show the relationship between different driving frequency f_k and back-EMF of the receiving coil. The simulation result shows that when the back-EMF reaches the maximum, the driving frequency f_k is not completely consistent with the inherent resonance frequency of the LC resonant circuit, there existed a certain deviation. For example, we can see the inherent resonance frequency of LC resonance circuit is 1150 kHz, while the back-EMF of receiving coil reaches the maximum when the driving frequency is 1450 kHz. The reason for this phenomenon needs to be studied in further research.

3.4 Feasibility of Resonant Coupling

Based on the above analysis, it is proved that energy transfer is completely feasible using the technology of magnetic coupling resonance. Nevertheless, there are still a lot of research and experimental work to be done to make this technology more practical.

Chapter 4

Microwave Power Transfer

Microwave Power Transfer (MPT) is a form of wave power transfer that, obviously, sends energy through the air in the form of microwaves (other forms can use lasers and visible light). MPT has a range miles longer than its inductive counterparts, and it's being investigated as a way to beam power to space or vice versa . According to a study done by NASA , to transmit energy from space to earth would require a 1km diameter transmitter and a 10km diameter receiver.Possible health risks associated with beams of microwaves.

Solar Power Satellites (SPS) could be an application for MPT. Beaming solar energy collected from satellites or solar panels on the moon to Earth could be a solution to our clean energy issues.

4.1 Concept of Solar Power Satellites (SPS)

Energy crisis will be a great problem in future.The most common sources of energy(oil,coal,gas,nuclear energy) have limited reserves.So human being must find out new source of energy. The next energy source must satisfy some very basic criteria. First, it must be nondepletable, so it will not have to be replaced by the next generation. Second, it must be low cost, or it will not be developed to produce large quantities of energy. Third, it must be environmentally clean, so the Earth is not destroyed as we develop. Fourth, it must become available to everyone on Earth if war is to be avoided. Fifth, it must be in a useful form *so* it can support the developing societies as they emerge as well as the developed nations.

The solution to the problems described above can be accomplished by the development of Solar Power Satellites. The Solar Power Satellite system is the only energy source with known technology that can meet the criteria for a viable major new energy source and move the world into the fourth era of energy.

4.2 Problem of Solar Power Satellites (SPS)

Space Solar Power Stations are costly because of the great size of their radiating and receiving antennas. These sizes are the result of the divergence of the wave beam, which transmits the energy from space to the Earth. This is a matter of radiating and receiving antennas and their interaction. It is shown that a correct choice of the field distribution on the radiation antenna allows us to increase the wireless power transmission efficiency and to lessen its cost.

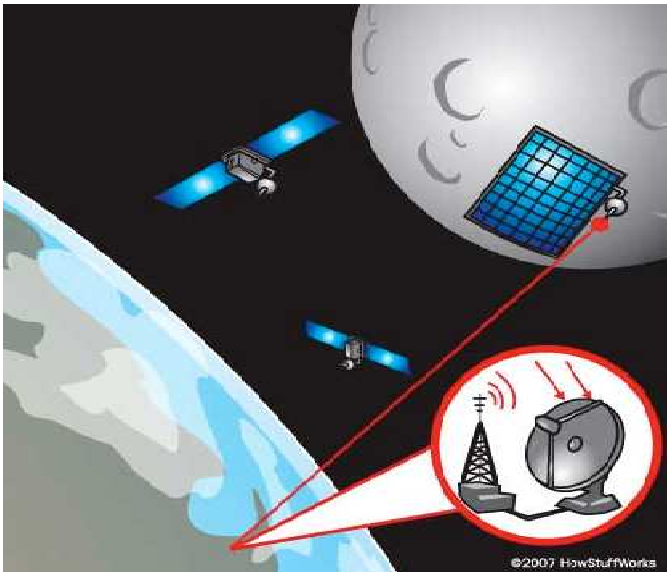

Figure 4.1: Solar Power Satellites (SPS) system

4.3 Antenna Design For SPS:

The main disadvantage of microwave Wireless Power Transmission (WPT) is that that the significant part of the radiating energy does not reach the given area of space because of the diffraction divergence. As the transmission distance increases as compared to diffraction length of the radiating antenna this disadvantage is most conspicuous. The size of the radiating and receiving antennas must be selected so as not to exceed the diffraction length of the radiating aperture. It shouldn't go out of the Fresnel area.

Lately in literature great attention is given to microwave power transmission systems with discontinuous antennas. One of the main theoretical problems is the synthesis of optimal antenna systems including transmitting and receiving antennas. The main theoretical results are received for WPT apertures including discontinuous antennas. Gauss-like optimal field distribution in the aperture of the round or square transmitting antennas is well known.

It is supposed to use the solution of quasi optical problem to minimize the losses. In WPT the correlation between wave length λ , the distance between the antennae *d* and the transmitting and receiving antenna half sizes *a* and *b* is defined by the Fresnel parameter

$$C = 2\pi \frac{ab}{\lambda d} \qquad (4.1)$$

Usually it equals about 2-3. The receiving antenna is situated near of the Fresnel area. As it is shown from above equation the increase of the distance *d* requires for the increase of the ratio $\frac{ab}{\lambda}$

The transmission is considered to be optimal, when the receiving antenna does not intercept the minimal part of the transmitted energy. The distribution of current on the transmitting antenna is the taper type (usually it is used Gauss field distribution). The radiation from the transmitting antenna is focused in the center of the receiving one. This distribution is not optimal !

There are two peculiarities in the taper field distribution:

The first: The maximum of energy flow density at the transmitting antenna can't be made unlimitedly large, the admitted power density limits it. If this maximum is fixed, the noticeably more energy may be transmitted by means of best filling of the aperture, for instance at the uniform distribution. Of course in that case the losses of the transmission will be bigger. But as the accounts shows we will create more energy at the receiving end of power transmitting system.

The second: The side maximums are not so small at the .Gauss transmission. They occur because the Gauss function is limited (it is cut at the edge of antenna). The first diffraction maximum at the level of - 13dB occurs at the uniform distribution (a table form function). The side maximums of the cut Gauss distribution depend on a value of coefficients σ in the expression of the Gauss curve

$$e^{-\frac{\sigma r^2}{a^2}} \qquad (4.2)$$

If the value σ is large the cutting of Gauss curve takes place at the low level and the side maximums on the receiving side are small but effectiveness of WPT is small too because the antenna surface is used very poorly. It is found that the optimal field distribution has a taper form too. If the value σ is small the level of the wave field out of the receiving aperture reaches also about - 13dB.

The product of the effective cross sizes of two antennas (receiving and transmitting antennas) is increasing at the change of the taper distribution to the uniform one. Therefore the field is contracted at the receiving side. It means that the field at an edge of receiving antenna is decreased.Calculations showed that the field at the receiving antenna edge for taper transmission is about equal to the field, which will take place in the diffraction maximum at the uniform distribution. So from the point of view of the field level at the edge of the receiving antenna the uniform distribution slightly differs from the optimum one. But the aim is to transmit as much energy as possible. It is realized only with the uniform distribution. The most effective and the most technological method to make a good antenna for the WPT is to use incompletely filled aperture. If separate parts divide the continuous aperture and these parts (sub apertures) are situated on the radiating plate in the determinate order (discontinuous array), the effectiveness of the WPT is increased. This idea at first was reported at the WPT'95 Conference in 1995 (Japan).

Discontinuous antenna has a wonderful feature. It allows creating on the receiving antenna essentially more energy by comparison with continuous antenna if the efficiency and active antenna squares are equal. It is because they (discrete antennas) use the aperture edges better than the continuous antennas. Of course in that case the sub apertures must be distributed correctly. Apparently unequal distant distribution of sub apertures allows improving the result.

Differently, we substitute the optimal continuous aperture with the same discontinuous antenna, which consists of identical sub apertures with uniform amplitude distribution. Practically equal efficiency leads to the higher transmitted power (if the permitted level of amplitude is limited and its value is in the center of a continuous antenna). It is very good for practical purposes.

Radiating antenna of the WPT systems usually has a taper distribution of the field. This distribution allows to increase the efficiency and to decrease the field out of the receiving antenna.
The efficiency of energy transmission is expressed by the functional

$$\Lambda^2 = \frac{\int_{-\frac{q}{2}}^{\frac{q}{2}} |E(\xi)|^2 d\xi}{\int_{-\frac{Q}{2}}^{\frac{Q}{2}} |E(\xi)|^2 d\xi} \qquad (4.3)$$

Here $Q \times Q$ is the total area where the energy of the electric field E(x) is radiated and $q \times q$ is the square plate of the receiving antenna. For simplicity we take square of transmitting and receiving apertures, which have separating amplitude distributions $U(x, y)= U(x)U(y)$.

To increase Λ the field distribution on radiating aperture is made as a tapered distribution. It is shown that the best result is obtained at the field distribution which is close to the Gauss one $\exp\left\{\frac{-\sigma x^2}{r}\right\}$ and which has edges cut on a definite level. For example,σ is and the Fresnel parameter C is about 1 (it is usually 2-3). High value of Λ is supposed to be in the majority of known projects of the WPT systems. However, the effectiveness of the WPT system is defined not only by the value of Λ. It is also determined by the rectangularity of the field distribution on the radiating aperture, which for the square antenna is equal to

$$\chi = \frac{\left\{\int_{-a}^{a} |U(x)|^2 dx\right\}^2}{4a^2 |U_m(x)|^2} \qquad (4.4)$$

where $U(x)\ m$ is maximal admissible value of the field on the radiating antenna. It is usually situated in the center of the antenna. The rectangular distribution factor in the theory of antennas is usually called the surface utilization factor χ.The meaning of these two parameters Λ and χ is discrepant because to increase Λ^2 it is necessary to have the field falling down to edges, but to increase χ it is necessary to have a uniform field. The purpose of this paper is to find the conditions at which this discrepancy is cancelled.

A demand to increase c has been shown in literature before . The increase of c permits to increase the transmitting power without the extension of sizes of the radiating antenna but the efficiency Λ^2 is decreased at the same time. To increase the effectiveness of WPT system it is necessary to increase the product Λ^2c , though the requirements for each of both multipliers are opposite. This product is named a generalize criterion! It is possible to find the way out of this contradiction if the antenna is discontinuous (discrete) one. Let us produce the field distribution in the radiating discrete antenna falling to its edges not by means of creation of non-uniform distribution of the field but with the help of irregular situation of identical sub apertures, each of them having the uniform field distribution. It is supposed that the number of these apertures is sufficiently high in order to admit the approximation of the integral optimum monotonous Gauss distribution by means of step function. The places of sub aperture disposition can be found by the differentiation of this step function.

Discrete distribution of sub apertures presents non-equadistant antenna array consisting of the similar elements. Such optimization is optimal in Chebyshev's sense since the maximum error tends to zero while the number of sub apertures is tended to infinity. So the field in the place of observer's disposition would be similar to step and the monotonous signal source.

The falling to the edge field distribution is typical for the WPT problems. For the discrete-step distributions that means the concentration of sub apertures in the center and their gradual discharge on the edges. Thus all sub apertures are similar and have the uniform distribution of the field with the equal amplitude, which may reach the maximum admissible value. The example of the computer simulation for this case is submitted in the paper .

The dismemberment of continuous apertures and slight moving of them apart in the space when all of apertures are equal and uniformly feed increases their effectiveness (the generalized criterion is increased). The generalized criterion determines the quality of the WPT Systems better than usual criterion.

The optimal distribution form may be reached for the large radiating apertures where dismemberment at many parts is easily realized by disposition of sub aperture clots in places, which correspond to high field intensity (first of all it concerns the center of the radiator) and relieving sub aperture density at edges of antenna. This construction allows to approach to unit the value both of coefficients Λ^2 and χ. As a result the effectiveness of the WPT system will be essentially increased.

4.4 Probable Antenna Array

The resolve of the synthesis problem of the WPT shows that WPT efficiency may be improved by using special current discontinuous distribution on the antenna. Here we have three possibilities:

1. To use a discontinuous equidistant array with the quasi Gauss distribution.
2. To use a discontinuous non-equidistant array with the uniform distribution.
3. To use uniform continuous phase synthesis antenna array.

All of these methods are original and they have been modeled only in the frame of International Science and Technology Center Project.

The possibility of decrease of the wave beam expansion permits to make the WPT systems less expensive. Such approach to the problem of the continuous radiators and of the real antennas, which can be created, is new.

4.5 Bio-effects

A general public perception that microwaves are harmful has been a major obstacle for the acceptance of power transmission with microwaves. A major concern is that the long-term exposure to low levels of microwaves might be unsafe and even could cause cancer. Since 1950, there have been thousands of papers published about microwave bio-effects. The scientific research indicates that heating of humans exposed to the radiation is the only known effect. There are also many claims of low-level non-thermal effects, but most of these are difficult to replicate or show unsatisfying uncertainties. Large robust effects only occur well above exposure limits existing anywhere in the world .

The corresponding exposure limits listed in IEEE standards at 2.45 or 5.8 GHz are 81.6 W/m^2 and 100 W/m^2 averaged over 6 minutes, and 16.3 or 38.7 W/m^2 averaged over 30 minutes. This low compared to average solar radiation of 1000 W/m^2.

A clearly relevant bio-effect is the effect of microwave radiation on birds, the so-called "fried bird effect". Research is done on such effect at 2.45 GHz. The outcome showed slight thermal effects that probably are welcome in the winter and to be avoided in the summer. Larger birds tend to experience more heat stress than small birds .

The overall conclusion of bio-effects research is that microwave exposures are generally harmless except for the case of penetrating exposure to intense fields far above existing exposure limits.Further discussions about the maximum microwave power density are necessary. A range of environmental issues and safety-related factors should continue to receive consideration because of public concern about radio wave and microwave exposure.

Chapter 5

Wireless Power Transfer via Strongly Coupled Magnetic Resonances

Radiative transfer , although perfectly suitable for transferring information, poses a number of difficulties for power transfer applications: The efficiency of power transfer is very low if the radiation is omnidirectional, and unidirectional radiation requires an uninterrupted line of sight and sophisticated tracking mechanisms. A recent theoretical paper presented a detailed analysis of the feasibility of using resonant objects coupled through the tails of their nonradiative fields for midrange energy transfer . Intuitively, two resonant objects of the same resonant frequency tend to exchange energy efficiently, while dissipating relatively little energy in extraneous offresonant objects. In systems of coupled resonances, there is often a general “strongly coupled” regime of operation. If one can operate in that regime in a given system, the energy transfer is expected to be very efficient. Midrange power transfer implemented in this way can be nearly omnidirectional and efficient, irrespective of the geometry of the surrounding space, with low interference and losses into environmental objects.

The above considerations apply irrespective of the physical nature of the resonances. Here, we focus on one particular physical embodiment: magnetic resonances. Magnetic resonances are particularly suitable for everyday applications because most of the common materials do not interact with magnetic fields, so interactions with environmental objects are suppressed even further. We must identify the strongly coupled regime in the system of two coupled magnetic resonances by exploring nonradiative (near-field) magnetic resonant induction at megahertz frequencies. At first glance, such power transfer is reminiscent of the usual magnetic induction ; however, note that the usual nonresonant induction is very inefficient for midrange applications.

5.1 Overview of The Formalism

Efficient midrange power transfer occurs in particular regions of the parameter space describing resonant objects strongly coupled to one another. Using coupled-mode theory to describe this physical system , we obtain the following set of linear equations:

$$a_m(t) = (i\omega_m - \Gamma_m)a_m(t) + \sum_{n \neq m} i\kappa_{mn} a_n(t) + F_m(t) \qquad (5.1)$$

where the indices denote the different resonant objects. The variables $a_m(t)$ are defined so that the energy contained in object m is $|a_m(t)|^2$, ω_m is the resonant angular frequency of that isolated object, and Γ_m is its intrinsic decay rate (e.g., due to absorption and radiated losses). In this framework, an uncoupled and undriven oscillator with parameters ω_0 and Γ_0 would evolve in time as . $\exp(i\omega_0 t - \Gamma_0 t)$. The $\kappa_{mn} = \kappa_{nm}$ are coupling coefficients between the resonant objects indicated by the subscripts, and $F_m(t)$ are driving terms. We limit the treatment to the case of two objects, denoted by source and device, such that the source (identified by the subscript S) is driven externally at a constant frequency, and the two objects have a coupling coefficient κ. Work is extracted from the device (subscript D) by means of a load (subscript W) that acts as a circuit resistance connected to the device, and has the effect of contributing an additional term Γ_w to the unloaded device object's decay rate Γ_D. The overall decay rate at the device is therefore $\Gamma'_D = \Gamma_D + \Gamma_W$. The work extracted is determined by the power dissipated in the load, that is, $2\Gamma_w\ |a_D(t)|^2$. Maximizing the efficiency η of the transfer with respect to the loading Γ_w, given
Eq. 5.1, is equivalent to solving an impedance matching problem. One finds that the scheme works best when the source and the device are resonant, in which case the efficiency is

$$\eta = \frac{\Gamma_W |a_D|^2}{\Gamma_S |a_S|^2 + (\Gamma_D + \Gamma_W)|a_D|^2} \qquad (5.2)$$

$$= \frac{\frac{\Gamma_W}{\Gamma_D}\frac{\kappa^2}{\Gamma_S\Gamma_D}}{\left[\left(1+\frac{\Gamma_W}{\Gamma_D}\right)\frac{\kappa^2}{\Gamma_S\Gamma_D}\right] + \left[\left(1+\frac{\Gamma_W}{\Gamma_D}\right)^2\right]}$$

The efficiency is maximized when $\Gamma_W/\Gamma_D = [1 + (\kappa^2/\Gamma_S\Gamma_D)]^{1/2}$. It is easy to show that the key to efficient energy transfer is to have $\kappa^2/\Gamma_S\Gamma_D > 1$. This is commonly referred to as the strong coupling regime. Resonance plays an essential role in this power transfer mechanism, as the efficiency is improved by approximately $\omega^2/\Gamma_D{}^2$ (~10^6 for typical parameters) relative to the case of inductively coupled nonresonant objects.

5.2 Theoretical Model For Self-resonant Coils

Our experimental realization of the scheme consists of two self-resonant coils. One coil (the source coil) is coupled inductively to an oscillating circuit; the other (the device coil) is coupled inductively to a resistive load . Self resonant coils rely on the interplay between distributed inductance and distributed capacitance to achieve resonance. The coils are made of an electrically conducting wire of total length l and

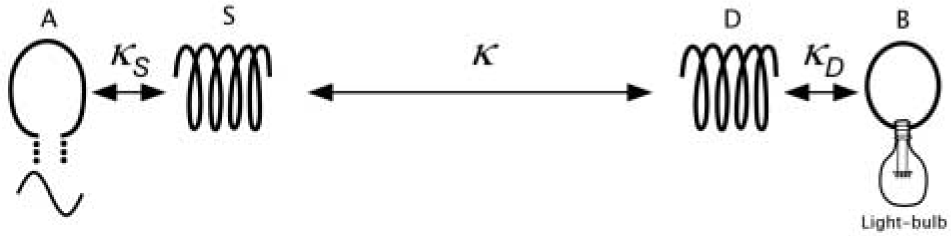

Figure 5.1:Two coupled self resonant coil

cross-sectional radius a wound into a helix of n turns, radius r, and height h. To the best of our knowledge, there is no exact solution for a finite helix in the literature, and even in the case of infinitely long coils, the solutions rely on assumptions that are inadequate for our system. We start by observing that the current must be zero at the ends of the coil, and we make the educated guess that the resonant modes of the coil are well approximated by sinusoidal current profiles along the length of the conducting wire. We are interested in the lowest mode, so if we denote by s the parameterization coordinate along the length of the conductor, such that it runs from −l/2 to +l/2, then the time-dependent current profile has the form I_0 cos(ps/l) exp(iωt). It follows from the continuity equation for charge that the linear charge density profile is of the form λ_0 sin(ps/l) exp(iωt), so that one-half of the coil (when sliced perpendicularly to its axis) contains an oscillating total charge (of amplitude $q_0 = \lambda_0 l/\pi$) that is equal in magnitude but opposite in sign to the charge in the other half. As the coil is resonant, the current and charge density profiles are π/2 out of phase from each other, meaning that the real part of one is maximum when the real part of the other is zero. Equivalently, the energy contained in the coil is at certain points in time completely due to the current, and at other points it is completely due to the charge. Using electromagnetic theory, we can define an effective inductance L and an effective capacitance C for each coil as follows:

$$L = \frac{\mu_0}{4\pi|I_0|^2}\iint dr dr' \frac{J(r).J(r')}{|r-r'|} \qquad (5.3)$$

$$\frac{1}{C} = \frac{1}{4\pi\varepsilon_0|q_0|^2}\iint dr dr' \frac{\rho(r).\rho(r')}{|r-r'|} \qquad (5.4)$$

where the spatial current J(r) and charge density r(r) are obtained respectively from the current and charge densities along the isolated coil, in conjunction with the geometry of the object. As defined, L and C have the property that the energy U contained in the coil is given by

$$\begin{aligned} U &= \frac{1}{2}L|I_0|^2 \\ &= \frac{1}{2C}|q_0|^2 \end{aligned} \qquad (5.5)$$

Given this relation and the equation of continuity, the resulting resonant frequency is $f_0 = 1/[2\pi\,(LC)^{1/2}]$. We can now treat this coil as a standard oscillator in coupled-mode theory by defining $a(t) = [(L/2)^{1/2}]I_0(t)$.We can estimate the power dissipated by noting that the sinusoidal profile of the current distribution implies that the spatial average of the peak current squared is $|I_0|^2/2$. For a coil with n turns and made of a material with conductivity σ , we modify the standard formulas for ohmic (Ro) and radiation (Rr) resistance accordingly:

$$R_0 = \sqrt{\frac{\mu_0 \omega}{2\sigma}}\frac{l}{4\pi a} \qquad (5.6)$$

$$R_r = \sqrt{\frac{\mu_0}{\varepsilon_0}}\left[\frac{\pi}{12}n^2\left(\frac{\omega r}{c}\right)^4 + \frac{2}{3\pi^3}\left(\frac{\omega h}{c}\right)^2\right] \qquad (5.7)$$

The first term in Eq. 5.7 is a magnetic dipole radiation term (assuming $r \ll 2\pi c/\omega$, where c is the speed of light); the second term is due to the electric dipole of the coil and is smaller than the first term for our experimental parameters.The coupled-mode theory decay constant for the coil is therefore $\Gamma = (Ro + Rr)/2L$, and its quality factor is $Q = \omega/2\Gamma$. We find the coupling coefficient κ_{DS} by looking at the power transferred from the source to the device coil, assuming a steady-state solution in which currents and charge densities vary in time as $\exp(i\omega t)$:

$$
\begin{aligned}
P_{DS} &= \int d\mathbf{r}\mathbf{E}_S(\mathbf{r}) \cdot \mathbf{J}_D(\mathbf{r}) \\
&= -\int d\mathbf{r}\left[\dot{\mathbf{A}}_S(\mathbf{r}) + \nabla\phi_S(\mathbf{r})\right] \cdot \mathbf{J}_D(\mathbf{r}) \\
&= -\frac{1}{4\pi}\iint d\mathbf{r}d\mathbf{r}' \\
&\times \left[\mu_0 \frac{\dot{\mathbf{J}}_S(\mathbf{r}')}{|\mathbf{r}'-\mathbf{r}|} + \frac{\rho_S(\mathbf{r}')}{\varepsilon_0}\frac{\mathbf{r}'-\mathbf{r}}{|\mathbf{r}'-\mathbf{r}|^3}\right] \cdot \mathbf{J}_D(\mathbf{r}') \\
&\equiv -i\omega M I_S I_D
\end{aligned}
\tag{5.8}
$$

Where M is the effective mutual inductance, f is the scalar potential, A is the vector potential, and the subscript S indicates that the electric field is due to the source. We then conclude from standard coupled-mode theory arguments that $\kappa_{DS} = \kappa_{SD} = \kappa = \omega M/[2(L_S L_D)^{1/2}]$. When the distance D between the centers of the coils is much larger than their characteristic size, κ scales with the D^{-3} dependence characteristic of dipole-dipole coupling. Both κ and Γ are functions of the frequency, and $\kappa / \Gamma$and the efficiency are maximized for a particular value of f, which is in the range 1 to 50 MHz for typical parameters of interest. Thus, picking an appropriate frequency for a given coil size, as we do in this experimental demonstration, plays a major role in optimizing the power transfer.

5.3 Concluding Remarks

From the above discussion we have come in a conclusion that efficient power transfer can take place between two self resonant coils of equal resonant frequency.For efficient power transfer we must consider some factors.The quality factor ,coupling co-efficient and decay constant are major factors to be considered.All of them are function of frequency.The increase in frequency increase quality factor and coupling co-efficient but also increase decay constant,so we must select a frequency for which coupling co-efficient is greater than decay constant and quality factor is also better.The number of turns increases radiation resistance so decay constant also increases,it lowers quality factor,solid conductor gives a solution to this problem.The ohmic resistance of the coil is proportional to the length of the coil,high conductivity and large cross sectional area coil element is a solution to this problem.
Considering all of the above factors efficient wireless power transfer between two coils can be possible.

Chapter 6

Project of Wireless Power Transfer

We have done a simple project of LED lighting wirelessly.In this project we use two copper coil.We made an oscillator by L-C circuit.One copper coil was connected to the oscillator and other was connected to the LED.We observed the results for various conditions such as varying distance,varying number of turns,taking external objects between the coils,varying frequency and connecting several LEDs.Next we designed a mobile phone charger that can charge a mobile phone wirelessly

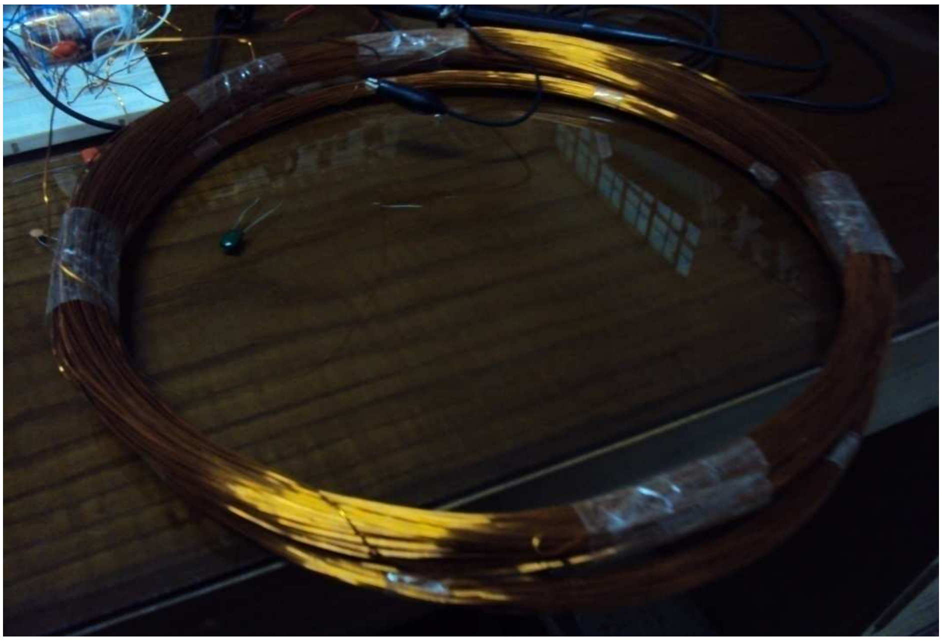

Figure 6.1:Transmitter and receiver coil

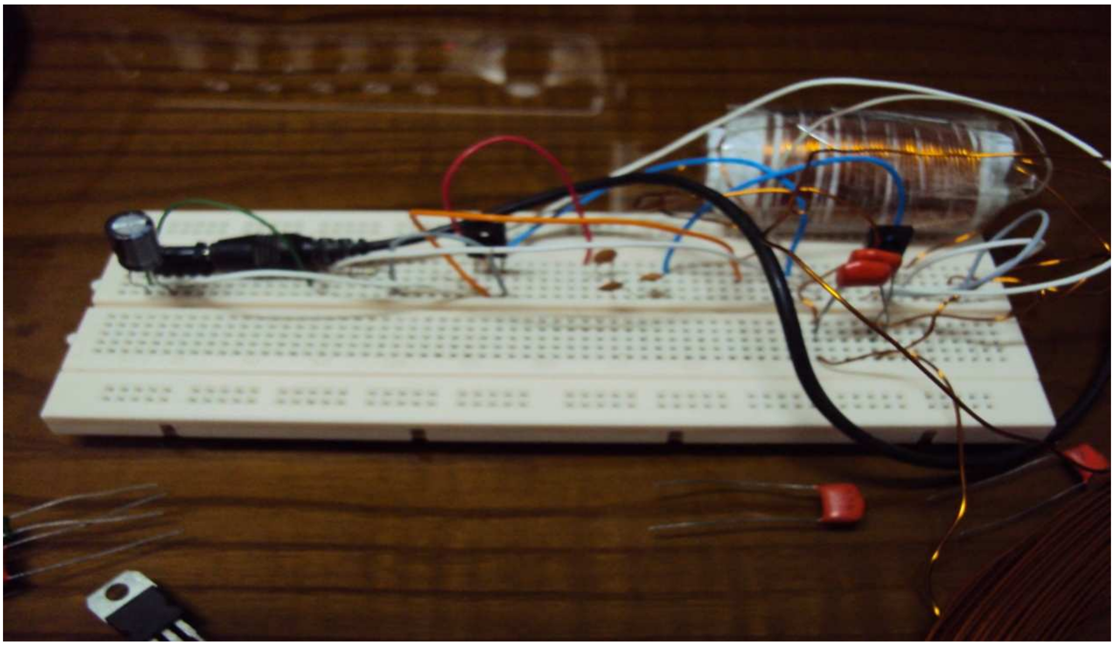

Figure 6.2:Transmitter circuit

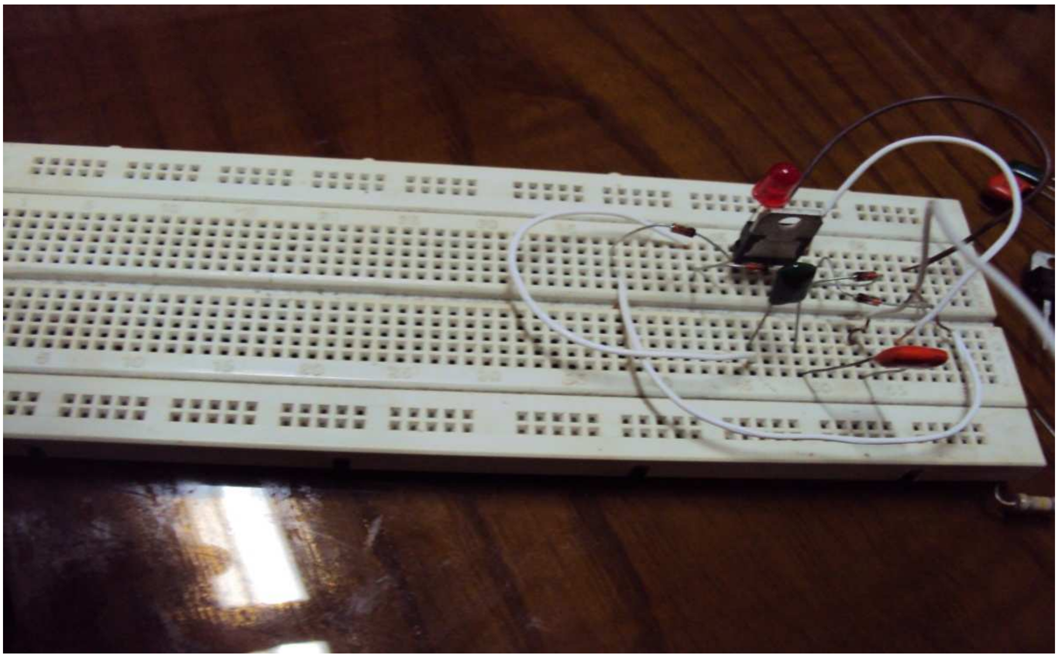

Figure 6.3:Receiver circuit

6.1 Circuit and Working Procedure

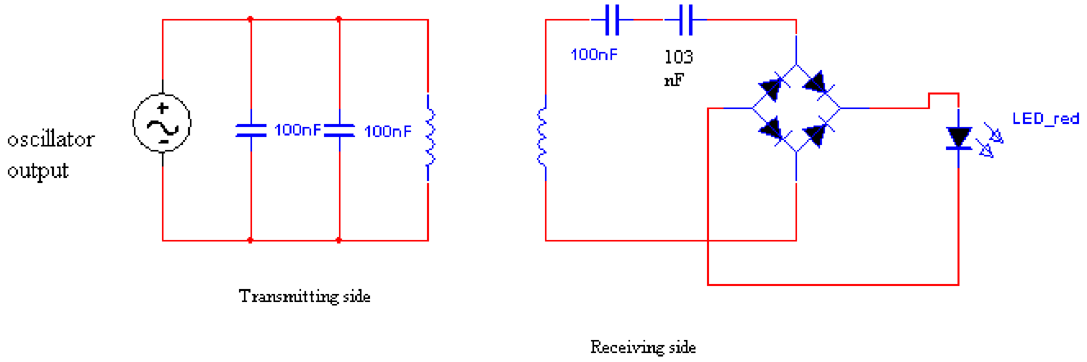

Figure 6.4:Circuit for LED lighting

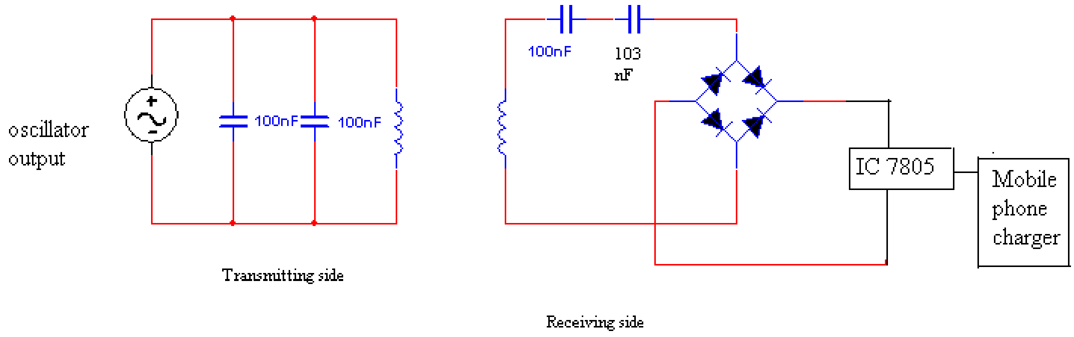

Figure 6.5:Mobile phone charger circuit

We used 22-gauge copper wire.Coil was made by circularly wrapped the wire.One coil has 200 turns and other has 50 turns.Transmitter coil has inductance 4.68 mH and receiver coil has inductance 11.905 mH.An oscillator was made by L-C combination.The oscillator circuit is shown below

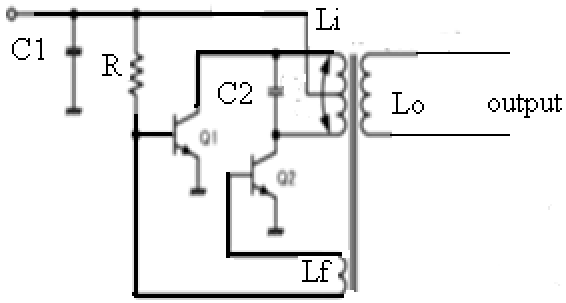

Figure 6.6: Oscillator circuit

Here,C1=100µF

R=180Ω

Q1,Q2 are BD135 power transistors

C2 is five 104pF capacitors connected in series

Li =Primary coil 50 turns

Lo=secondary coil 150 turns

Lf=feedback coil 20 turns

The oscillator generates 8KHz signal.Oscillator was connected to 50 turns coil.Two 100 nF capacitor were connected in parallel with transmitter coil and one 103 nF and one 100nF capacitor were connected in series with receiver coil.Receiver coil has 200 turns. A bridge rectifier was connected with receiver coil.LED was connected with rectifier output and result was observed.

Now a 7805 IC was connected with rectifier output.IC output was connected with mobile phone battery charger.

6.2 Result

Table of Output power at different distance

Distance cm	V volt	I mA	P_{out} mw
3	6.7	56	375.2
6	6.38	53	338.14
8	6.15	52	319.8
11	6.0	50.1	300.6
13	5.95	36	214.2
16	5.78	25	144.5
18	4.9	15.5	75.95
20	3.55	14.2	50.41
22	2.05	1.63	3.3415
24	1.41	0.32	0.4512
27.5	0.76	0.04	0.0304
29	.0078	0.01	0.000078
31	.0002	.008	0.0000016
32	0	0	0

Table 6.1: Output power at different distance for 8KHz signal.

Distance cm	V volt	I mA	P_{out} mw
3	7.00	58	406
6	6.58	55	350.90
8	6.30	53	333.90
11	6.1	50	305
13	5.98	42	251.16
16	5.85	30	175.5
18	5.20	17	88.4
20	4.8	15	72
22	3.2	2.43	7.776
24	2.80	1.30	3.64
27.5	1.57	0.08	0.1256
29	0.05	0.03	0.0015
31	0.0008	0.01	0.000008
32	0.0003	.00007	0.00000021

Table 6.2: Output power at different distance for 30KHz signal.

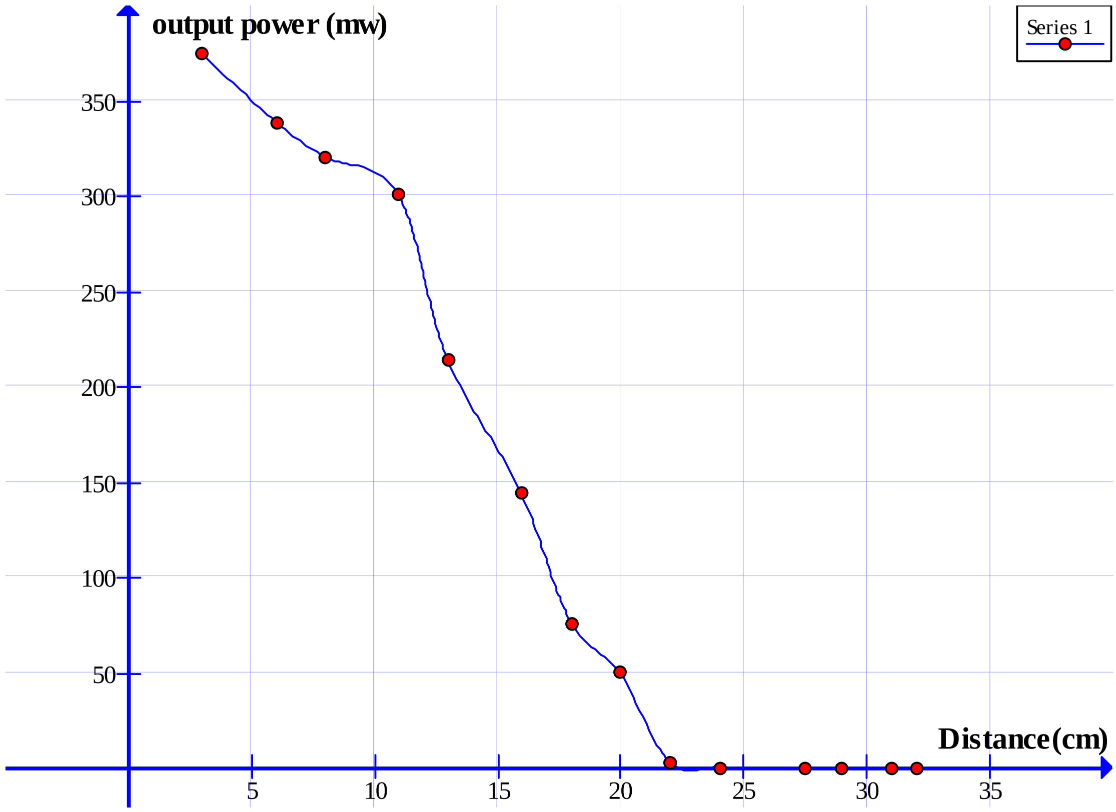

Figure 6.7:Graph of output power vs distance for 8KHz signal.

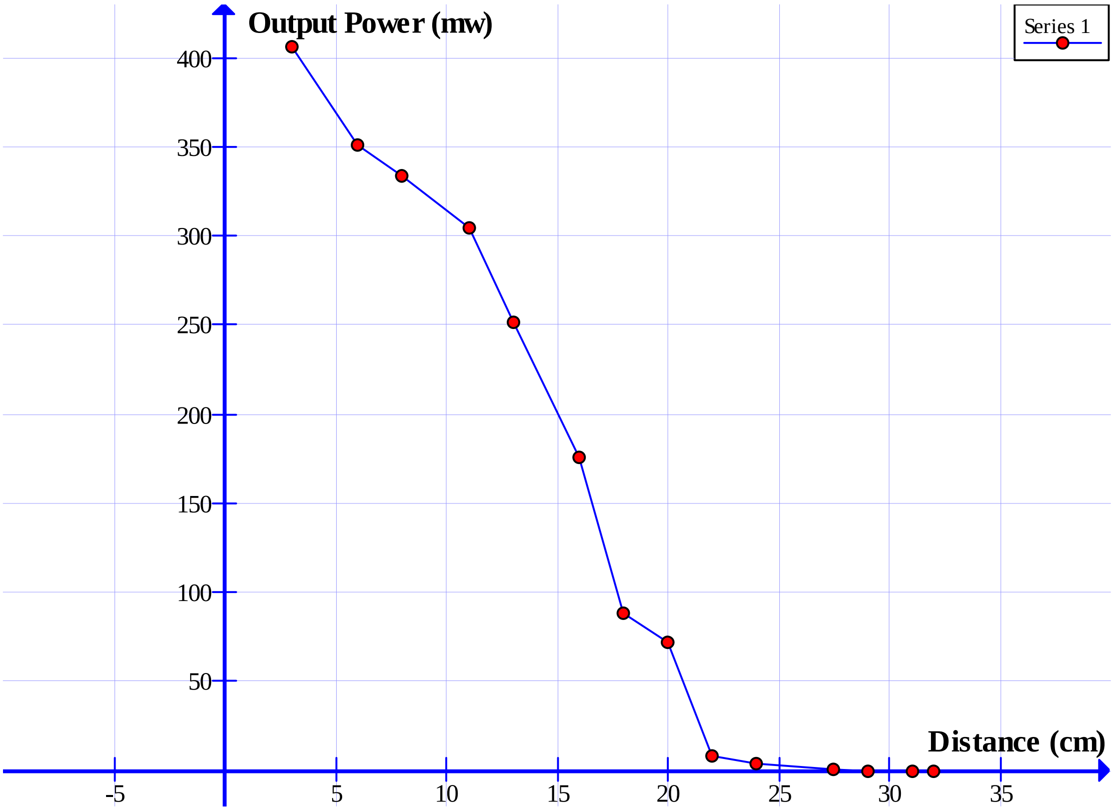

Figure 6.8: Graph of output power vs distance for 30KHz signal.

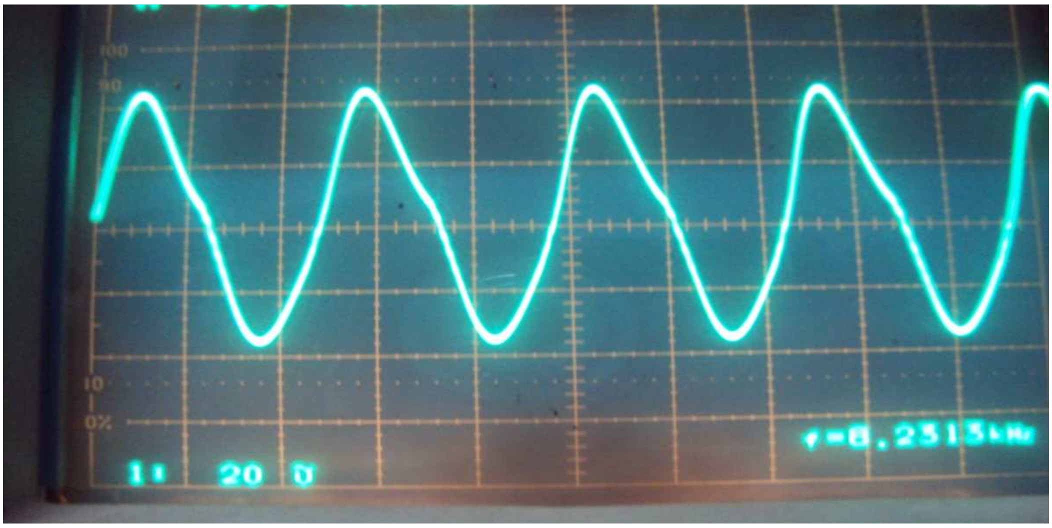

Figure 6.9:Input voltage waveform

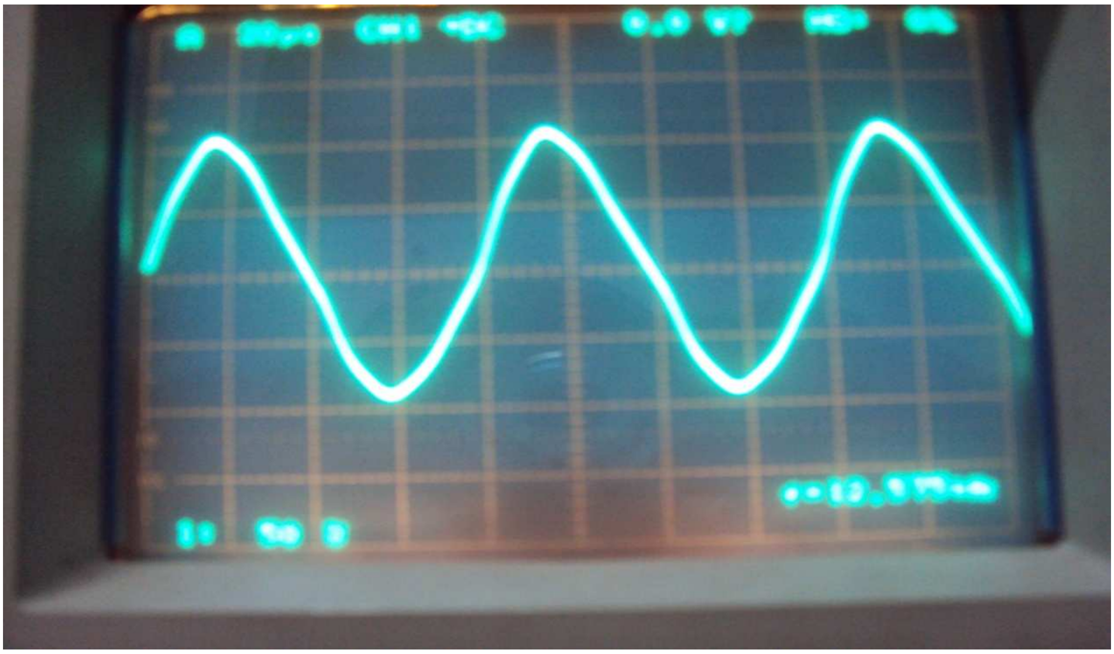

Figure 6.10: Output voltage waveform

6.3 Effect of external objects

A detailed and quantitative analysis of the effect of external objects on our scheme is beyond the scope of this work, but we note here that the power transfer is not visibly affected as humans and various everyday objects, such as metals, wood, and electronic devices large and small, are placed between the two coils—even in cases where they completely obstruct the line of sight between source and device. External objects have a noticeable effect only when they are within a few centimeters from either one of the coils. Some materials (such as aluminum foil, Styrofoam, and humans) mostly just shift the resonant frequency, which can in principle be easily corrected with a feedback circuit; other materials (cardboard, wood, and polyvinyl chloride) lower Q when placed closer than a few centimeters from the coil, thereby lowering the efficiency of the transfer.

6.4 Comment

From our observation we see that receiving power diminishes as distance increases.At first power diminishes slowly but at a certain distance power drops rapidly to zero.With the increasing frequency the distance also increases.Our designed mobile phone charger charges mobile phone slowly because output current is low.

Chapter 7

Conclusion & Field of Further Analysis

From the diverge analysis of our research we succeed to take several decisions concerning the performance of wireless power transfer.The main problem of wireless power transfer *is it's low range and low efficiency.Strongly coupled magnetic resonance is a good solution to these problem.* In systems of coupled resonances, there is often a general "strongly coupled" regime of operation. If one can operate in that regime in a given system, the energy transfer is expected to be very efficient. For efficient power transfer we must consider some factors.The quality factor ,coupling co-efficient and decay constant are major factors to be considered.All of them are function of frequency.The increase in frequency increase quality factor and coupling co-efficient but also increase decay constant,so we must select a frequency for which coupling co-efficient is greater than decay constant and quality factor is also better.The number of turns increases radiation resistance so decay constant also increases,it lowers quality factor,solid conductor gives a solution to this problem.The ohmic resistance of the coil is proportional to the length of the coil,high conductivity and large cross sectional area coil element is a solution to this problem.
Considering all of the above factors efficient wireless power transfer between two coils can be possible.In our practical experiment we have faced some problem.Our power transfer range is very low.The main cause is that our oscillator frequency is in KHz range but for efficient power transfer frequency must be in MHz range.We were not able to design that kind of oscillator because capacitor needed for that are not available at local market.Another cause is that the quality factor of our coil is low,if we use solid conductor then quality factor will be improved but solid conductor is not available at market.

Field of Further Analysis

The analytical part of our thesis may lead to myriad aspects of further research regarding performance inhancement of wireless power transfer.Optimization of each performance controlling parameters considered in our work,might be the subjects to individual researches.In practical experiment several problems have limit our work.Replacement of copper coil by solid conductor and using MHz range frequency to increase the range will be the field of further research.