



WIRELESS POWER TRANSFER SYSTEM FOR EV's, USING MAGNETIC RESONANCE

¹Mr. Vikas Verma, ²Mr. Aditya Pratap Singh, ³Mr. Vivek Singh Rai

¹Assistant Professor, ²Assistant Professor, ³Assistant Professor,

¹ Department of Automobile Engineering,

¹University Institute of Technology - RGPV, Bhopal, India

Abstract: Electric vehicles are seen as an alternative option in response to the depletion of resources. In order to increase the use of EV's in daily life, practical and reliable methods to charge batteries of EV' s are quite important, accordingly wireless power transfer (WPT) is considered as a solution to charge batteries. In this project, a prototype system of wireless charger which has 60 kHz operation frequency is designed. Plug-in Electric Vehicles (PEV) are burdened by the need for cable and plug charger, galvanic isolation of the on-board electronics, bulk and cost of this charger and the large energy storage system (ESS) packs needed. But by using Wireless Charging system's Wireless charging opportunity. It Provides convenience to the customer, inherent electrical isolation, regulation done on grid side and reduce on-board ESS size using dynamic on-road charging. The main objective of our project is to design and develop antenna system suitable for vehicle using resonant magnetic coupled wireless power transfer technology to electric vehicle charging system. Application of WPT in EV's provides a clean, convenient and safe operation. At the core of the WPT systems are primary and secondary coils. These coils construct a loosely coupled system where the coupling coefficient is between 0.1-0.5. In order to transfer the rated power, both sides have to be tuned by resonant capacitors. The operating frequency is a key selection criterion for all applications and it especially affects the dimensions of the coils and the selection of the components for the power electronic circuit. A Resonant wireless transfer system for vehicle charging technology is designed.

Index Terms – Electric Vehicle, Wireless power transfer, PEV, charging.

I. INTRODUCTION

Recently, wireless power supply devices which supply electric power wirelessly (in the medium of air) to apparatuses without power cables or the like have come to be in practical use. The principles upon which wireless electric power transmission is realized are generally categorized into three types:

- Electromagnetic induction type,
- Radio reception type and
- Resonance type.

Electromagnetic induction non-contact power transmission employs the phenomenon in which application of an electric current to one of adjacent coils induces an electromotive force in the other coil with magnetic flux as the medium.

Wireless power transfer (WPT) is a breakthrough technology that provides energy to communication devices without the power units. With the remarkable progress being made recently, this technology has been attracting a lot of attention of scientists and R&D firms around the world. Recently, the usage of mobile appliances such as cell phones, PDAs, laptops, tablets, and other handheld gadgets, equipped with rechargeable batteries has been widely spreading. It is known that electromagnetic energy is associated with the propagation of electromagnetic waves. Theoretically, we can use all electromagnetic waves for a wireless power transmission (WPT).

The difference between the WPT and communication systems is only efficiency. Maxwell's Equations indicate that the electromagnetic field and its power diffuse to all directions. Though we transmit energy in a communication system, the transmitted energy is diffused to all directions. Though the received power is enough for a transmission of information, the efficiency from the transmitter to receiver is quite low. Therefore, we do not call it the WPT system.

During the last few decades, increased concern over the environmental impact of the petroleum-based transportation infrastructure, along with the specter of peak oil, has led to renewed interest in an electric transportation infrastructure.

Battery-powered electric vehicles (EVs) seem like an ideal solution to deal with the energy crisis and global warming since they have zero oil consumption and zero emission. Moreover, we are quite rapidly reaching the end of the cheap oil era. Therefore, the need for alternative growing and the price competition of alternatives against oil is becoming more and more realistic.

Electric vehicles differ from fossil fuel-powered vehicles in that the electricity they consume can be generated from a wide range of sources, including fossil fuels, nuclear power, and renewable sources such as tidal power, solar power, and wind power or any combination of those. However it is generated, this energy is then transmitted to the vehicle through use of overhead lines, wireless energy transfer such as inductive charging, or a direct connection through an electrical cable.

The electricity may then be stored onboard the vehicle using a battery, flywheel, or super-capacitors. Vehicles making use of engines working on the principle of combustion can usually only derive their energy from a single or a few sources, usually non-renewable fossil fuels. A key advantage of electric or hybrid electric vehicles is regenerative braking and suspension, their ability to recover energy normally lost during braking as electricity to be restored to the on-board battery. However, EVs are highly depended on the external energy support.

II. LITERATURE REVIEW

1. In 1864, **James C. Maxwell** predicted the existence of radio waves by means of mathematical model. In 1884, John H. Poynting realized that the Poynting vector would play an important role in quantifying the electromagnetic energy. In 1888, bolstered by Maxwell's theory, Heinrich Hertz succeeded in showing experimental evidence of radio waves by his spark-gap radio transmitter. The prediction and evidence of the radio wave in the end of 19th century was start of the wireless power transmission.

2. During the same period of **Marchese G. Marconi and Reginald Fessenden** who are pioneers of communication via radio waves, Nicola Tesla suggested an idea of the wireless power transmission and carried out the first WPT experiment in 1899. He said "This energy will be collected all over the globe preferably in small amounts, ranging from a fraction of one to a few horse-powers. One of its chief uses will be the illumination of isolated homes". He actually built a gigantic coil which was connected to a high mast of 200-ft with a 3 ft-diameter ball at its top. He fed 300 Kw power to the Tesla coil resonated at 150 kHz. The RF potential at the top sphere reached 100 MV.

Unfortunately, he failed because the transmitted power was diffused to all directions with 150 kHz radio waves whose wave length was 21 km. To concentrate the transmitted power and to increase transmission efficiency, we have to use higher frequency than that used by Tesla. In 1930s, much progress in generating high-power microwaves, namely 1-10 GHz radio waves, was achieved by invention of the magnetron and the klystron. After World War II, high power and high efficiency microwave tubes were

advanced by development of radar technology. We can concentrate a power to receiver with microwaves. We call the wireless power transmission with microwaves as microwave power transmission (MPT). Based on the development of the microwave tubes during the World War II, W. C. Brown started the First MPT research and development in 1960.

First of all, he developed a rectenna, rectifying antenna which he named, for receiving and rectifying microwaves. The efficiency of the first rectenna developed in 1963 was 50 % at output 4WDC and 40% at output 7WDC, respectively. With the rectenna, he succeeded in MPT experiments to wired helicopter in 1964 and to free-flied helicopter in 1968. In 1970s; he tried to increase DC-RF-transmission-RF-DC total efficiency with 2.45 GHz microwave. In 1970, overall DC-DC total efficiency was only 26.5 % at 39WDC in Marshall Space Flight Center. In parallel, he and his team succeeded in the largest MPT demonstration in 1975 at the Venus Site of JPL Goldstone Facility. Distance between a transmitting parabolic antenna, whose diameter was 26m, and a rectenna array, whose size was 3.4 m x 7.2 m, was 1 mile. After 1990s, many MPT laboratory and field experiments were carried out in the world. We often use 2.45 GHz or 5.8 GHz of the ISM band (ISM=Industry, Science, and Medical) for the MPT system. A Canadian group demonstrated fuel-free airplane flight experiment with MPT in 1987 which was called SHARP (Stationary High Altitude Relay Platform) with 2.45 GHz.

3. In USA, there were many MPT research and development projects after **W. C. Brown**: for instance, retro directive microwave transmitters, rectenna, new devices and microwave circuit technologies.

In Japan, there were many field MPT experiments such as fuel-free airplane flight experiment with MPT phased array with 2.411 GHz in 1992, ground-to-ground MPT experiment with Power Company and universities in 1994-95.

Antennas for Microwave Power Transmission: All antennas can be applied for both the MPT system and communication systems, for example, Yagi-Uda antenna, horn antenna, parabolic antenna, micro strip antenna, phased array antenna or any other type of antenna.

To fixed target of the MPT system, we usually select a large parabolic antenna, for example, in MPT demonstration in 1975 at the Venus Site of JPL Goldstone Facility and in ground-to-ground MPT experiment in 1994-95 in Japan. In the fuel-free airship light experiment with MPT in 1995 in Japan, they changed a direction of the parabolic antenna to chase the moving airship.

However, we have to use a phased array antenna for the MPT from/to moving transmitter/receiver which include the SPS because we have to control a microwave beam direction accurately and speedily. The phased array is a directive antenna which generates a beam form whose shape and direction by the relative phases and amplitudes of the waves at the individual antenna elements.

4. The practical and efficient magnetron tube attracted worldwide interest only after when the scientist **K. Okabe** proposed divided anode-type magnetron in 1928. Magnetron technologies received a boost during the World War II, especially with the Japanese Army.

The magnetrons were also useful for microwave ovens. As a result, the magnetron of 500 – 1,000 W is widely in use for microwave ovens in 2.45 GHz, and is a relatively inexpensive oscillator (below \$5). There is a net global capacity of 45.5GW/year for all magnetrons used in microwave ovens whose production is 50– 55 millions. It was W. C. Brown who invented a voltage controlled oscillator with a cooker-type magnetron in PLL.

5. **Semiconductor Amplifier**: After 1980s, semiconductor devices became dominant in microwave world instead of the microwave tubes. This was driven by advances in mobile phone networks. The semiconductor device is expected to expand microwave applications, for example, phased array and active integrated antenna (AIA), because of its manageability and mass productivity. After 1990s, some MPT experiments were carried out in Japan with phased array of semiconductor amplifiers.

Typical semiconductor devices for microwave circuits are FET (Field Effect Transistor), HBT (Hetero junction Bipolar Transistor), and HEMT (High Electron Mobility Transistor). Present materials for the semiconductor devices are Si for lower frequency below a few GHz and GaAs for higher frequency.. It is easy to control phase and amplitude through the microwave circuits with semiconductor devices, for

example, amplifiers, phase shifters, modulators, and so on. Currently, new materials are under development to enable semiconductor devices yield increased output power and efficiency.

6. Transmitter Issues and Answers for Space Use: Largest MPT application is a SPS in which over GW microwave will be transmitted from space to ground at distance of 36,000km. In the SPS, we will use microwave transmitters in space. For space use, the microwave transmitter will be required lightness to reduce launch cost and higher efficiency to reduce heat problem.

7. Recent Technologies of Rectenna: The word “rectenna” is composed of “rectifying circuit” and “antenna”. The rectenna can receive and rectify a microwave power to DC. The rectenna is passive element with a rectifying diode, operated without any power source. The circuit, especially diode, mainly determines the RF-DC conversion efficiency. Silicon Schottky barrier diodes were usually used for earlier rectenna. New devices like SiC and GaN are expected to increase the efficiency. The rectenna with FET or HEMT appear ed recently. The single shunt full-wave rectifier is always used for the rectenna. It consists of a diode inserted in the circuit in parallel, a $\lambda/4$ distributed line, and a capacitor inserted in parallel. In an ideal situation, 100% of the received microwave power should be converted into DC power.

8. Recent Technologies of Rectenna Array: The rectenna will be used as an array for high power MPT because one rectenna element rectifies a few W only. For usual phased array antenna, mutual coupling and phase distribution are problems to solve. For the rectenna array, problem is different from that of the array antenna because the rectenna array is connected not in microwave phase but in DC phase.

III. OBJECTIVE

In an effort to address battery problems, the concept of roadway-powered electric vehicles has been proposed. With this system, the electric vehicle is charged on the road by wireless power charging, and the battery can hence be downsized and no waiting time for charging is needed.

Problem Statement - To design and develop antenna and wireless power transfer system suitable for moving electric vehicles (EVs). Using resonant magnetic coupling principle,

The wireless power transfer technology to the electric vehicle has designed. When the vehicle's power receiver's frequency is tuned in exact with the resonance frequency of the transmitter unit below the road, the electrical power will flow from the transmitter coil inside the platform to the receiving coil inside the bottom of the electric vehicle.

This project describes the design and implementation of a wireless power transfer system for moving electric vehicles involving the model EV system.

IV. BLOCK AND CIRCUIT DIAGRAM OF THE SET-UP

4.1 BLOCK DIAGRAM

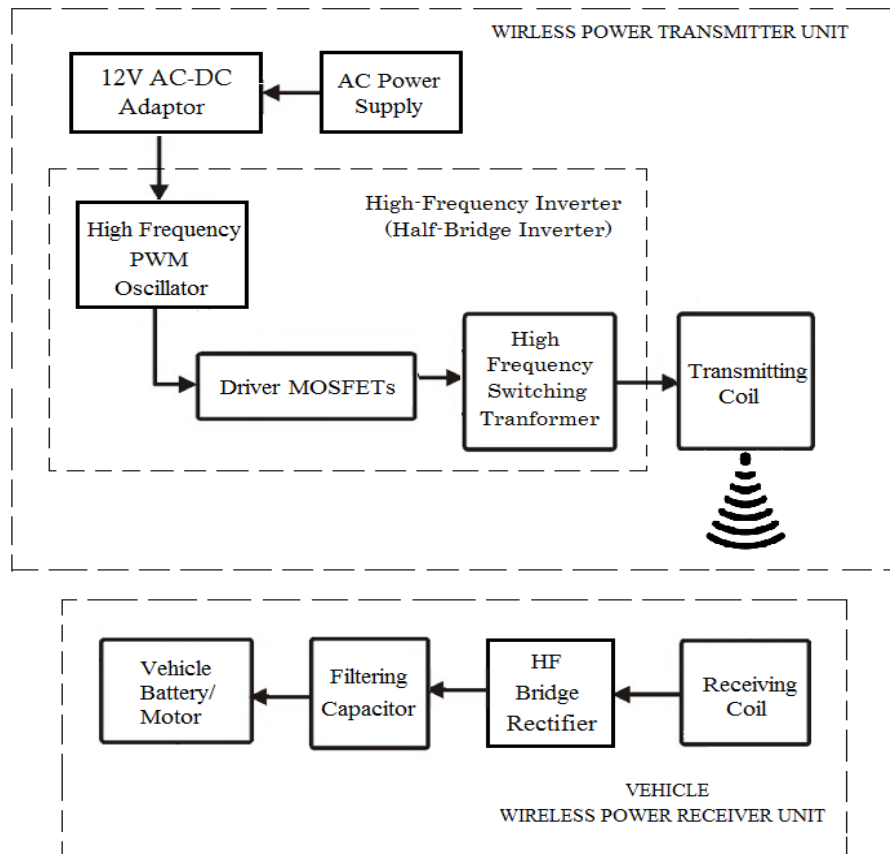


Figure 4.1: Block Diagram

4.1 BLOCK DIAGRAM DESCRIPTION

4.1.1 AC Power Supply

The supply for the wireless power transmitter is taken from AC220v source.

4.1.2 AC-DC Adaptor (SMPS)

Switching Mode power supply is used here to convert AC to DC. Here the input of the SMPS is 220v AC and output will be 12v DC.

4.1.3 High Frequency PWM Oscillator

High Frequency oscillator is designed using KA3525 IC. The IC circuit generates PWM switching pulses for driving the MOSFETs. The oscillator produces a PWM frequency of 65 KHz range. Here two separate PWM pulses PWM1 and PWM2 are produced which are supplied to the two MOSFET gate. Each PWM pulses are 90 degrees out of phase, which result in alternative switching of each MOSFETs.

4.1.4 Driver MOSFETs

Here two driver MOSFETs are used to switch the high frequency transformer. The two ends of the transformer primary is connected to the 'Drain' pin of the two MOSFETs. When a MOSFET gets turned ON, then current flows through the primary winding of the transformer. Half of the primary gets turned ON by one MOSFET and another half by another MOSFET. Both MOSFETs switch alternatively producing a AC square wave in the primary of the transformer.

4.1.5 High Frequency Transformer

Here the DC-AC conversion takes place in the high-frequency switching transformer. Unlike normal transformer, the core of the HF transformer is made of ferrite which makes it capable of operating at higher frequencies. Due to high frequency switching the losses in conversion is very lower than normal transformer. Here the HF transformer converts DC current into a high-frequency AC current. The primary of transformer has three tappings, one is centre tap for DC current input and other two tapings for return

path of the current through MOSFETs during switching. The secondary output will be HF AC current, which is given to the transmitter coil.

4.1.6 Half bridge Inverter

Half bridge inverter circuit driver consists of a high-frequency switching transformer and two MOSFETs. The switching transformer primary is connected to two MOSFETs and secondary is connected to transmitting coil. The half bridge inverter converts input DC voltage into a high frequency AC voltage.

4.1.7 Transmitting Coil

The transmitter coil is designed with windings of copper coils which convert the high frequency oscillating electrical current into electromagnetic waves resonating at a particular frequency.

4.1.8 Receiving Coil

The receiver coil receives electromagnetic waves from the transmitter antenna and converts back into high frequency electrical output.

4.1.9 HF Bridge Rectifier

High Frequency (HF) bridge rectifier consists of fast switching rectifier diodes which converts HF AC voltage from the receiving coil into a DC voltage.

4.1.10 Filtering Capacitor

The filtering capacitor filters out the ripple generated at the rectifier and produces as smooth and stable DC voltage output which can be used for driving the vehicle motor or for battery charging purpose.

4.2 CIRCUIT DIAGRAM

4.2.1 Transmitter Circuit Diagram

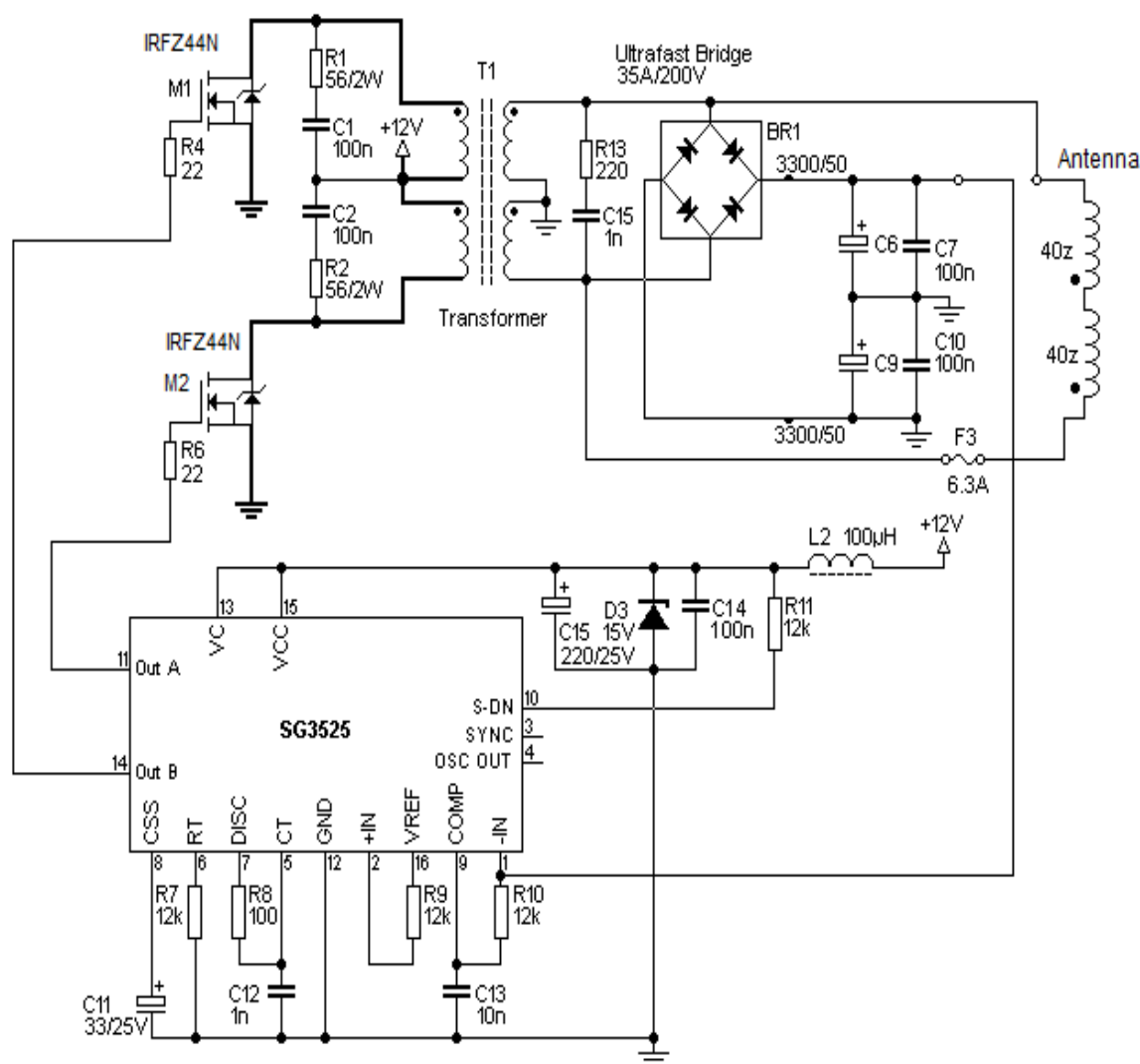


Figure 4.2: Transmitter Circuit Diagram

4.2.2 Vehicle Receiver Circuit Diagram

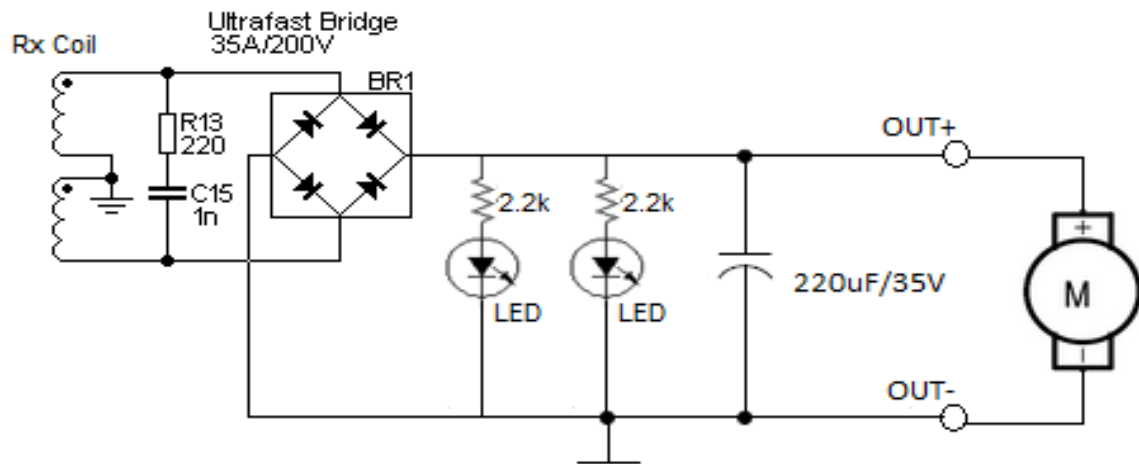


Figure 4.3: Vehicle Receiver Circuit Diagram

4.2.3 Input and Output of High Frequency Inverter

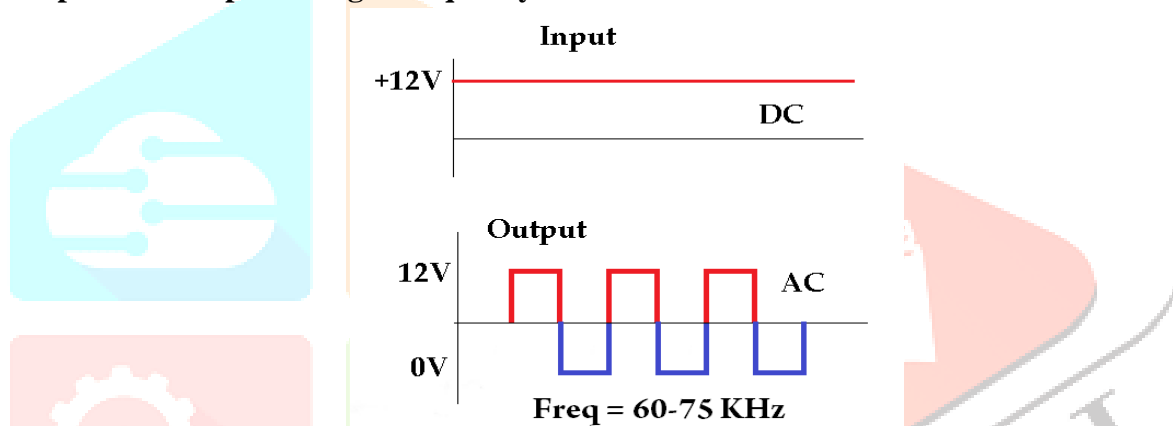


Figure 4.4: Input and Output of High Frequency Inverter

4.2. CIRCUIT EXPLANATION

4.2.1 Transmitter Section

1. The first section of the circuit is the High-Frequency inverter which is designed using SG3525 IC. It produces High Frequency PWM signal. The frequency range is 60 – 75 KHz.
2. The second section is the Half-Bridge Driver circuit which consists of two N-channel MOSFETs. MOSFETs drivers feed the PWM signal to the primary of a HF switching transformer.
3. The third section is the High-Frequency Transformer. It converts the DC DC input fed in the primary coil by the MOSFETS into HF AC output at its secondary coil.
4. The fourth section is the transmitting coil. It converts the fed HF-AC current into electromagnetic waves.

SG3525 IC is basically a PWM oscillator chip which produces high-frequency PWM signal which can drive MOSFETs directly to switch them ON and OFF. The frequency of the PWM signal can be set and also adjusted using the timing control resistor and capacitor which are connected to the pin-6 and pin-5 (RT and CT). The IC has two PWM outputs which are pin-11 and pin-14 (out A and out B). Two pwm outputs are connected to the gate terminal of MOSFETs connected in half-bridge configuration. Transmitter coil is a centre tapped coil, so it has three terminals. The Drain terminal of the two MOSFETs are connected to two ends of the transmitter coil. Centre tap of the coil is connected to the DC source power supply which is 12v.

When power is turned ON the IC SG3525 starts oscillating and produces PWM signals. The MOSFETs connected to its outputs are switched ON and OFF alternatively. The Out A and Out B of the IC output are 90degrees out of phase. So when one MOSFET is in ON condition the other # will be in OFF condition. Here we use a oscillator frequency of 60 to 80KHz frequency range. So the MOSFETs are switched at high frequency. When on MOSFET is in ON condition the DC current will flow from the centre tap of transmitter coil through MOSFET drain terminal and reach the source terminal which is connected to ground. So in first half cycle the direction of DC current will be in first half coil portion of the transmitter coil. In the same way the current flow will be in second half portion of the coil during next half cycle.

Thus the two MOSFETs create a current flow which are opposite in direction in each switching cycle. So as a result an alternating current is produced in the transmitting coil. This configuration thus produces a high frequency AC current from the input DC current. Transmitter coil converts the HF AC electric current into HF electromagnetic field. Thus the transmitter coil converts electric current and transmits in the form of electromagnetic waves.

4.2.2 Receiver Section

Receiver has a three section.

1. First is the receiver coil
2. Second is the High-Frequency rectifier
3. Third is the DC ripple filter

Receiver has a receiving coil which has same resonant frequency of the transmitter coil. So when placed near the transmitter coil it will pick up the electromagnetic field and converts it into the high frequency AC current. Output of receiver coil is given to a high frequency rectifier which converts HF AC to DC voltage output. A capacitor filter at the output of rectifier filters the ripple in DC and gives a stable DC output voltage. A DC output is produced at the output of receiver which is used to power any DC loads.

V. PRACTICAL APPLICATION

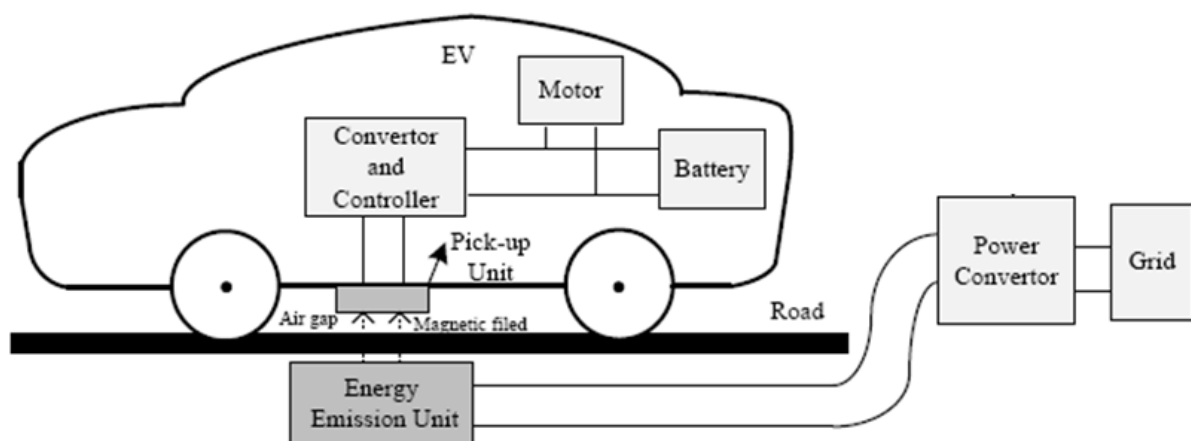


Figure 5.1: Practical Application

The electrical power flows from the power transmitter coil inside the platform to the receiving coil inside the bottom of the electric vehicle. Electrical charging is done once the resonant frequency of both the coils matches and the vehicle charged automatically. When the vehicle is moved the charger goes to the power saving mode and cut off the charger coil.

5.1 Basic Design

A wireless power transfer system uses inductive coupling. One of the most important factors that must be considered in designing an inductive coupling system is the target power of the system. Voltage and current ranges, usable devices, and operating frequency of the system depend on the target power. Because the wireless power transfer system for moving electric vehicles is a public service system that is installed in a road, the use of the resonance frequency must be permitted by the government.

Generally, wireless power transfer systems for electric vehicles use 10–100-kHz frequency. In the EV system, the target power is 100 kW, and the resonance frequency is 78 kHz. The circuit is fundamentally the same as the circuit model of transformers. In the circuit, a larger mutual inductance M facilitates more effective power transfer. The mutual inductance M is determined by L_1 , L_2 , and the coupling coefficient k , as follows:

$$M = k\sqrt{L_1L_2}$$

where k indicates the degree of coupling strength and is between zero and one.

5.2 System Operation

The wireless power transfer system consists of a power transmitter part and a power receiver part. The power transmitter part is composed of an inverter and power lines. The inverter provides power, and the power lines carry current and generate magnetic flux. The power receiver part is composed of pickup modules, rectifiers, and regulators. The pickup modules generate power from induced voltage and current, the rectifiers convert ac power to dc, and the regulators control the output voltage, which is input to batteries and motors.

The inverter receives power from an electric power company and converts 60-Hz operating frequency into 20-kHz resonance frequency. Although the inverter can be controlled to provide constant voltage, constant current control is more advantageous in dealing with changes in the load resistance or multi-pickup charging. Therefore, in the OLEV system, the inverter converts 60-Hz power to 260-A constant current at 20-kHz resonance frequency. The power line modules are installed underneath the road and along the road.

Some of the transferred power is used to drive the motors, and the remainder is used to charge the batteries. When the vehicle stops, all of the power is used to charge the batteries.

VI. WIRELESS POWER THEORY

6.1 Wireless power transmission

Wireless power transmission is not a new idea. Nikola Tesla demonstrated transmission of electrical energy without wires in early 19th century. Tesla used electromagnetic induction systems. William C Brown demonstrated a micro wave powered model helicopter in 1964. This receives all the power needed for flight from a micro wave beam. In 1975 Bill Brown transmitted 30kW power over a distance of 1 mile at 84% efficiency without using cables. Researchers developed several technique for moving electricity over long distance without wires. Some exist only as theories or prototypes, but others are already in use.

Consider an example, in these electric devices recharging without any plug-in. The device which can be recharged is placed on a charger. Supply is given to the charger and there is no electrical contact between charger and device.

Previous schemes for wireless power transmission included attempts by the late scientist Nikola Tesla and the Microwave power transmission. Both Tesla's design and the later microwave power were forms of radiative power transfer. Radiative transfer, used in wireless communication, is not particularly suitable for power transmission due to its low efficiency and radiative loss due to its Omni directional nature.

6.2 Theoretical background

The principle of Evanescent Wave Coupling extends the principle of Electromagnetic induction. Electromagnetic induction works on the principle of a primary coil generating a predominantly magnetic field and a secondary coil being within that field so a current is induced within its coils. This causes the relatively short range due to the amount of power required to produce an electromagnetic field. Over greater distances the non-resonant induction method is inefficient and wastes much of the transmitted energy just to increase range.

This is where the resonance comes in and helps the efficiency dramatically by "tunneling" the magnetic field to a receiver coil that resonates at the same frequency.

Theoretical analysis shows that by sending electromagnetic waves around in a highly angular waveguide¹, evanescent waves are produced which carry no energy. If a proper resonant waveguide is brought near the transmitter, the evanescent waves can allow the energy to tunnel to the power drawing waveguide, where they can be rectified into DC power. Since the electromagnetic waves would tunnel, they would not propagate through the air to be absorbed or be dissipated, and would not disrupt electronic devices or cause physical injury.

6.3 Methods of wireless power transmission

- Inductive coupling
- Transformer coupling
- Resonant Inductive Coupling
- Radio and Microwave Energy Transfer

6.3.1 Inductive Coupling

The coupling between two electric circuits through inductances linked by a common changing magnetic field.

6.3.2 Transformer Coupling

Electrical energy transferred from one circuit to another with by use of a magnetic core.

6.3.3 Radio & Microwave Energy Transfer

To use RF or Microwave energy for transmitting power, in which the radiated RF energy from an antenna is extracted and converted into usable energy through a receiving antenna.

6.3.4 Resonant Inductive Coupling

The inductive coupling is the resonant coupling between the coils of two LC circuits with the same resonant frequency, transferring energy from one coil to the others.

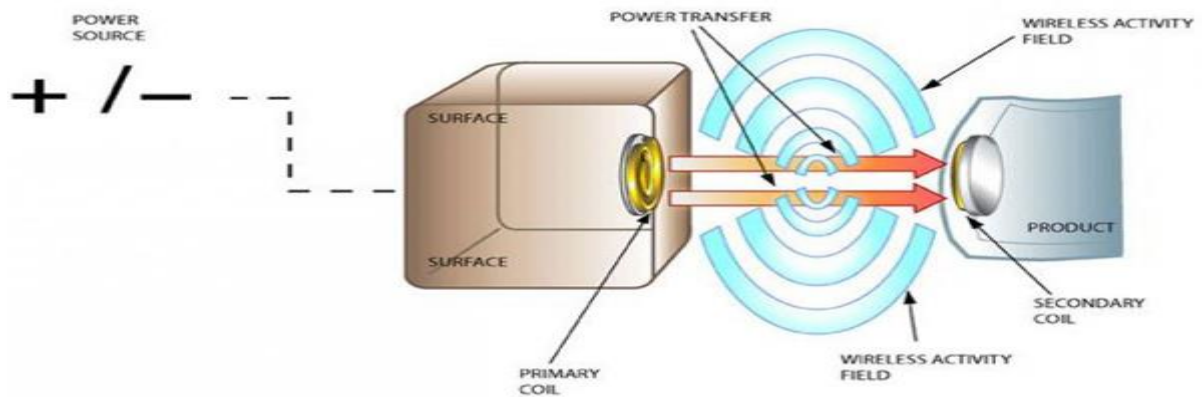


Figure 6.1: Resonant Inductive Coupling

With inductive resonance, electromagnetic energy is only transferred to recipient devices that share the identical resonant frequencies as the energy source, so energy transfer efficiency is maintained, even when misalignment occurs.

6.4 Concept of Resonant Wireless Power Transmission

6.4.1 Resonance

Resonance is a phenomenon that occurs in nature in many different forms. In general, resonance involves energy oscillating between two modes, a familiar example being a mechanical pendulum in which energy oscillates between potential and kinetic forms. In a system at resonance, it is possible to have a large build up of stored energy while having only a weak excitation to the system. The build-up occurs if the rate of energy injection into the system is greater than the rate of energy loss by the system.

The behavior of an isolated resonator can be described by two fundamental parameters, its resonant frequency and its intrinsic loss rate, Γ . The ratio of these two parameters defines the quality factor or of the resonator (Q) a measure of how well it stores energy.

An example of an electromagnetic resonator is the circuit shown in Figure, containing an inductor, a capacitor and a resistor.

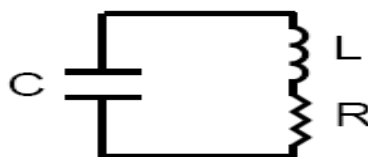


Figure 6.2: Electromagnetic Resonator

6.4.2 Example of a Resonator

In this circuit, energy oscillates at the resonant frequency between the inductor (energy stored in the magnetic field) and the capacitor (energy stored in the electric field) and is dissipated in the resistor. The resonant frequency and the quality factor for this resonator are

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

And

$$Q = \frac{\omega_0}{2\Gamma} = \sqrt{\frac{L}{C}} \frac{1}{R} = \frac{\omega_0 L}{R}$$

The expression shows that decreasing the loss in the circuit, i.e., reducing, increases the quality factor of the system. In highly-resonant wireless power transfer systems, the system resonators must be high-Q in order to efficiently transfer energy. High-Q electromagnetic resonators are typically made from conductors and components with low absorptive (also sometimes referred to as ohmic, resistive, series resistive, etc.) losses and low radiative losses, and have relatively narrow resonant frequency widths. Also, the resonators may be designed to reduce their interactions with extraneous objects.

6.4.3 Coupled Resonators

If two resonators are placed in proximity to one another such that there is coupling between them, it becomes possible for the resonators to exchange energy. The efficiency of the energy exchange depends on the characteristic parameters for each resonator and the energy coupling rate, κ , between them. The dynamics of the two resonator system can be described using coupled-mode theory, or from an analysis of a circuit equivalent of the coupled system of resonators. One equivalent circuit for coupled resonators is the series resonant circuit.

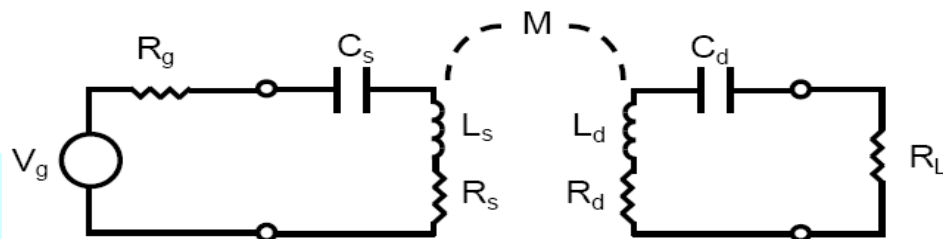


Figure 6.3: Equivalent circuit for the coupled resonator system

Here the generator is a sinusoidal voltage source with amplitude at frequency with generator resistance. The source and device resonator coils are represented by the inductors and, which are coupled through the mutual inductance M , where.

$$M = k\sqrt{L_s L_d}$$

Each coil has a series capacitor to form a resonator. The resistances and are the parasitic resistances (including both ohmic and radiative losses) of the coil and resonant capacitor for the respective resonators. Where

$$U = \frac{\omega M}{\sqrt{R_s R_d}} = \frac{\kappa}{\sqrt{\Gamma_s \Gamma_d}} = k\sqrt{Q_s Q_d}$$

We have the ability to choose the generator and load resistances which give the best system performance (or use an impedance transformation network to match to other resistance values). If we choose

$$\frac{R_g}{R_s} = \frac{R_L}{R_d} = \sqrt{1 + U^2}$$

Then the efficiency of the power transmission is maximized

$$\eta_{opt} = \frac{U^2}{(1 + \sqrt{1 + U^2})^2}$$

Here one can see that highly efficient energy transfer is possible in systems with large values of.

Note that the impedance matching described above is equivalent to the coupled mode theory treatment that shows that work extracted from a device can be modeled as a circuit resistance that has the

effect of contributing an additional term w , to an unloaded device object's energy loss rate d , so that the overall energy loss rate is given by

$$\Gamma'_d = \Gamma_d + \Gamma_w$$

And that the efficiency of the power transmission is maximized when

$$\frac{\Gamma_w}{\Gamma_d} = \sqrt{\left[1 + \left(\kappa^2 / \Gamma_s \Gamma_d\right)\right]} = \sqrt{1 + k^2 Q_s Q_d} = \sqrt{1 + U^2}$$

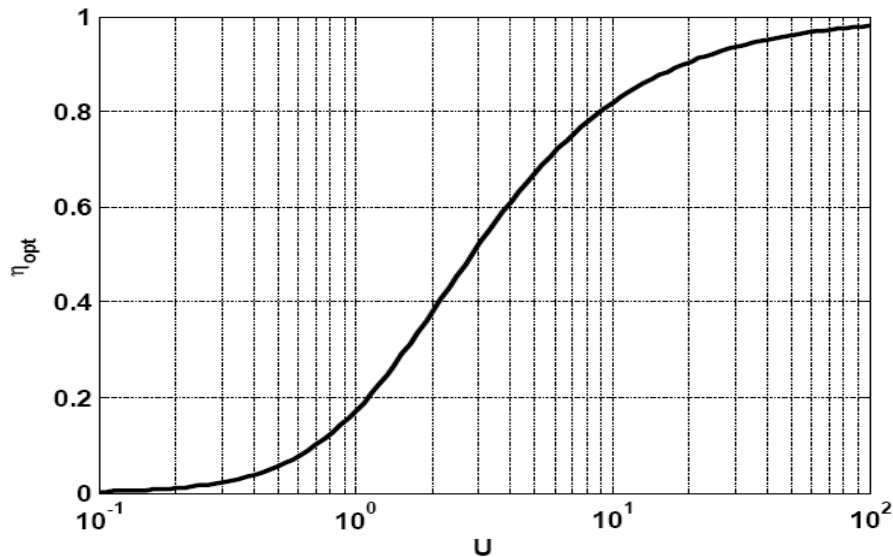


Figure 6.4: Optimum efficiency of energy transfer

Note that the best possible efficiency of a wireless power transmission system only depends on the system figure-of-merit, which can also be written in terms of the magnetic coupling coefficient between the resonators, k , and the unloaded resonator quality factors, Q_s and Q_d , and

$$U = \frac{\omega M}{\sqrt{R_s R_d}} = k \sqrt{Q_s Q_d}$$

Knowing the resonator quality factors and the range of magnetic coupling between them for a specific application, one can use Equations to determine the best efficiency possible for the system.

6.5 Transmitter Unit

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.

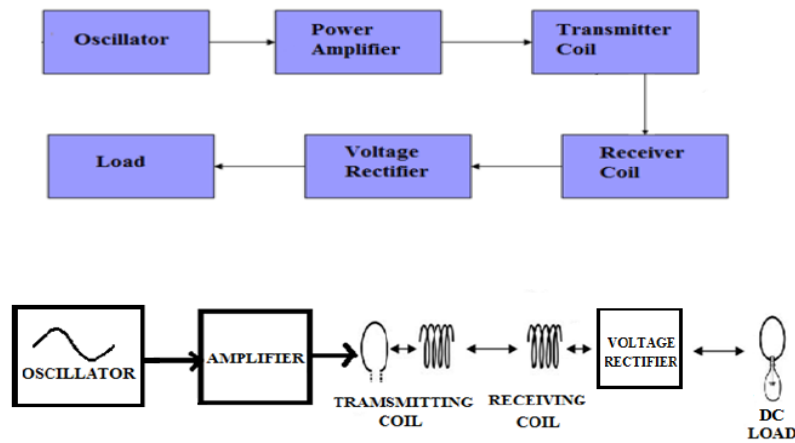


Figure 6.5: Transmitter and Receiver Unit

6.6 Voltage Rectifier

A rectifier would be needed to rectify the AC voltage received from the receiver coil to drive a DC load. A type of circuit that produces an output waveform that generates an output voltage which is purely DC or 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.

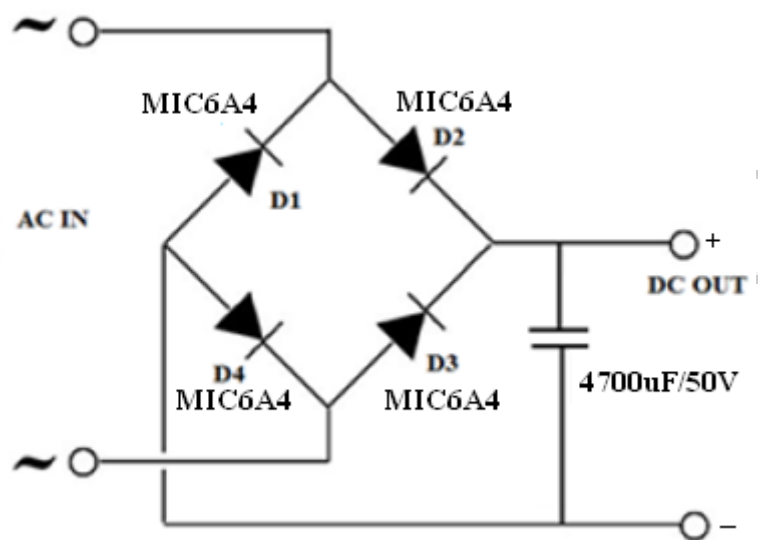


Figure 6.6: Bridge Rectifier

Since the diodes had to rectify AC signals of Megahertz frequencies, fast signal diodes, MIC6A4, 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.

6.7 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.

6.8 Power Amplifier/ Driver

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.

6.9 Switching MOSFET'S

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.

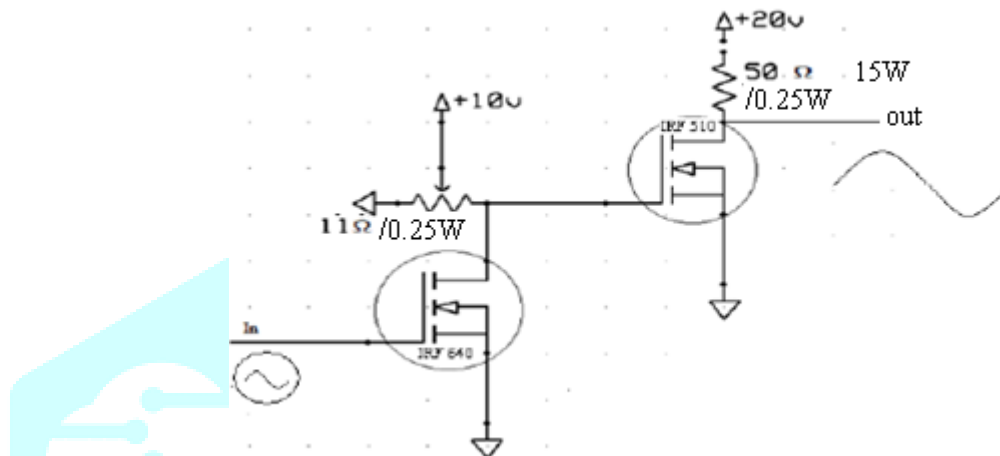


Figure 6.7: Switching MOSFET'S

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 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.

6.10 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. 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.

VII. HARDWARE DETAILS

7.1 MOSFET

7.1.1 Introduction

The metal–oxide–semiconductor field-effect transistor (MOSFET, MOS-FET, or MOS FET) is a transistor used for amplifying or switching electronic signals. Although the MOSFET is a four-terminal device with source (S), gate (G), drain (D), and body (B) terminals, the body (or substrate) of the MOSFET often is connected to the source terminal, making it a three-terminal device like other field-effect transistors. When two terminals are connected to each other (short-circuited) only three terminals appear

in electrical diagrams. The MOSFET is by far the most common transistor in both digital and analog circuits, though the bipolar junction transistor was at one time much more common.

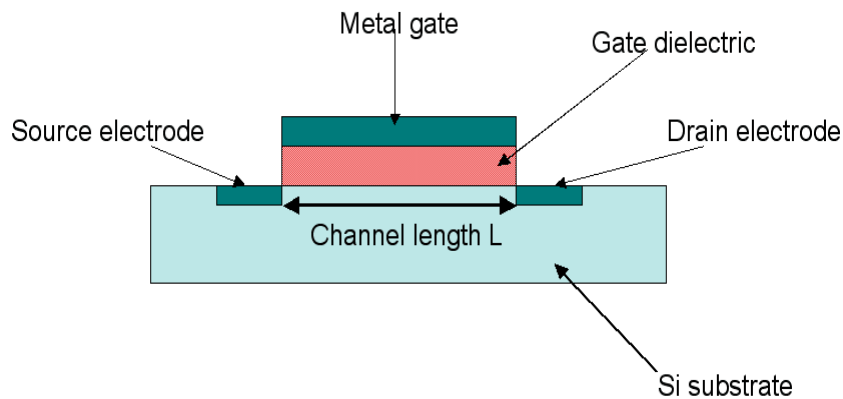


Figure 7.1: MOSFET Construction Diagram

In enhancement mode MOSFETs, a voltage drop across the oxide induces a conducting channel between the source and drain contacts via the field effect. The term "enhancement mode" refers to the increase of conductivity with increase in oxide field that adds carriers to the channel, also referred to as the inversion layer. The channel can contain electrons (called an nMOSFET or nMOS), or holes (called a pMOSFET or pMOS), opposite in type to the substrate, so nMOS is made with a p-type substrate, and pMOS with an n-type substrate (see article on semiconductor devices).

7.1.2 Circuit Symbols

A variety of symbols are used for the MOSFET. The basic design is generally a line for the channel with the source and drain leaving it at right angles and then bending back at right angles into the same direction as the channel. Sometimes three line segments are used for enhancement mode and a solid line for depletion mode. Another line is drawn parallel to the channel for the gate.

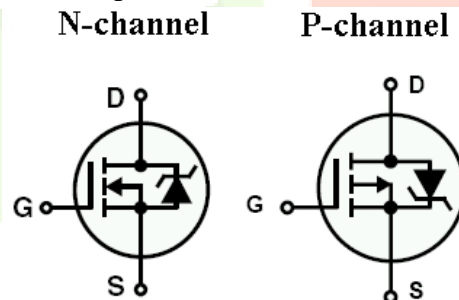


Figure 7.2: Symbols Of MOSFET

The bulk connection, if shown, is shown connected to the back of the channel with an arrow indicating PMOS or NMOS. Arrows always point from P to N, so an NMOS (N-channel in P-well or P-substrate) has the arrow pointing in (from the bulk to the channel). If the bulk is connected to the source (as is generally the case with discrete devices) it is sometimes angled to meet up with the source leaving the transistor. Comparison of enhancement-mode and depletion-mode MOSFET symbols, along with JFET symbols

7.2 Power MOSFET

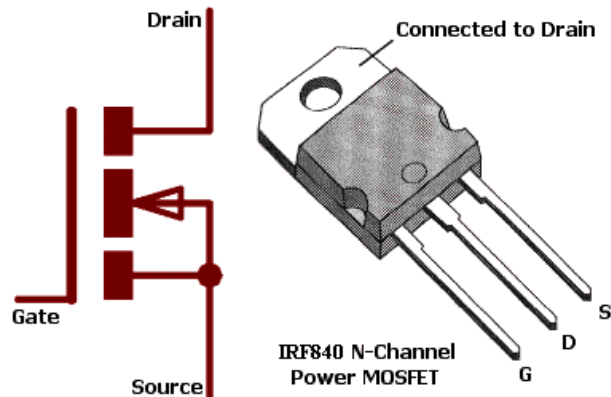


Figure 7.3: Pin Details Of MOSFET IRF840

A Power MOSFET is a specific type of metal oxide semiconductor field-effect transistor (MOSFET) designed to handle significant power levels. Compared to the other power semiconductor devices (IGBT, Thyristor...), its main advantages are high commutation speed and good efficiency at low voltages. It shares with the IGBT an isolated gate that makes it easy to drive.

It was made possible by the evolution of CMOS technology, developed for manufacturing Integrated circuits in the late 1970s. The power MOSFET shares its operating principle with its low-power counterpart, the lateral MOSFET.

7.3 KA3525 Pulse Width Modulator

The KA3525 regulating pulse width modulator contains all of the control circuit necessary to implement switching regulators of either polarity transformer coupled DC to DC converters, transformer less polarity converters and voltage doublers, as well as other power control applications. This device includes a 5V voltage regulator capable of supplying up to 50mA to external circuit, a control amplifier, an oscillator, a pulse width modulator, a phase splitting flip-flop, dual alternating output switch transistors, and current limiting and shut-down circuit. Both the regulator output transistor and each output switch are internally current limiting and, to limit junction temperature, an internal thermal shutdown circuit is employed.

7.3.1 Features

- Complete PWM power control circuit
- Operation beyond 100KHz
- 2% frequency stability with temperature
- Total quiescent current less than 10mA
- Single ended or push-pull outputs
- Current limit amplifier provides external component protection
- On-chip protection against excessive junction temperature and output current
- 5V, 50mA linear regulator output available to user

7.3.2 Pin Details

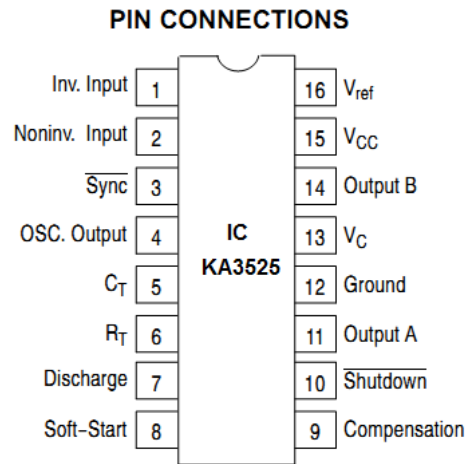


Figure 7.4: Pin Details Of IC KA3525

7.3.3 INTERNAL BLOCK DIAGRAM

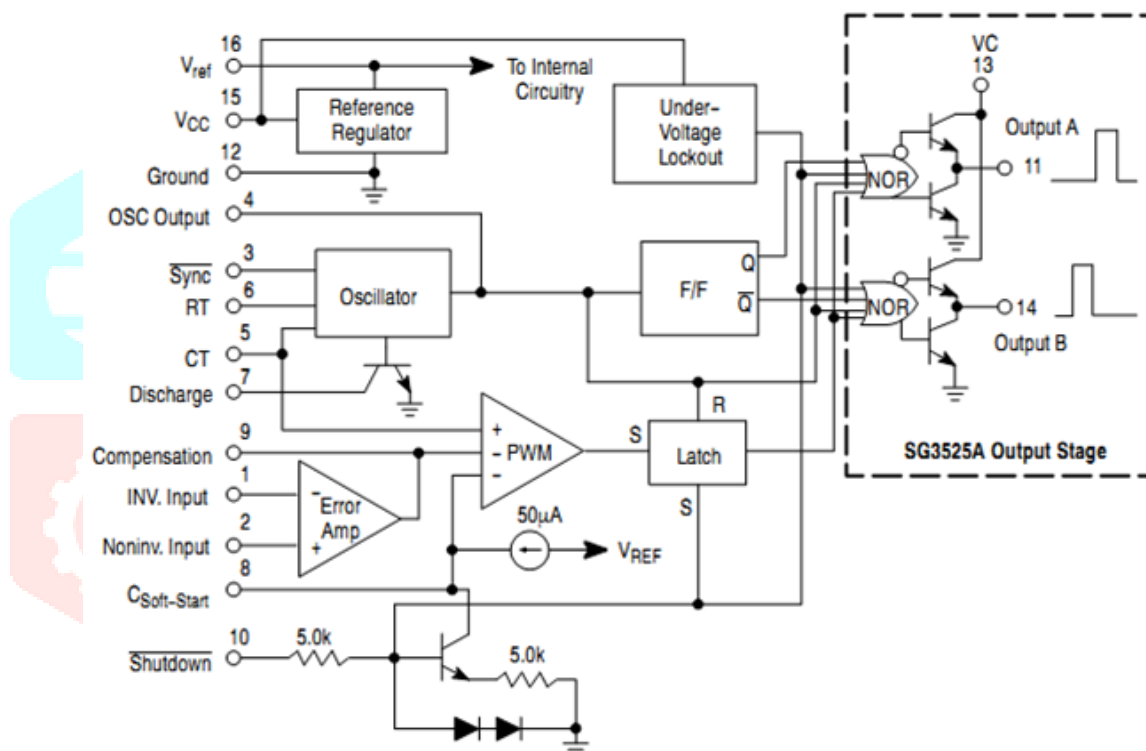


Figure 7.5: Internal Block Diagram Of IC KA3525

7.3.4 IC KA3525

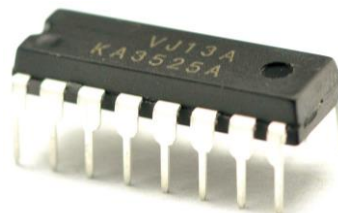


Figure 7.6: DIP package

7.3.5 IC SG3525 PWM Controller

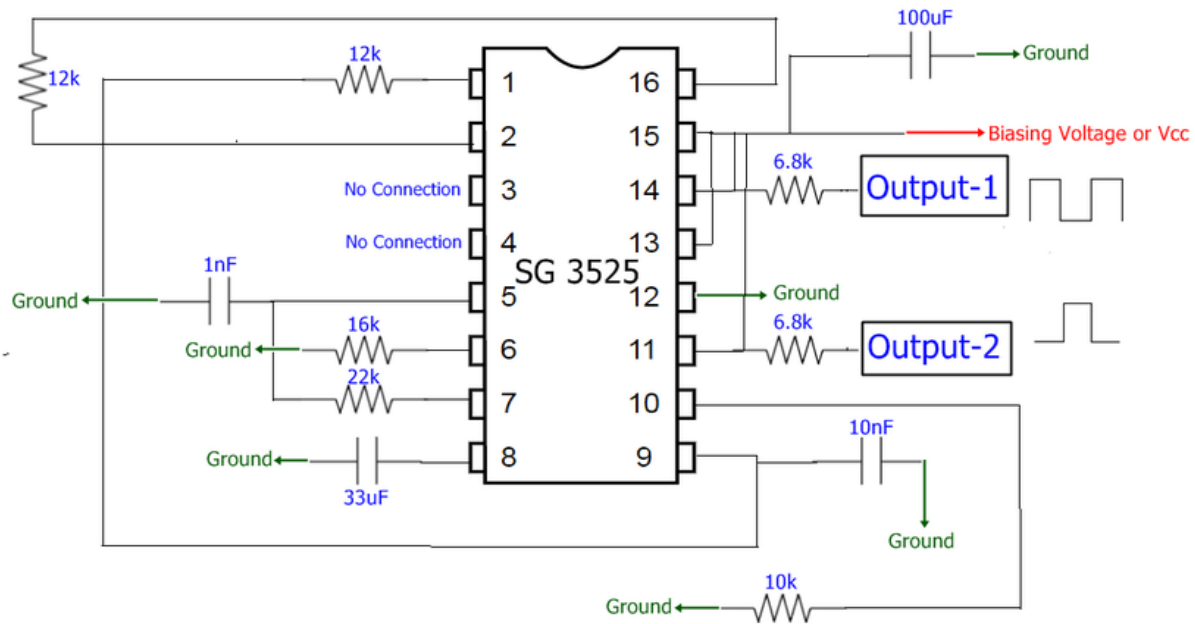


Figure 7.7: Schematic of a Basic Push-Pull Converter

7.3.6 Pin Function of KA3525 IC

Pins 1 (Inverting Input) and 2 (Non Inverting Input) are the inputs to the on-board error amplifier. We can think of it as a comparator that controls the increase or decrease of the duty cycle for the “feedback” that you associate with Pulse Width Modulation (PWM).

This functions either to increase or decrease the duty cycle depending on the voltage levels on the Inverting and Non-Inverting Inputs – pins 1 and 2 respectively. When voltage on the Inverting Input (pin 1) is greater than voltage on the Non-Inverting Input (pin 2), duty cycle is decreased. When voltage on the Non-Inverting Input (pin 2) is greater than voltage on the Inverting Input (pin 1), duty cycle is increased.

The frequency of PWM is dependent on the timing capacitance and the timing resistance. The timing capacitor (CT) is connected between pin 5 and ground. The timing resistor (RT) is connected between pin 6 and ground. The resistance between pins 5 and 7 (RD) determines the deadtime (and also slightly affects the frequency).

The frequency is related to RT, CT and RD by the relationship:

$$f = \frac{1}{C_T (0.7 R_T + 3 R_D)}$$

With RT and RD in Ω and CT in F, f is in Hz.

Typical values of RD are in the range 10Ω to 47Ω . The range of values usable (as specified by the manufacturers of SG3525) is 0Ω to 500Ω .

RT must be within the range $2k\Omega$ to $150k\Omega$. CT must be within the range 1nF (code 102) to $0.2\mu\text{F}$ (code 224). The oscillator frequency must be within the range 100Hz to 400kHz. There is a flip-flop before the driver stage, due to which your output signals will have frequencies half that of the oscillator frequency that is calculated using the above mentioned formula. So, if you are looking to use this for a 50Hz inverter, you require drive signals of 100Hz. So, the oscillator frequency must be 100Hz.

A capacitance connected between pin 8 and ground provides the soft-start functionality. The larger the capacitance, the larger the soft-start time. This means that the time taken to go from 0% duty cycle to the desired duty cycle or maximum duty cycle is larger.

So, the duty cycle increases more slowly initially. Keep in mind that this only affects initial rate of increase of duty cycle, ie, the rate of increase of duty cycle after the SG3525 starts up. Typical values of the soft-start capacitance lie within the range $1\mu\text{F}$ to $22\mu\text{F}$ depending on the desired soft-start time.

Pin 16 is the output from the voltage reference section. SG3525 contains an internal voltage reference module rated at $+5.1\text{V}$ that is trimmed to provide a $\pm 1\%$ accuracy. This reference is often used to provide a reference voltage to the error amplifier for setting the feedback reference voltage. It can be directly connected to one of the inputs or a voltage divider can be used to further scale down the voltage.

Pin 15 is VCC – the supply voltage to the SG3525 that makes it run. VCC must lie within the range 8V to 35V . SG3525 has an under-voltage lockout circuit that prevents operation when VCC is below 8V , thus preventing erroneous operation or malfunction.

Pin 13 is VC – the supply voltage to the SG3525 driver stage. It is connected to the collectors of the NPN transistors in the output totem-pole stage. Hence the name VC. VC must lie within the range 4.5V to 35V . The output drive voltage will be one transistor voltage drop below VC. So when driving Power MOSFETs, VC should be within the range 9V to 18V (as most Power MOSFETs require minimum 8V to be fully on and have a maximum VGS breakdown voltage of 20V). For driving logic level MOSFETs, lower VC may be used. Care must be taken to ensure that the maximum VGS breakdown voltage of the MOSFET is not crossed. Similarly when the SG3525 outputs are fed to another driver or IGBT, VC must be selected accordingly, keeping in mind the required voltage for the device being fed or driven. It is common practice to tie VC to VCC when VCC is below 20V .

Pin 12 is the Ground connection and should be connected to the circuit ground. It must share a common ground with the device it drives.

Pins 11 and 14 are the outputs from which the drive signals are to be taken. They are the outputs of the SG3525 internal driver stage and can be used to directly drive MOSFETs and IGBTs. They have a continuous current rating of 100mA and a peak rating of 500mA . When greater current or better drive is required, a further driver stage using discrete transistors or a dedicated driver stage should be used. Similarly a driver stage should be used when driving the device causing excessive power dissipation and heating of SG3525. When driving MOSFETs in a bridge configuration, high-low side drivers or gate-drive transformers must be used as the SG3525 is designed only for low-side drive.

Pin 10 is shutdown. When this pin is low, PWM is enabled. When this pin is high, the PWM latch is immediately set. This provides the fastest turn-off signal to the outputs. At the same time the soft-start capacitor is discharged with a $150\mu\text{A}$ current source. An alternative method of shutting down the SG3525 is to pull either pin 8 or pin 9 low. However, this is not as quick as using the shutdown pin. So, when quick shutdown is required, a high signal must be applied to pin 10. This pin should not be left floating as it could pick up noise and cause problems. So, this pin is usually held low with a pull-down resistor.

Pin 9 is compensation. It may be used in conjunction with pin 1 to provide feedback compensation. Let's look at pin 8 now. We have connected a $1\mu\text{F}$ capacitor from pin 8 to ground and this provides a small soft-start.

Let's look at pin 10 now. Initially it's pulled up to VREF with a pull-up resistor. So, PWM is disabled and does not run. However, when the switch is on, pin 10 is now at ground and so PWM is enabled. So, we've made use of the SG3525 shutdown option (via pin 10). Thus the switch acts like an on/off switch.

Pin 2 is connected to VREF and is thus at a potential of $+5.1\text{V}$ ($\pm 1\%$). The output of the converter is connected to pin 1 through a voltage divider with resistances.

Pins 11 and 14 drive the MOSFETs. There are resistors in series with the gate to limit gate current. The resistors from gate-to-source ensure that MOSFETs don't get accidentally turned on.

7.3.8 Absolute Maximum Ratings

Parameter	Symbol	Value	Unit
Supply Voltage	VCC	40	V
Reference Output Current	IREF	50	mA
Output Current (Each Output)	IO	100	mA
Oscillator Charging Current (pin 6 or 7)	ICHG(OSC)	5	mA
Lead Temperature (Soldering, 10 sec)	TLEAD	300	°C
Power Dissipation (TA = 25°C)	PD	1000	mW
Operating Temperature	TPOR	0 ~ +70	°C
Storage Temperature	TSTG	-65 ~ + 150	°C

Table 7.1 Absolute Maximum Ratings Of KA3525 IC

7.3.7 Electrical characteristics

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit
REFERENCE SECTION						
Reference Output Voltage	VREF	-	4.6	5.0	5.4	V
Line Regulation	ΔV_{REF}	VCC = 8V to 40V	-	10	30	mV
Load Regulation	ΔV_{REF}	IREF = 0 mA to 20 mA	-	20	50	mV
Ripple Rejection	RR	f = 120Hz, TA = 25°C	-	66	-	dB
Short-Circuit Output Current	ISC	VREF = 0, TA = 25°C	-	100	-	mA
Temperature Stability	STT	-	-	0.3	1	%
Long Term Stability	ST	TA = 25°C	-	20	-	mV/KHr
OSCILLATOR SECTION						
Maximum Frequency	f(MAX)	CT = 0.001uF, RT = 2K Ω	-	350	-	KHz
Initial Accuracy	ACCUR	RT and CT constant	-	5	-	%
Frequency Change with Voltage	$\Delta f/\Delta V_{CC}$	VCC = 8V to 40V, TA = 25°C	-	-	1	%
Frequency Change with Temperature	$\Delta f/\Delta T$	Over operating temperature range	-	-	2	%
Clock Amplitude (Pin 3)	V(CLK)	TA = 25°C	-	3.5	-	V
Clock Width (Pin 3)	tw(CLK)	CT = 0.01uF, TA = 25°C	-	0.5	-	μ s
ERROR AMPLIFIER SECTION						
Input Offset Voltage	VIO	VCM = 2.5V	-	2	10	mV
Input Bias Current	IBIAS	VCM = 2.5V	-	2	10	μ A
Open Loop Voltage Gain	GVO	-	60	80	-	dB
Common-Mode Input Voltage	VCM	TA = 25°C	1.8	-	3.4	V
Common-Mode Rejection Ratio	CMRR	TA = 25°C	-	70	-	dB
Small Signal Bandwidth	BWSS	GV = 0dB, TA = 25°C	-	3	-	MHz
Output Voltage Swing	VO(ERR)	TA = 25°C	0.5	-	3.8	V

Table 7.2 Electrical Characteristics Of KA3525 IC

7.4 Vertical Ferrite Core Transformer

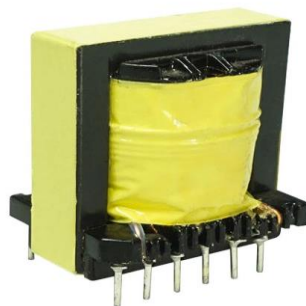


Figure 7.8: EC28 Vertical Ferrite Core Transformer

7.4.1 Specifications

- Bobbin 5+5Pin
- Type: EC28
- Pin spacing: 5mm/0.19"

- Ferrite core Size: 28.5 x 11.5 x 14mm/1.1" x 0.4" x 0.5"(L*W*T)
 - Bobbin size: 25 x 23 x 32mm/1" x 0.9" x 1.2"(L*W*H)
 - Winding frame size: 17 x 12mm/0.6" x 0.4" (L*W)
- Package content: 2 SET = 4 ferrite halves + 2bobbin

7.4.2 Winding Ratio

- Primary -15Turns 18SWG
- Secondary - 24turns 20SWG

VIII WIRELESS POWER CALCULATIONS

8.1 Frequency calculation of transmitter & receiver coils

The calculations are done based on the components specifications used in hardware through online calculators. The obtained results of the calculations are mentioned as follows.

8.1.1 Air core coil inductance calculation

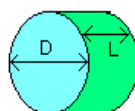
Air Core Inductor Inductance Calculator

The following is a design tool which calculates the inductance of an air core inductor.

$$L = (d^2 * n^2) / (18d + 40l)$$

where:

L is inductance in micro Henrys,
d is coil diameter in inches,
l is coil length in inches, and
n is number of turns.



Coil: 24SWG Enamel Copper Wire

d (coil diameter in inches)	4.5	(inches)
l (coil length in inches)	0.393701	(inches) (1CM)
n (number of turns)	120	(60+60Turns)
Calculate Inductance		
L (Inductance)	3014.01455	(uH)

Microhenry ↔ Nanohenry Conversion

Microhenry:

Nanohenry:

Figure 8.1: Inductance Calculation of Transmitter

8.1.2 LC Resonance frequency calculation

LC Resonance Calculator

When an inductor or capacitor are placed in series or parallel they will have a resonant frequency which is determined by the design equation below. LC resonant circuits are useful as notch filters or band pass filters. They are also found in oscillator circuits.

Frequency:	<input type="text" value="0.0749"/>	(MHz)
Capacitance:	<input type="text" value="1.50e+3"/>	(pF)
Inductance:	<input type="text" value="3.01e+6"/>	(nH)
<input type="button" value="Calculate"/>		

Design Equations:

$$2\pi F = 1/\sqrt{L \cdot C}$$

0.0749 megahertz =
74.9 kilohertz

Figure 8.2: Frequency Calculation of Transmitter

8.1.3 Frequency calculation of transmitter coil

$$L = (d^2 \cdot n^2) / (18d + 40l)$$

where:

- L is inductance in micro Henrys,
- d is coil diameter in inches,
- l is coil length in inches, and
- n is number of turns.

d (coil diameter in inches)	<input type="text" value="3.5"/>	(inches)
l (coil length in inches)	<input type="text" value="5"/>	(inches)
n (number of turns)	<input type="text" value="100"/>	
<input type="button" value="Calculate Inductance"/>		
L (Inductance)	<input type="text" value="1475.90361"/>	(uH)

Frequency:	<input type="text" value="0.0720"/>	(MHz)
Capacitance:	<input type="text" value="3.30e+3"/>	(pF)
Inductance:	<input type="text" value="1.48e+6"/>	(nH)
<input type="button" value="Calculate"/>		

Design Equations:

$$2\pi F = 1/\sqrt{L \cdot C}$$

F=72.0KHz

Figure 8.3: Frequency Calculation of Transmitter Coil

8.1.4 Frequency calculation of transmitter coil

$$L = \frac{d^2 * n^2}{18d + 40l}$$

where:

L is inductance in micro Henrys,
 d is coil diameter in inches,
 l is coil length in inches, and
 n is number of turns.

d (coil diameter in inches)	3.0	(inches)
l (coil length in inches)	.25	(inches)
n (number of turns)	100	
Calculate Inductance		
L (Inductance)	1406.25000	(uH)

Frequency:	0.0738	(MHz)
Capacitance:	3.30e+3	(pF)
Inductance:	1.41e+6	(nH)
Calculate		

Design Equations:

$$2 * \pi * F = 1 / \sqrt{L * C}$$

F=73.8KHz

Figure 8.4: Frequency Calculation of Receiver Coil

8.2 PWM Frequency calculation of IC KA3525

$$f = \frac{1}{C_T(0.7 R_T + 3 R_D)}$$

C=0.001 uF
 R=19 Kohms
 F=75.188 KHz

Rvar=5K
 Rfixed=16K
 Rtotal=21K

Oscillator Frequency Range:

Frage=68-89.3 KHz

Dead time Resistance

RD =0 ohms

Figure 8.5: PWM Frequency Calculation of KA3525

IX APPLICATION

- 1) Wireless power has a bright future in providing wireless electricity. There are no limitations in power applications. Some of the potential applications are powering of cell phones, laptops and other devices that normally run with the help of batteries or plugging in wires.
- 2) Wireless power applications are expected to work on the gadgets that are in close proximity to a source of wireless 'power, where in the gadget's charges automatically without necessarily, having to get plugged in.
- 3) By the use of Wireless power there is no need of batteries or remembering to recharge batteries periodically. If a source is placed in each room to provide power supply to the whole house
- 4) Wireless power has many medical applications. It is used for providing electric power in many commercially available medical implantable devices.

- 5) Another application of this technology includes transmission of information. It would not interfere with radio waves and it is cheap and efficient

X ADVANTAGES

- 1) No need of line of sight - In Wireless power transmission there is any need of line of sight between transmitter and receiver. That is power transmission can be possible if there is any obstructions like wood, metal, or other devices were placed in between the transmitter and receiver.
- 2) No need of power cables and batteries - Wireless power replaces the use of power cables and batteries.
- 3) Does not interfere with radio waves
- 4) Negative health implications - By the use of resonant coupling wave lengths produced are far lower and thus make it harmless.
- 5) Highly efficient than electromagnetic induction - Electromagnetic induction system can be used for wireless energy transfer only if the primary and secondary are in very close proximity. Resonant induction system is one million times as efficient as electromagnetic induction system.
- 6) Less costly - The components of transmitter and receivers are cheaper. So this system is less costly.

XI CONCLUSION

In this project we have introduced a controller that can be used in Wireless EV charging systems to charge electric vehicles without wires. The proposed controller is capable of self-tuning the switching operations of the converter to the resonance frequency of the WPT system, and therefore eliminates the need for switching frequency tuning. Also, it enables soft-switching operations in the converter, which will result in a significant increase in the efficiency of the power electronic converter. Contactless electric vehicle (EV) charging based on inductive power transfer (IPT) systems is a new technology that brings more convenience and safety to the use of EVs. Since it eliminates the electrical contacts, it would not get affected by rain, snow, dust and dirt, it is a safe, reliable, robust and clean way of charging electric vehicles, reduces the risk of electric shock.

XII FUTURE SCOPE

- 1) Wireless power transmission can be possible only in few meters.
- 2) Efficiency is only about 40% for long distances and near 85% for short distances.
- 3) As Wireless power is in development stage, lot of work is done for improving the efficiency and distance between transmitter and receiver.

XIII BIBLIOGRAPHY

- [1] T. Blackwell, "Recent demonstrations of laser power beaming at DFRC and MSFC," AIP Conference Proceeding, Beamed Energy Propulsion: Third International Symposium on Beam Energy Propulsion, vol. 766, pp.73-85, Apr. 2005.
- [2] G. Chattopadhyay, H. Manohara, M. Mojarradi, Tuan Vo, H. Mojarradi, Sam Bae, and N. Marzwell, "Millimeter-wave wireless power transfer technology for space applications," Asia-Pacific Microwave Conference, pp.1-4, Dec. 2008.
- [3] H. H. Wu, G. A. Covic, J. T. Boys, and D. J. Robertson, "A series-tuned inductive-power-transfer pickup with a controllable AC-voltage output," IEEE Transactions on Power Electronics, vol.26, no.1, pp.98-109, Jan. 2011.
- [4] S. P. Kamat, "Energy management architecture for multimedia applications in battery powered devices," IEEE Transactions on Consumer Electronics, vol.55, no.2, pp.763-767, May 2009.

- [5] M. Kato and C. -T. D. Lo, "Power Consumption Reduction in Java-enabled, Battery-powered Handheld Devices through Memory Compression," IEEE International Symposium on Consumer Electronics, pp.1-6, 20-23 June 2007.
- [6] A. Karalis, J. D. Joannopoulos, and M. Soljacic, "Efficient wireless nonradiative mid-range energy transfer," Annals of Physics, vol.323, no.1, pp.34-48, Jan. 2008.
- [7] J. Sallan, J. L. Villa, A. Llombart, and J. F. Sanz, "Optimal design of ICPT systems applied to electric vehicle battery charge," Industrial Electronics, IEEE Transactions on , vol.56, no.6, pp.2140-2149, June 2009.
- [8] IEEE-SA Standards Board, "IEEE standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3 kHz to 300 GHz," IEEE Std. C95.1, 1999.
- [9] N. Tesla, "Apparatus for transmission of electrical energy", US Patent, May 1900, No. 649621.
- [10] N. Tesla, "Art of transmitting electrical energy through the natural mediums", US Patent, April 1905, No. 787412.
- [11] J. A. C.Theeuwes, H. J. Visser, M. C. van Beurden, and G. J. N. Doodeman, "Efficient, compact, wireless battery design," European Conference on Wireless Technologies, pp.233-236, Oct. 2007.

