Journal of Faculty of Engineering & Technology

journal homepage: www.pu.edu.pk/journals/index.php/jfet/index

WIRELESS POWER TRANSMISSION THROUGH MAGNETIC RESONANCE COUPLING

A.S. Malik[1], M.A. Farooq[2], W.A. Shah[3] and O.M. Butt[4]

[*1]Department of Electrical Engineering, UCE & T, BZU, Multan

[2]Department of Physics, Govt. Post Graduate College, Muzaffargarhl

[3]Frequency Allocation Board, Lahore

[4]Department of Electrical Engineering, University of the Punjab

Abstract

This work contains the formulation and implementation of the concept of transmission of electoral power wirelessly by using the principal of resonant coupling. In order to implement the idea of transmission of electrical power wirelessly, a power transmitter circuit on the sending side and a power receiver circuit on the receiving side has been designed. We used self-resonating Royer oscillator in the power transmitter circuit on the sending side. Both the power transmitter and power receiver circuits has been designed to operate at a similar frequency to accomplish the phenomenon of resonance on both sides. The common operating frequency is 1.2 MHz on both power transmitting and power receiving sides. Rectification and filtration circuits were also included in the power receiving circuitry to operate electrical appliances on the receiving side. Primarily, we charged the batteries of cell phone and emergency light of low wattage using this wirelessly transmitted received power. As our designed circuitry was of medium range, thus it worked efficiently within a range of 01 meter. The process of Wireless power transmission was not affected even when we placed a thick and opaque obstacle between the wireless power transmitter and wireless power receiver.

Keywords: resonant coupling, WiTricity, Royer oscillator, Wireless Power Transmission, quality factor

1. Introduction

Transmission of electrical power without requiring cables is termed as Wireless Power Transmission (WPT). In this process, power transmission takes place without any physical interconnection in the form of wires between the source and the destination [1]. This process is suitable when connection through wires is either impossible or inconvenient. One can get liberated of a large number of cables or wires that are required to recharge the battery of cell phone or laptop batteries and other low power appliances that include DVD players, mp3 players, WiFi modems, dish receivers, CD players, energy savers and night bulbs to name the few. The process of wireless power transmission can make usage of electrical appliances easier. It can also reduce the risk of electric shock which can be over there when we energize electrical appliances using traditional wired techniques. Wireless Power Transmission is also named as Wireless Electricity or sometimes WiTricity [2-4].

* Corresponding Author: maliksattar777@bzu.edu.pk

The concept of wireless transmission of electrical power through air as a medium is around there for more than hundred years. In 1903, Nikola Tesla started his revolutionary work using Tesla Tower [5]. There are many existing techniques for the wireless transmission of electrical power. In most of the cases, electromagnetic field is used as a medium from which power is transferred. In case of a high frequency, lasers are used to transmit the power through a collimated light beam towards the detector, situated at a far off distance from the source. This detector is then equipped with a mechanism to convert these photons of visible light into electrical energy. However, tracking techniques involved in this process of power transmission are very complicated, because the proper alignment of the transmitting source and detector is necessary, which can be in the state of motion. The obstruction of beam can also take place in the presence of any other object between the transmitting source and detector, due to which an interruption will occur in the transmission of power. Obstruction of beam can be very dangerous for the objects when we start increasing the intensity of the transmitted beam. In microwave frequency band, radiated electromagnetic fields can be used for the transmission of power over large distances [6]. However, in almost all the cases when we use laser beams, system complexity and Safety problems are always there.

Non-radiative methods can also be used for the wireless transmission of electrical power when we employ non-radiative fields for the purpose. Transformers are a very good example. In case of a transformer, energy transfer from primary coil to secondary coil is based upon the magnetic induction, not requiring any electrical connection as shown in Figure 1. This principle is used in inductive chargers and works very efficiently if source and the appliance to be energized are in close vicinity and are positioned very carefully.

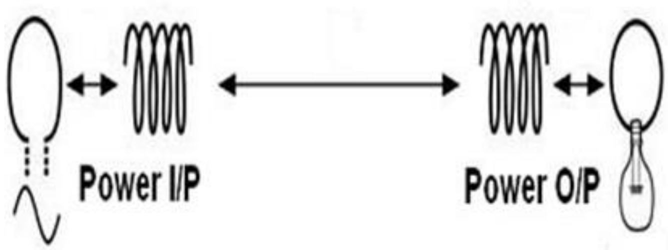


Figure 1. Wireless power transmission using inductive chargers

Wireless power transmission can be a real facility if more choice and flexibility can be offered regarding coupling and positioning of source and device. This has led to the selection of resonant magnetic coupling for the wireless transmission of electrical power over mid-range distance [7-10]. One can increase the efficiency of energy transfer at lower coupling rates by using the resonators of high quality factor. This technique is termed as Highly Resonant Wireless Power Transfer (HR-WPT). This technique is also known as Magnetic Resonance. In this approach, resonance of magnetic field results in very efficient transfer of electrical power over large distances providing more flexibility regarding position and orientation.

Many applications can be envisioned by using HR-WPT or Magnetic Resonance which were not possible to be visualized before. Nowadays, with the change in the lifestyle compact and portable devices are getting replaced by the fixed ones. Normally, all the portable electronic devices that we use in our daily life are battery operated and are required to be charged again & again. Obviously the comfort of an end user can increase, if all the portable devices can be charged without requiring any cable or cord. Thus rather than plugging in your laptop, cell phone or any other device to recharge, one can envisage the gratification is all such devices receive their power wirelessly from the source without getting them plugged in. Electrical energy is transferred from the source to the device required to be charged even when an obstacle is present between the source or the transmitter of the electrical power and the device or receiver required to be charged or operated [11]. Unlike the freely propagating electromagnetic waves, in which the components of both electric and magnetic fields have equal intensity, whereas in magnetic resonance method only magnetic field is used. Human beings, other living objects and most of the materials interact strongly with electric field rather than with the magnetic field [12]. This helps in improving the efficiency of the power transfer by using resonant coils, as loss of power due to absorption objects or obstacles is least. This will also result in an additional benefit with reference to health hazards.

2. Background

This concept of energy transfer without using wires started by Nicola Tesla [3]. It was observed at that time that power can be transmitted over a considerable distance through induction. In order to transfer significant power, the two inductors must be kept close to each other. However, the distance between the coils can be increased if concept of resonance coupling is used [13]. In 1891 Tesla improved the RF wireless power supply transmitter and in 1893 he demonstrated the illumination of wireless phosphorescent lamps in Chicago [14]. In the same year, 1893, wireless power transfer was demonstrated by him publically in St. Louis [15]. In 1894 Tesla used the resonant inductive coupling method to illuminate the incandescent lamps wirelessly [16-18].

As mentioned earlier, with the invention of hundreds of battery operated portable devices of daily use, demand for their wireless charging mechanism increased. In 2007, Dr. Xun Liu and Professor Ron Hui developed a localized charging technique of wireless charging. During the same year, a research group at Michigan Institute of Technology, illuminated a 60W bulb wirelessly separated from the source by a distance of 2m with 40 % efficiency using two 60 cm diameter resonant coils [19]. In 2008, a cordless or wireless electrical power transmission system was introduced by Bombardier Company trams and light rail vehicles [20]. In 2010, using resonant method, world’s first LCD television based on completely wireless power transfer was introduced [21]. During the same year a research group in Columbia University, developed System on Chip (SoC) which is actually a multiple coil wireless power transmission system for implantable applications [22].

3. Resonance Coupling

Some successful efforts have been made in this field, but range is very small (in centimetre distance). Power falls off rapidly if range is increased. So this facility is restricted to the power pad on which typical devices can be placed to charge which are not mobile. If we want to charge a device in mobile state then range should be increased. This is possible only if we choose a suitable frequency in order to make the system in resonance coupling state.

In 2006, the researchers at the Michigan Institute of Technology found that if we transmit electromagnetic waves, evanescent waves are also produced which actually carry no energy or power. These evanescent waves can transfer energy if proper resonance occur, and thus propagate energy to the receiving circuit, where it is first rectified and then used. The energy is not absorbed or dissipated by air and do not disturb the electrical appliances. Unlike microwaves they do not cause any physical injury.

3.1 Quality factor of a circuit and selectivity

If we want a circuit which gives response to the signals of a given frequency and this response has a narrow peak around this specific frequency, then ‘selectivity’ of the circuit is said to be higher. A measure of this selectivity is called ‘quality factor’ and is given below:

$$Q = \frac{\omega_o}{\Delta\omega} \qquad (1)$$

Where $\Delta\omega$ is the width of the resonance curve at half maximum. As width $\Delta\omega = \frac{R}{L}$, so Q value can be written as:

$$Q = \frac{\omega_o L}{R} \qquad (2)$$

The Q value is a parameter of the electronic resonance circuit. For most applications the numerical value of this factor ranges from 10 to 100.

3.2 Development of Wireless Energy Transfer (WET) system using resonance

We developed a wireless Energy Transfer (WET) system. This system is made up of two coils as transmitter and receiver as shown in Figure 2. Energy from one coil can tunnel to the other when both have same resonance frequency. This occurs in just the same way in which one vibrating pendulum causes the other similar pendulum to vibrate.

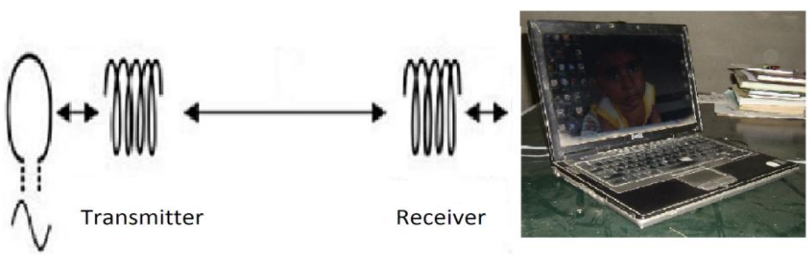


Figure 2. A Wireless Energy Transfer (WET) system using resonance

No transfer of energy will take place if either both the coils are out of range or the operating frequency of the two coils is different. On the other hand if operating frequency of both the coils is same and coils are within the range of each other, then transmitter coil can send energy to even more than one receiving coils as long as all the coils operate at the same frequency. This method of energy transfer is called non-radiative because it involves the stationary fields instead of the fields that actually spread in all directions.

Magnetic resonance coupling is the safe for human beings and other living creatures. The system will work even when there is an obstruction or an obstacle placed in between the two coils. If power is not picked up by the receiving coils, then it remains within the vicinity of transmitter coil and is not radiated to the environment. The similar dimensions of the two coils is not necessary for the resonance to take place, it is actually the frequency that should be matched. Therefore it is quite possible to cause resonance to occur even if the receiver coil is made small enough to fit into the receiving device and still efficiency is not affected. However, if the distance between the two coils, one used to transmit the electrical power and the other to receive the electrical power is increased, then the efficiency of energy transfer decreases. However with specially designed coils the energy can be transferred within the room to power up the appliances automatically without plugged in their power cables.

Electromagnetic induction for wireless power transfer is based on the principle of non-resonant inductive coupling. In this approach, a primary coil generates a magnetic field and a secondary coil lying with in this field develops the induced current. Since power that is required to be transmitted wirelessly is large and same power is used to produce the electromagnetic field, therefore the resulting range is short. In order to transfer electrical power over large distance, the non-resonant induction method is not efficient, because much of the transmitted energy is lost while increasing the range. In order to decrease the power wastage and to increase the efficiency of wireless power transfer, resonant coupling is involved. The LC resonant circuit consists of a coil of single turn with closely spaced capacitor plates on its ends. This forms a specific frequency which is then matched with the receiver to increase the range. When the frequency of the transmitter and receiver becomes equal, then exchange of energy takes place efficiently. The objects having frequency other than this resonance frequency form a weak interaction with this system.

4. Experimental Procedure

Our Wireless Energy Transfer (WET) system consists of at least two coils. One coil which oscillates the circuit is called the source coil and other coil attached with the receiver (i.e. the resistive load) is called receiver coil. To achieve resonance the inductors and capacitors used in transmitter and receiver have same numerical values. In this way same frequency is produced for the resonance process.

The LC circuits used for the production of frequency components in the transmitter and receiver are shown below in Figure 3 (a) and Figure 3 (b). Royer oscillator is the main building block of our Wireless Energy Transfer (WET) system. Royer oscillator is principally based on relaxation oscillator and was invented by H. Royer in 1954.

Figure. 3 Snapshot of Resonant coils of Wireless Energy Transfer System (a) transmitter (b) receiver

It has many advantages over other oscillators that include simplicity, lesser circuit components & utilization of rectangular wave input. Figure 4 shows the schematic diagram of the Royer oscillator transmitter circuit. As can be seen from the schematic diagram, we have used Field effect transistors, 100 µH radio frequency coils as drain resistors, five 0.012 µF capacitors connected in parallel for the resonant tank circuit. Transmitter coil is a single loop copper tube. The diameter of the loop is 154mm whereas the diameter of the copper tube is 8mm. The resonant frequency of the resonant tank is set to 1.2 MHz. Figure 5 shows the snapshot of the assembled circuit of the transmitter.

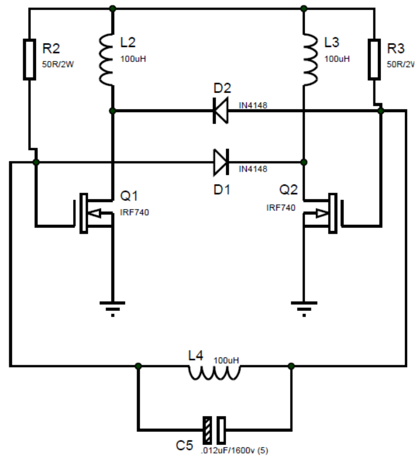


Figure 4. Schematic diagram of Royer Oscillator Transmitter

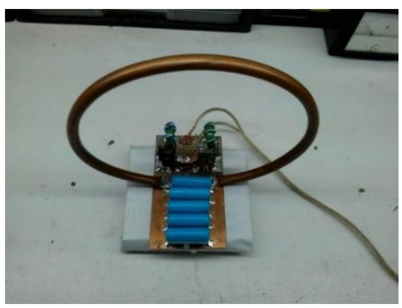


Figure 5. Snapshot of Wireless Energy Transfer System transmitter

Figure 6 shows the schematic diagram of the Royer oscillator receiver circuit. This circuit consists of a resonant tank to resonate with the transmitter circuit. The output voltage of the resonant circuit of the receiver then rectified by using full wave bridge rectifier circuit. Filter capacitors attached next smoothen the rectified voltage which is then regulated to 5 volts by using LM7805 regulator. This output voltage can be used to charge any portable device. Figure 7 shows the snapshot of the assembled circuit of the receiver.

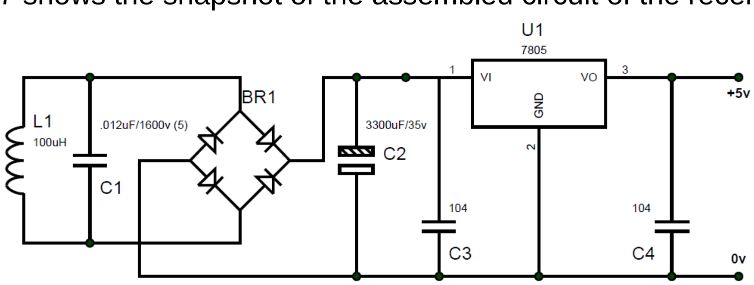


Figure 6. Schematic diagram of Royer Oscillator Receiver

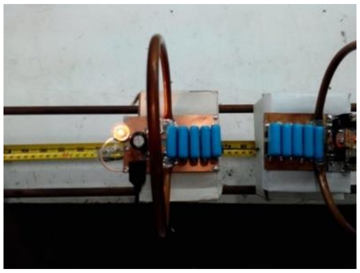
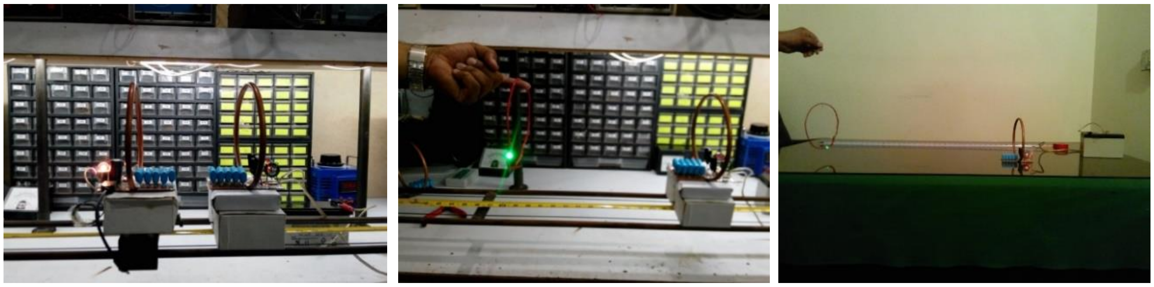


Figure 7. Snapshot of Wireless Energy Transfer System receiver

Figure 8 (a) shows the Snapshot Wireless Energy Transfer System showing its working in resonant mode. In resonance mode, we used a 5W bulb as a load. Figure 8 (b) shows the Snapshot Wireless Energy Transfer System showing its working in non-resonant mode. In non-resonance mode, we used a green LED as load. Figure 8(c) shows the snapshot of Wireless Energy Transfer System phenomenon of wireless electrical energy transfer over a larger distance.



(a) **(b)** **(c)**

Figure 8. Snapshot Wireless Energy Transfer System showing its working in (a) resonant (b) non-resonance mode (c) phenomenon of wireless electricity is shown at large distance

5. Results and discussions

In order to carry out different measurements, we developed a testing environment for our Wireless Energy Transfer System. Figure 9 shows the schematic diagram to test the functionality of our developed system and to measure output short circuit current and closed circuit current with a load resistance of 100Ω, output open circuit voltage and closed circuit voltage across load resistance of 100Ω and output power absorbed by a load resistance of 100. Measurements were made for the output voltage, output current, output power both for open circuit and closed circuit by varying the distance between the transmitter and receiver of wireless energy transfer system.

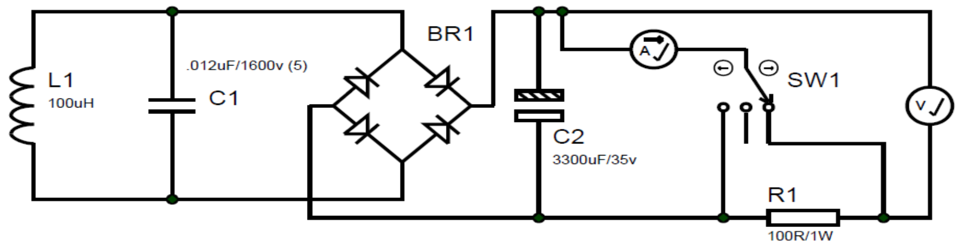


Figure 9. Schematic diagram for test set up to measure output current, voltage and power

Figure 10(a) shows the graph between output open circuit voltage and closed circuit across a load resistance of 100Ω versus distance. Figure 10(b) shows the graph between short circuited output current and current through a load resistance of 100Ω versus distance. Figure 11(a) shows the graph between output power absorbed by the load resistance of 100Ω versus distance. Figure 11(b) shows the graph between efficiency of Wireless Energy System versus distance. Experimental results prove the proper functionally of our developed Wireless Energy Transfer System. Results further reveal that efficiency of the system decreases exponentially with the increase in the distance between the transmitter and receiver of Wireless Energy Transfer system.

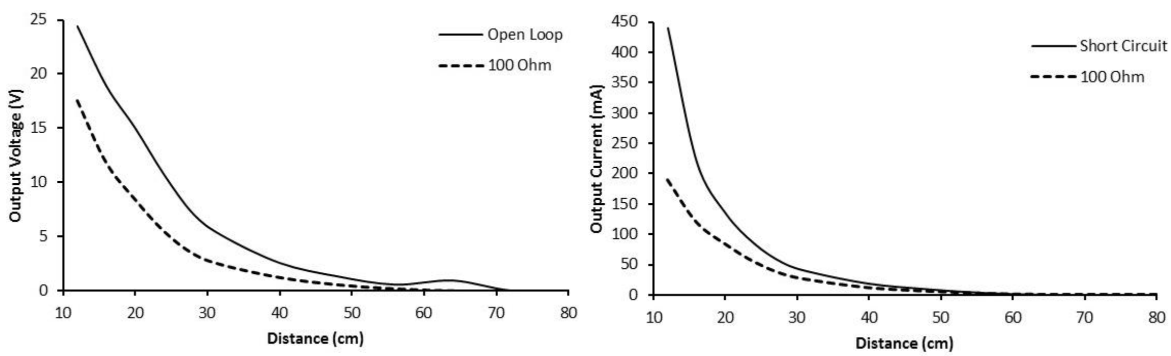


Figure 10. (a) (b)

(a) Graph between output voltage for open circuit and closed circuit with a load resistance of 100Ω versus distance for Wireless Energy Transfer System

(b) Graph between output current for open circuit and closed circuit with a load resistance of 100Ω versus distance for Wireless Energy Transfer System

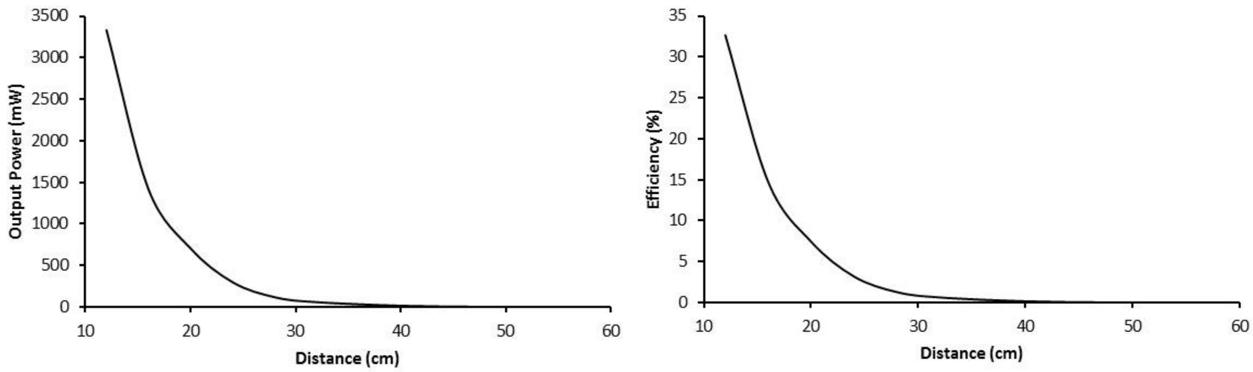


Figure 11. **(a)** **(b)**

(a) Graph between output power versus distance for WET
(b) Graph of efficiency of Wireless Energy Transfer System versus distance

6. Applications of Wireless Energy Transfer System

As already mentioned, a lot of research work in under progress to improve the efficiency of Wireless power transmission systems. One can envision hundreds of applications that can range from Charging of Laptop batteries, Charging of Cell phone batteries, hearing aids, charging and operation of household appliances, to energize implanted medical equipment and devices, energizing pacemakers, supply of constant energy to factory robots etc. Figure 12 shows a snapshot of charging of a cell phone using our developed Wireless Energy Transfer System.

Figure 12. A snapshot of charging of a cell phone using Wireless Energy Transfer System

7. Conclusions & Future Recommendations

The applications of wireless power transfer are anticipated to be implemented practically in near future. These applications will look like novel gadgets. Most of the electronic devices in the houses will be charged automatically without getting plugged in. There is no limit in the application of wireless power transfer in the sense that everything that works with batteries can be linked with this system. Just imagine after the introduction of this technology you will feel free from the tension of remembering to recharge or replace batteries periodically, or plugging in different devices with the risk of electric shock. Wireless Energy Transfer developed can serve as a prototype for any future extension or modification. It can serve as test work bench for wireless energy transfer. One can enhance & expand the efficiency of the Wireless Energy Transfer system by employing different types of coils, by changing the material of the coils used, e.g. by changing the gauge size of the wire and by using wires of different relative permeability. One can achieve the factor of portability of wireless energy transfer system is by reducing the size of circuitry of power receiver. Once the size of the power receiver system is reduced, it will become more portable and can be used to operate or charge home appliances. By increasing the ratings of the components used in wireless energy transfer system, the power rating capability of the system can also be increased. Effect of variation of resonant frequency either by varying the capacitance or inductance of LC tank on overall systems efficiency need to be explored.

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