

WiTricity: Wireless Power Transfer By Non-radiative Method

Ajey Kumar. R¹, Gayathri. H. R², Bette Gowda. R³, Yashwanth. B⁴

¹Dept. of ECE, Malnad College of Engineering, Hassan, India

²Centre for Emerging Technologies, Jain University, Bangalore, India

³Dept. of EEE, Basaveshwara College of Engineering, Bagalkot, India

⁴Dept. of ECE, BVB College of Engineering & Technology, Hubli, India

Abstract— A non-radiative energy transfer, commonly referred as WiTricity and based on ‘strong coupling’ between two coils which are separated physically by medium-range distances, is proposed to realize efficient wireless energy transfer. WiTricity idea is spear-headed by MIT researcher Marin Soljacic, which describes the ability to provide electricity to remote objects without wires. The advent of WiTricity technology is though old of 1899, explored by Nikola Tesla, but has founded its grip in recent years with numerous gadgets and there snaking cables around us. The technology is in turn expels E-waste and will free us from the power cords. WiTricity depends upon strong coupled resonance between transmitter and receiver coils. The transmitter emits a non-radiative magnetic field resonating at MHz frequencies and the receiving unit load resonates in that field. Thin film WiTricitycells, consisting of a tape coil on one layer, which is separated by an insulation layer to conductive strips on another layer, are fabricated. These cells are light, compact, and flexible provide convenience and flexibility in the design of wireless devices. Experiments are conducted to showcase the performance of this energy transfer system.

Keywords— *WiTricity, Inductive magnetic coupling, Resonant wireless energy transfer, strong coupling.*

I. INTRODUCTION

In the 1890’s wireless energy transmission was demonstrated by Nikola Tesla using his demonstration on resonant transformers called Tesla coils. Since these coils had undesirable electric fields which radiated energy in all directions, the efforts made by Tesla made little success. Various technologies for wireless power transfer like capacitive coupling, microwave and laser method have been proposed involving far fields. However it is the technology using magnetic resonance coupling has been found to be a viable technology for midrange energy transfer. Further, this means of energy transfer uses non-radiative mode of transmission and offers the use of connector free devices and is an alternative to the use of hazardous disposable batteries. Wireless energy transfer or WiTricity is currently extending its applications to medical implants saving patients from undergoing operations to replace the lithium ion batteries used for pacemakers. Magnetic resonance is also being used for charging of electric vehicles while driving on a highway. Since this technology can work even in water, powering of under- water cameras can be done reliably.

Traditional plug and socket charging method cannot keep up with demands of consumers for safety and fast charging.

Thanks to the advent in power electronics, inductive charging, also known as wireless charging, has found much successes and is now receiving increasing attention by virtue of its simplicity and efficiency. The most important distinctive structural difference between contactless transformers and conventional transformers is that the two ‘coils’ in the former are separated by a large air gap. Compared with plug and socket (i.e., conductive) charging, the primary advantage of the inductive charging approach is that the system can work with no exposed conductors, no interlocks and no connectors, allowing the system to work with far lower risk of electric shock hazards.



Fig. 1. Basic components of the WiTricity system

Physical separation between the primary and secondary windings incurs proximity-effect winding losses. Poor coupling can result in poor transmission performance and low efficiency. Due to the large air gap between the primary and secondary windings, contactless transformers have large leakage inductances, small mutual inductance and low efficiency [1]–[3]. Compared to direct contact charging, inductive charging efficiency is lower and resistive heating is higher. Realization of low frequency inductive charging in electrical devices will lead to slow charging and heat generation. Fig. 1 shows the basic components of the WiTricity system.

This paper reports the study on a topical mode of energy transmission using resonant technique, commonly known as WiTricity (short form of wireless electricity) [4]. Detailed theoretical and numerical analyses reveal that WiTricity is efficient and practical for mid-range wireless energy exchange. Unlike conventional inductive coupling methods, there are only very small energy dissipations in off-resonant objects for systems working on WiTricity principle [5].

II. ABOUT THE TECHNOLOGY

A. Brief History

- Nikola Tesla – Experimented in 1899
 - Imagined a global wireless power distribution system
- William Brown
 - Established microwave to electricity conversion
- Invention of the Solar Panel
 - 1) First NASA solar powered satellite 1958
- Oil Crisis
 - NASA program
- Marine Soijacic and team – Experimented in 2007
 - 60- watt light bulb from a power source 7 feet away without wires. [7]
 - Currently looking for WiTricity in the range of 100 watts.

B. WiTricity Mechanisms

There are various methods of transferring electricity wirelessly, basically they are classified as:

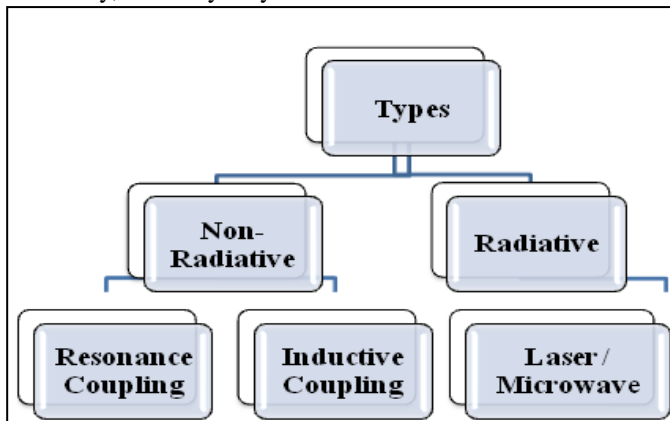


Fig. 2. Classification of WiTricity system.

1) *Near Field Transfer (Non-Radiative)*: These are wireless transmission techniques over distances comparable to, or a few times the diameter of the device(s).

a) *Inductive Coupling*: Inductive coupling is the action of electrical transformer is the simplest instance of wireless energy transfer. The primary and secondary circuits of a transformer are not directly connected. The transfer of energy takes place by electromagnetic coupling through a process known as mutual induction. The receiver must be very close to the transmitter or induction unit in order to inductively couple with it.

b) *Resonance Coupling*: The idea of such mid-range induction was given by Marin Soljacic for efficient wireless transfer. The reason behind it is that, if two such resonant objects are brought in mid-range proximity, their near fields (consisting of so-called 'evanescent waves') and can allow the energy to transfer from one object to the other within times much shorter than all loss times, which were designed to be long, and thus with the maximum possible energy-transfer efficiency. Electromagnetic resonance 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, when both of these are made to resonate at same frequency they become much efficient.

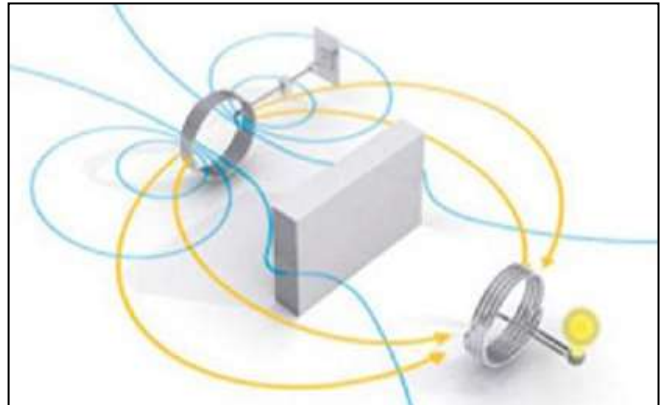


Fig. 3. Resonant Magnetic Coupled system.

2) *Far Field Transfer (Radiative)*: Far Field transfer refers to methods achieving longer range transfers, often multiple kilometre ranges, where the distance is much greater than the diameter of the device(s).

a) *Laser/Microwave Transmission*: Such power transmissions can be made effective at long range power beaming, with shorter wavelengths of electromagnetic radiation, typically in the microwave range. A rectenna may be used to convert the microwave energy back into electricity. These provide 95% efficiency. A new company, Powercast introduced wireless power transfer technology using RF energy this system is applicable for a number of devices with low power requirements. Currently, it achieves a maximum output of 6 volts for a little over one meter.



Fig. 4. Example of European Space Agency Aeolus Satellite with laser beam pointing at the Earth's atmosphere. Credits: ESA/AOES Medialab.

Energy Transmission via laser is an efficient way for long range, except for it requires a proper line of sight for power beaming. In the case of light, power can be transmitted by converting electricity into a laser beam that is then fired at a solar cell receiver. With such laser beam efficiencies it is planned to build a solar panel grid in space & transferring the solar energy to earth receivers via laser methods.

III. RESONANT COUPLED SYSTEM OVERVIEW

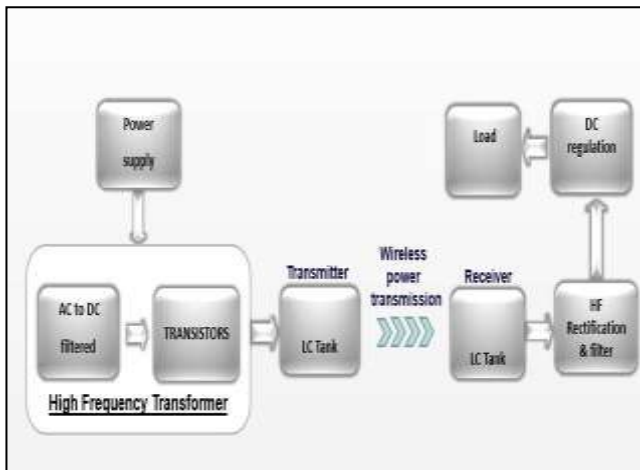
The resonant coupled system is formulated on the basis of coupled mode theory [6]. A high frequency power source drives power through a transmitting antenna. The transmitting antenna sends power wirelessly using electromagnetic resonance coupling to the receiving antennas. Near field coupling using evanescent field drives the receiving antennas. The distance of transmission can be increased using coupled source antennas which work as resonators [7]. This allows the transmission to follow a curved transmission path in space.

IV. COMPARISON WITH INDUCTIVE COUPLING

Traditional inductive coupling methods have limited transmission distance due to weak coupling between the source and loads. This occurs in the charging of conventional electric toothbrushes. The tooth brush with the receiving coil is placed on the source cradle for getting charged. The efficiency is as low as 1-2%. Using magnetic resonance the transmitting source coil frequency exactly matches the frequency of the receiving coils at resonance. Since the energy transfer is maximum at resonance, magnetic resonance coupling is found to have an efficiency of about 45% as has been demonstrated by the MIT team [7]–[8].

V. THEORY AND DESIGN OF THE PROPOSED SYSTEM

As a new wireless power transfer technology, WiTricity is based on the concept of near-field and strongly coupled magnetic resonance. The fundamental principle is that resonant object scan exchange energy efficiently, while non-resonant objects only interact weakly. Fig. 5 shows the basic design of the WiTricity system consists of source and device resonators, a driving loop, and an output loop. The source resonator is coupled to the driving loop which is linked to an oscillator that supplies energy to the system. The device



resonator coil is coupled to the output loop to provide the power to an external load.

Fig. 5. Basic Design of WiTricity System.

In Inductive Coupling due to its large physical separation, wireless inductive coupling transformers have large leakage

inductances and small mutual inductance. Thus the coupling rates are very small, quite often less than 0.1, while those for conventional transformers are between 0.95–0.98 [1]. Judging on this aspect, inductive coupling technology is impractical. For the WiTricity system, the coupling rate can however be as high as 0.7–0.9 by virtue of the strong resonant frequency coupling between primary and secondary windings.

To achieve high coupling rate and transmission efficiency, sources with certain resonant frequency (in the MHz range) is fed to the primary windings. Common formulas in the low frequency range to predict the performance of the system are inapplicable as the values of inductances and resistors vary greatly as frequency changes, especially at high frequency.

A. Circuit Analysis

The proposed WiTricity system uses a pair of rectangular spiral copper windings with the same shape and structure to achieve wireless energy transfer. The amplitude of the exciting voltage, which is given by an amplifier, is 25 V at the frequency range from 0.01 MHz to 10 MHz. The induced electric field in the receiver is generated by variations in the magnetic flux produced by the transmitter coil. Particular attention is paid to the analysis of the voltage received by the receiver with different distances and different frequencies in order to find the energy transfer pattern.

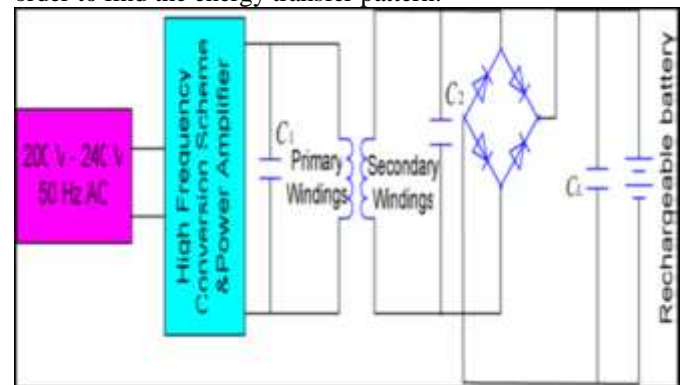


Fig. 6. Circuite Design of WiTricity System.

B. Parameters for Designing and Simulation

a) Design Aspects: Design of Coil

The LC circuit does not resonate by itself the word resonance refers to a class of phenomena in which a small driving perturbation gives rise to a large effect in the system. The LC circuit must be driven, for example by an AC power supply, for resonance to occur. The frequency at which this equality holds for the particular circuit is called the resonant frequency.

In order to achieve a resonance frequency in the oscillator circuit the inductive reactance and the capacitive reactance of the resonator coil will equal such that:

$$X_L = X_C \tag{1}$$

Where $\omega L = 1 \div \omega C$
And $\omega = 2 \times \pi \times f$

$$\text{Capacitive Reactance: } X_C = 1 \div 2\pi fC \tag{2}$$

$$\text{Inductive Reactance: } X_L = 2\pi fL \tag{3}$$

Resonant Circuit formula: $4\pi^2 f^2 LC = 1$ (4)

Where $f = 1 \div 2\pi\sqrt{LC}$ (5)

- X_C = Capacitive Reactance in ohms
- X_L = Inductive Reactance in ohms
- f = Frequency in hertz
- L = Inductance in Henry
- C = Capacitance in farads

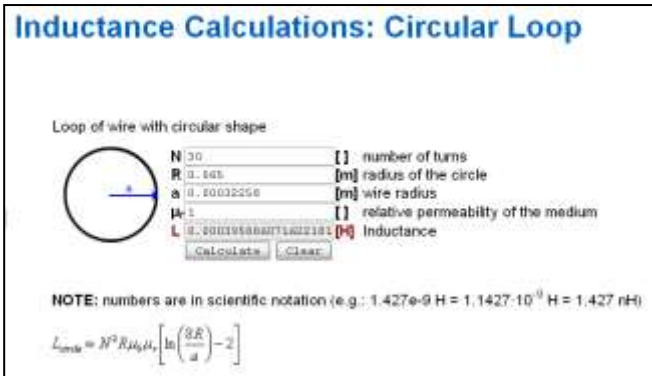


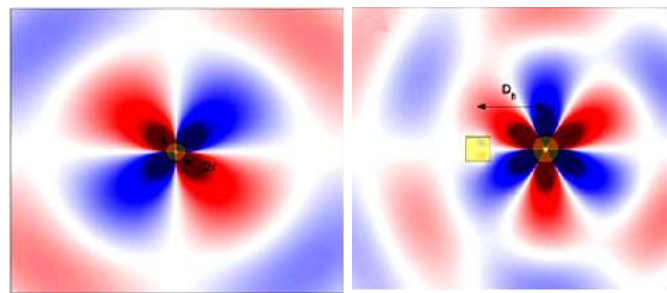
Fig. 7. Induction Calculations of Circular Coil.

a) Simulation Model of Resonant Magnetic Coupling

Our experimental scheme consists of two Self-resonant coils. One coil (source coil) is coupled inductively to an oscillating circuit and other (device coil) is coupled inductively to a resistive load. Self-resonant coils rely on their varying or oscillating magnetic fields. Resonant coupling occurs when the natural frequencies of the two objects are approximately the same. Two idealized resonant magnetic coils, shown in Fig. 8.



Fig. 8. Simulation Model using Resonant Magnetic Coupling.



b) With External Objects

a) Without External Objects

Fig. 9. Simulation Performance with and without External Objects in between the coils.

The blue and red colour bands illustrate their magnetic fields. The coupling of their respective magnetic fields is indicated by the connection of the colour bands. The simulation performance with and without external objects is shown in Fig. 9.

b) Fabrication

Firstly circuit was designed and simulated using live wire simulation software to test if the concept works. After getting output in the simulation, same circuit was tested on a breadboard with LED as load. The circuit on the breadboard worked perfectly fine. This ensured that the concept works. Then a PCB layout was obtained using PCB wizard software. The components were mounted on the general board according to the PCB layout and then solder.

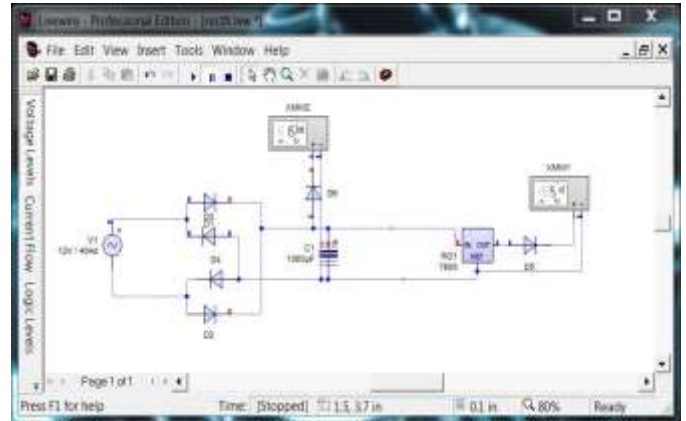


Fig. 10. PCB layout obtained using PCB wizard software.

VI. BENEFITS AND LIMITATIONS OF WITRICITY

A. Benefits of Design

1) More Convenient

- a) No manual recharging or changing batteries.
- b) Unaffected by the day night cycle, weather or seasons.
- c) Eliminate unsightly, unwieldy and costly power cords.

2) More Reliable

- a) Never run out of battery power.
- b) Reduce product failure rates by fixing the weakest link: flexing wiring and mechanical interconnects.

3) More Eco Friendly

- a) Reduce use of disposable batteries.
- b) Use efficient electric grid power directly instead of inefficient battery charging.

B. Limitations of Design

- 1) The resonance condition should be satisfied and if any error exists, there is no possibility of power transfer.
- 2) If there is any possibility of Very Strong ferromagnetic material presence, then there may be a possibility of low power transfer due to radiation.

VII. FEATURES AND APPLICATIONS OF WITRICITY

A. Features of WiTricity

1) *Highly Resonant Strong Coupling Provides High Efficiency Over Distance:* WiTricity mode of wireless power transfer is highly efficient over distances ranging from centimeters to several meters. Efficiency may be defined as the amount of usable electrical energy that is available to the device being powered, divided by the amount of energy that is drawn by the WiTricity source. In many applications, efficiency can exceed 90%. And WiTricity sources only transfer energy when it is needed. When a WiTricity powered device no longer needs to capture additional energy, the WiTricity power source will automatically reduce its power consumption to a power saving idle state.

2) *Energy Transfer via Magnetic Near Field Can Penetrate and Wrap Around Obstacle:* The magnetic near field has several properties that make it an excellent means of transferring energy in a typical consumer, commercial, or industrial environment. Most common building and furnishing materials, such as wood, gypsum wall board, plastics, textiles, glass, brick, and concrete are essentially transparent to magnetic fields enabling WiTricity technology to efficiently transfer power through them. In addition, the magnetic near field has the ability to wrap around many metallic obstacles that might otherwise block the magnetic fields. WiTricity applications engineering team will work with you to address the materials and environmental factors that may influence wireless energy transfer in your application.

B. Applications of WiTricity

WiTricity wireless power transfer technology can be applied in a wide variety of applications and environments. The ability of our technology to transfer power safely, efficiently, and over distance can improve products by making them more convenient, reliable, and environmentally friendly. WiTricity technology can be used to provide:

1) *Automatic Wireless Power Charging:* When all the power a device needs is provided wirelessly, and no batteries are required. This mode is for a device that is always used within range of its WiTricity power source. When a device with rechargeable batteries charges itself while still in use or at rest, without requiring a power cord or battery replacement. This mode is for a mobile device that may be used both in and out of range of its WiTricity power source.



Fig. 11. Automatic Wireless Power Charging.

2) Consumer Electronics

a) Automatic wireless charging of mobile electronics (phones, laptops, game controllers, etc.) in home, car, office, Wi-Fi hotspots while devices are in use and mobile.

b) Direct wireless powering of stationary devices (flat screen TV's, digital picture frames, home theatre accessories, wireless loud speakers, etc.) eliminating expensive custom wiring, unsightly cables and wall-wart power supplies.

c) Direct wireless powering of desktop PC peripherals: wireless mouse, keyboard, printer, speakers, display, etc. eliminating disposable batteries and awkward cabling.



Fig. 12. Automatic Wireless charging of Mobile electronics.

3) Industrial

a) Direct wireless power and communication interconnections across rotating and moving joints (robots, packaging machinery, assembly machinery, machine tools) eliminating costly and failure-prone wiring.

b) Direct wireless power for wireless sensors and actuators, eliminating the need for expensive power wiring or battery replacement and disposal.

4) Transportation

a) Automatic wireless charging for existing electric vehicle classes: golf carts, industrial vehicles.

b) Automatic wireless charging for future hybrid and all-electric passenger and commercial vehicles, at home, in parking garages, at fleet depots, and at remote kiosks.

c) Direct wireless power interconnections to replace costly vehicle wiring harnesses and slip rings.



Fig. 13. Automatic Wireless charging for Electric Vehicle.

5) *Medical Application:* Wireless charging systems are being developed for implanted medical devices including Left ventricular assist device (LVAD) heart assist pumps, pacemakers, and infusion pumps. Using highly resonant wireless power transfer, such devices can be efficiently powered through the skin and over distances much greater than the thickness of the skin, so that power can be supplied to devices deeply implanted within the human body. The HR-WPT technique eliminates the need for drive lines that penetrate the human body, and for surgical replacement of primary batteries.

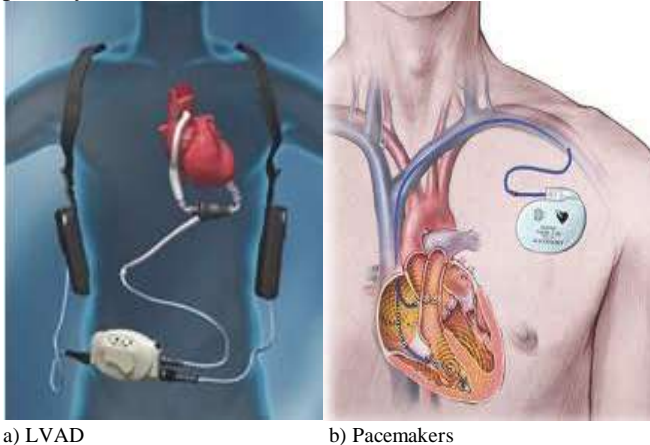


Fig. 14. Wireless charging system for implantable biomedical devices.

6) *Military Application:* Designers of defence systems are able to utilize wireless charging to improve the reliability, ergonomics, and safety of electronic devices. The Talon Tele-operated robot shown in Figure 9 is being equipped with wireless charging so that it can be recharged while it is being transported by truck from site to site. Helmet mounted electronics, including night vision and radio devices can be powered wirelessly from a battery pack carried in the soldier's vest, eliminating the need for disposable batteries or a power cord connecting the helmet to the vest mounted battery pack.



Fig. 15. Highly resonant wireless charging system for Military applications.

VIII. CONCLUSIONS AND FUTURE WORK

This provides mid-range non-radiative energy transfer scheme based on strongly-coupled resonances. Even very simple design has promising performance and provides better efficiency with respect to distance. As a powerful concept, it could enable a wide range of applications. We can call WiTricity as future technology of Electricity transmission for power consumer.

MIT's WiTricity is only 40 to 45% efficient and according to Soljagic, they have to be twice as efficient to compete with the traditional chemical batteries. The team's next aim is to get a robotic vacuum or a laptop working, charging devices placed anywhere in the room and even robots on factory floors.

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