A

Seminar report

On

Wireless Electricity

Submitted in partial fulfillment of the requirement for the award of degree
Of ECE

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Preface

I have made this report file on the topic **Wireless Electricity**; I have tried my best to elucidate all the relevant detail to the topic to be included in the report. While in the beginning I have tried to give a general view about this topic.

My efforts and wholehearted co-corporation of each and everyone has ended on a successful note. I express my sincere gratitude to ……..who assisting me throughout the preparation of this topic. I thank him for providing me the reinforcement, confidence and most importantly the track for the topic whenever I needed it.

Acknowledgement

I would like to thank respected Mr…….. and Mr. ……..for giving me such a wonderful opportunity to expand my knowledge for my own branch and giving me guidelines to present a seminar report. It helped me a lot to realize of what we study for.

Secondly, I would like to thank my parents who patiently helped me as i went through my work and helped to modify and eliminate some of the irrelevant or un-necessary stuffs.

Thirdly, I would like to thank my friends who helped me to make my work more organized and well-stacked till the end.

Next, I would thank Microsoft for developing such a wonderful tool like MS Word. It helped my work a lot to remain error-free.

Last but clearly not the least, I would thank The Almighty for giving me strength to complete my report on time.

CHAPTER 1

1. INTRODUCTION

Now day‘s electricity has become a cup of life. A moment without electricity makes your thinking go dry. The major source of conventional form of electricity is through wires. The continuous research and development has brought forward a major breakthrough, which provides electricity without the medium of wires. This wonder baby is called WiTricity. There are certain small but very useful discoveries made in history, which changed the world for ever, Newton‘s gravitational law, Watt‘s steam engine, Thomson‘s bulb and many more. But a renaissance occurred with the invention of Electromagnetic Waves by Maxwell. Sir Jadish Chandra Bose successfully generated electromagnetic waves having wavelength in the range of 5mm to 25 mm.

Thereafter an Italian scientist named Marconi succeeded in transmitting electromagnetic waves up to a distance of several miles. And with this there started a new era called WIRELESS TECHNOLOGY. Today, as we can see the word wireless ‘is common in day – to – day life. Wireless communication has made the world smaller. Almost each and everything is wireless or cordless. Cordless mouse, cordless keyboard, satellite communication, mobiles, cordless microphones and headphones, wireless internet service i.e. WIFI, etc. And these have definitely increased the standard of living. In fact it dates back to the 19th century, when Nikola Tesla used conduction based systems instead of resonance magnetic fields to transfer wireless power. As it is in radioactive mode, most of the Power was wasted and has less efficiency. Further, in 2005, Dave Gerding coined the term **WiTricity** which is being used by the MIT researchers and today‘s world.

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 quiet low. Therefore, we do not call it the WPT system.

Typical WPT is a point to point power transmission. For the WPT, we had better concentrate power to receiver. It was proved that the power transmission efficiency can approach close to 100%. We can more concentrate the transmitted microwave power to the receiver aperture areas with taper method of the Transmitting antenna power distribution. Famous power tapers of the transmitting antenna are Gaussian taper, Taylor distribution, and Chepachet distribution. Such taper of the transmitting antenna is commonly used for suppression of side lobes. It corresponds to increase in the power transmission efficiency. Concerning the power transmission efficiency of the WPT, there are some good optical approaches in Russia.

Future suitable and largest application of the WPT via microwave is a Space Solar Power Satellite (SPS). The SPS is a gigantic satellite designed as an electric power plant orbiting the Geostationary Earth Orbit (GEO). It consists of mainly three segments; solar energy collector to convert the solar energy into DC (direct current) electricity, DC to microwave

Converter and large antenna array to beam down the microwave power to the ground. The first solar collector can be either photovoltaic cells or solar thermal turbine. The second DC to microwave converter of the SPS can be either microwave tube system and/or semiconductor system. It may be their combination. The third segment is a gigantic antenna array.

An amplitude taper on the transmitting antenna is adopted in order to increase the beam collection efficiency and to decrease side lobe level in almost all SPS design. A typical amplitude taper is called 10 dB Gaussian in which the power density in the center of the transmitting antenna is ten times larger than that on the edge of the transmitting antenna.

The SPS is expected to be operational around 2030. Before realization of the SPS, we can consider other applications of WPT. In recent years, mobile devices advanced significantly and require decreasing power consumption. It means that we can use the diffused weak microwave power as power source of the mobile devices with low power consumption such as RF ID. The RF ID is radio IC tug with wireless power transmission and wireless information. This is a new WPT application like broadcasting.

CHAPTER 1, TABLE 1. FEATURES OF DIFERENT WITRICITY MODEL

model	Old JAXA model	JAXA1 model	JAXA 2 model	NASA DOE Model
Frequency	5.8 GHZ	5.8 GHZ	5.8 GHZ	2.45 GHZ
Diameter of transmitting Antenna	2.6 kmØ	1 kmØ	1.93 kmØ	1 kmØ
Amplitude taper	10 db Gaussian	10 db Gaussian	10 db Gaussian	10 db Gaussian
Output power (beamed to earth)	1.3 GW	1.3 GW	1.3 GW	6.72 GW
Maximum power Density at center	63 mW/cm^2	420 mW/cm^2	114 mW/cm^2	2.2 W/cm^2
Minimum power Density at edge	6.3 mW/cm^2	42 mW/cm^2	11.4 mW/cm^2	0.22 mW/cm^2
Antenna spacing	0.75 λ	0.75 λ	0.75 λ	0.75 λ
Power per one antenna (number of elements)	Max.0.95 W (3.54 billion)	Max.0.95 W (540 million)	Max.0.95 W (1.950 million)	Max.0.95 W (97 million)
Rectenna diameter	2.0 kmØ	3.4 kmØ	2.45 kmØ	1 kmØ
Maximum power density	180 mW/cm^2	26 mW/cm^2	100 mW/cm^2	23 mW/cm^2
Collection frequency	96.5 %	86 %	87 %	89 %

JAXA Japan Aerospace Exploration Agency, NASA –National Aeronautics and Space Administration, DOE U.S. Department Of Energy

CHAPTER 2

2. HISTORY OF WIRELESS POWER TRANSMISSION

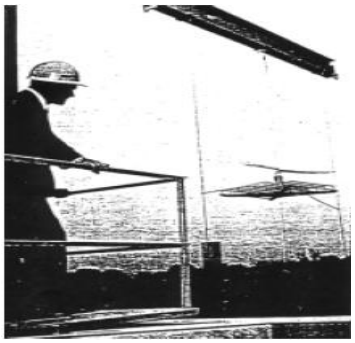
In 1864, James C. Maxwell predicted the existence of radio waves by means of mathematical model. In 1884, John H. Poynting realized that the Poynting vector would play an important role in quantifying the electromagnetic energy. In 1888, bolstered by Maxwell's theory, Heinrich Hertz succeeded in showing 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.

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.

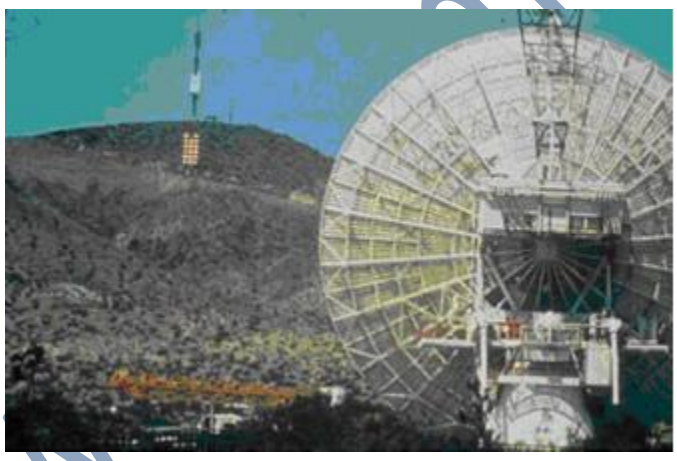
To concentrate the transmitted power and to increase transmission efficiency, we have to use higher frequency than that used by Tesla. In 1930s, much progress in generating high power microwaves, namely 1 10 GHz radio waves, was achieved by invention of the magnetron and the klystron. After World War 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 retina, 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



CHAPTER 2, FIG 2.1: MPT DEMONSTRATION WITH HELICOPTER BY W.C.BROWN

.With the rectenna, he succeeded in MPT experiments to wired helicopter in 1964 and to free flied helicopter in1968 (Fig. 1). In 1970s; he tried to increase DC RF transmission RF DC total efficiency with 2.45 GHz microwave. In 1970, overall DC total efficiency was only 26.5 % at 39WDC in Marshall Space Flight Center.



CHAPTER 2, FIG 2.2: FIRST GROUND TO GROUND MPT EXPERIMENT IN 1975 AT THE VENIUS SITE OF JPL GOLDSTONE FACILITY

In parallel, he and his team succeeded in the largest MPT demonstration in 1975 at the Venus Site of JPL Goldstone Facility (fig 2). Distance between a transmitting parabolic antennas, 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.

CHAPTER 2, FIG 2.3: STATIONARY HIGH ALTITUDE RELAY PLATFORM.

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.

CHAPTER 2, FIG 2.4: GROUND TO GROUND MPT EXPERIMENT IN JAPAN IN 1994 95

CHAPTER 3

3. WHAT IS WITRICITY?

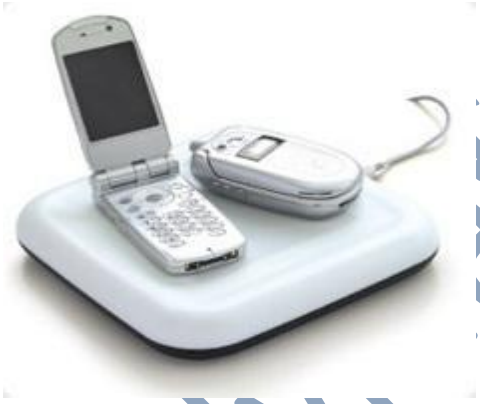
WiTricity is nothing but wireless electricity. Transmission of electrical energy from one object to another without the use of wires is called as WiTricity. WiTricity will ensure that the cell phones, laptops, iPods and other power hungry devices get charged on their own, eliminating the need of plugging them in. WiTricity technology *is* transferring electric energy or power over distance without wires. With the basics of electricity and magnetism, and work our way up to the WiTricity technology. Even better, because of WiTricity some of the devices won't enquire batteries to operate. No, this concept of wireless electricity is not new. In fact it dates back to the 19th century, when Nikola Tesla used conduction based systems instead of resonance magnetic fields to transfer wireless power. Further,

In 2005, Dave Gerding coined the term WiTricity which is being used by the MIT researchers today. Moreover, we all are aware of the use of electromagnetic radiation (radio waves) which is quite well known for wireless transfer of information. In addition, lasers have also been used to transmit energy without wires. However, radio waves are not feasible for power transmissions because the nature of the radiation is such that it spreads across the place, resulting into a large amount of radiations being wasted. And in the case of lasers, apart from requirement of uninterrupted line of sight (obstacles hinders the transmission process), it is also very dangerous. WiTricity founding technical team was the first to discover that by specially designing the magnetic resonators, one could achieve *strong coupling* and highly efficient energy exchange over distances much larger than the size of the resonator coils, distances very large compared to traditional schemes. These so called resonantly enhanced induction techniques are used in certain Medical implants and high frequency RFIDs for example.

CHAPTER 4

4. NEED OF WITRICITY

Now a days there is a Rapid development of autonomous electronics like Laptops, Cell phones, House hold robots and all those devices typically relay on chemical energy storage(Battery) As they are becoming daily needs to present generation, Wireless energy transfer would be useful for many applications as above and they need midrange energy.



CHAPTER 4, FIG 4.1: WIRELESS ENERGY TRANSFER

4.1 WITRICITY TECHNOLOGY IS DIFFERENT THAN TRADITIONAL MAGNETIC INDUCTION

At first glance, WiTricity technology for power transfer appears to be traditional magnetic induction, such as is used in power transformers, where conductive coils transmit power to each other wirelessly, over very short distances. In a transformer, an electric current running in a sending coil induces another current in a receiving coil .The two coils must be very close together, and may even overlap, but the coils do not make direct electrical contact with each other. However, the efficiency of the power exchange in traditional magnetic induction systems drops by orders of magnitude when the distance between the coils becomes larger than their sizes The power exchange efficiency of some induction systems is improved by utilizing resonant circuits.

CHAPTER 5

5. RECENT TRENDS

1. 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.

It is possible to steer the direction of the microwave beam. The antenna elements might be dipoles, slot antennas, or any other type of antenna, even parabolic antennas. In some MPT experiments in Japan, the phased array antenna was adopted to steer a direction of the microwave beam (Fig.5).
All SPS is designed with the phased array antenna.

2. RECENT TECHNOLOGIES FOR TRANSMITTERS

The technology employed for generation of microwave Radiation is an important subject for the MPT system. We need higher efficient generator/amplifier for the MPT system than that for the wireless communication system. For highly efficient beam collection on rectenna array, we need highly stabilized and accurate phase and amplitude of microwaves for phased array system for the MPT.There are two types of microwave generators/amplifiers. One is a microwave tube and the other is semiconductor amplifier

CHAPTER 5, FIG 5.1: PHASED ARRAY USED IN JAPANESE FIELD MPT EXPERIMENT

3. MAGNETRON

Magnetron is a crossed field tube in which electrons emitted from the cathode take cyclical path to the anode. The magnetron is self-oscillatory device in which the anode contains a resonant RF structure. The magnetron has long history from invention by A. W. Hull in 1921.

The practical and efficient magnetron tube attracted worldwide interest only after 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.

4. 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.

CHAPTER 5, FIG 5.2: COMPACT MICROWAVE ENERGY TRANSMITTER WITH THE PCM (COMET)

The COMET includes DC/Converters, a control circuit of the phase controlled magnetron with 5.8 GHz, a heat radiation Circuit, a wave guide, and an antenna.

The power weight ratio of the COMET is lightest weight in all microwave generators and amplifiers. TWTA for satellite use has lighter power weight ratio: 220Wat 2.45GHz at 2.65 kg (the TWTA weighs 1.5kg, the power supply weighs 1.15kg). 130W at 5.8 GHz at 2.15 kg (the TWTA weighs 0.8kg, the power supply weighs 1.35kg). Hence, they can deliver12g/W and 16.5g/W, respectively. They do not include a heat radiation circuit, a wave guide, and an antenna.

5. RECENT TECHNOLOGICAL TRENDS

5.5.1 RETRO DIRECTIVE BEAM CONTROL

A microwave power transmission is suitable for a power transmission from/to moving transmitters/targets. Therefore, accurate target detection and high efficient beam forming are important. Retro directive system is always used for SPS.

A corner reflector is most basic retro directive system. The corner reflectors consist of perpendicular metal sheets, which meet at an apex. Incoming signals are reflected back in the direction of arrival through multiple reflections off the wall of the reflector. Van Atta array is also a basic technique of the retro directive system. This array is made up of pairs of antennas spaced equidistant from the center of the array, and connected with equal length transmission lines. The signal received by an antenna is re radiated by its pair, thus the order of re radiating elements are inverted with respect to the center of the array, achieving the proper phasing for retro directivity.

Usual retro directive system have phase conjugate circuits in each receiving/transmitting antenna, which play same role as pairs of antennas spaced equidistant from the center of the array in Van Atta array. The signal is called a pilot signal. We do not need any phase shifters for beam forming. The retro directive system is usually used for satellite communication, wireless LAN, military, and so on.

5.5.2 ENVIRONMENTAL ISSUES

One of the characteristics of the MPT is to use more intense microwave than that in wireless communication systems. Therefore, we have to consider MPT safety for humans.

5.5.3 INTERACTION WITH ATMOSPHERE

In general, effect of atmosphere on microwaves is quite small. There are absorption and scatter by air, rain, and irregularity of air refraction ratio. In 2.45 GHz and 5.8 GHz, the absorption by water vapor and oxygen Dominate the effect in the air. Especially, it is enough to consider only absorption by the oxygen in the microwave frequency. It is approximately 0.007 dB/km. In the SPS case, the amount of total absorption through the air from space is approximately 0.035 dB

5.5.4 INTERACTION WITH SPACE PLASMAS

When microwaves from SPS propagate through ionospheric plasmas, some interaction between microwaves and the ionospheric plasmas occurs. It is well known that refraction, Faraday rotation, scintillation, and absorption occur between weak microwave used for satellite communication and the plasmas. However, influence on the MPT system is negligible. It is nonlinear interaction between intense microwave and the space plasmas that we have to investigate before the commercial SPS. We theoretically predict that the following may occur: heating of the plasmas, plasma hall effect, thermal self-focusing effect of the microwave beam, and three wave interactions and excitation of electrostatic waves in MHz bands. These interactions don't not occur in existent satellite communication systems because microwave power is very weak.

6. RECENT TRENDS: WIRELESS POWER TRANSMISSION – RECEIVERS AND RECTIFIERS

Point to point MPT system needs a large receiving area with a rectenna array because one rectenna element receives and creates only a few W. Especially for the SPS, we need a huge rectenna site and a power network connected to the existing power networks on the ground. On contrary, there are some MPT applications with one small rectenna element such as RF ID.

5.6.1 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 Scotty 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 appeared 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.

5.6.2 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. When we connect two rectenna in series or in parallel, they will not operate at their optimum power output and their combined power output will be less than that if operated independently. This is theoretical prediction.

7. EFFICIENCY

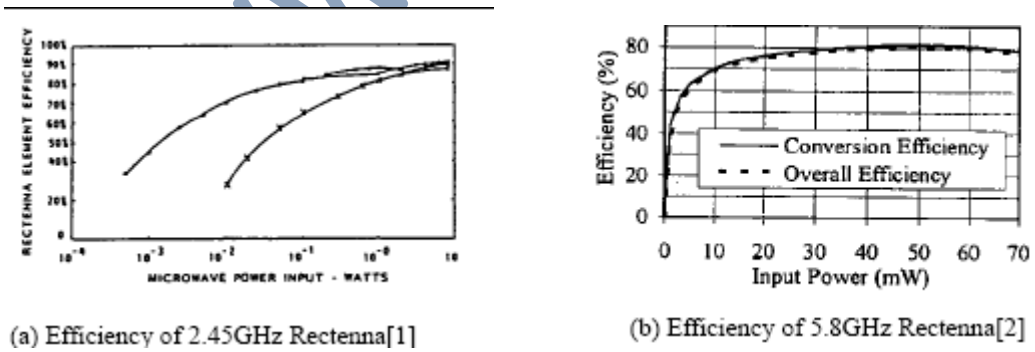
We classify the MPT efficiency roughly into three stages; DC RF conversion efficiency which includes losses caused by beam forming, beam collection efficiency which means ratio of all radiated power to collected power on a receiving antenna, and RF DC conversion efficiency.

5.7.1 RF DC CONVERSION EFFICIENCY

The RF DC conversion efficiency of the rectenna or the CWC is over 80 % of experimental results as shown. Decline of the efficiency is caused by array connection loss, change of optimum operation point of the rectenna array caused by change of connected load, trouble of the rectenna, and any losses on the systems, for example, DC/AC conversion, cables, etc. However, it is easier to realize higher efficiency than that on the other two

5.7.2 BEAM COLLECTION EFFICIENCY

The beam collection efficiency depends on the transmitter and receiver aperture areas, the wavelength, and the separation distance between the two antennas.



(a) Efficiency of 2.45GHz Rectenna[1]

(b) Efficiency of 5.8GHz Rectenna[2]

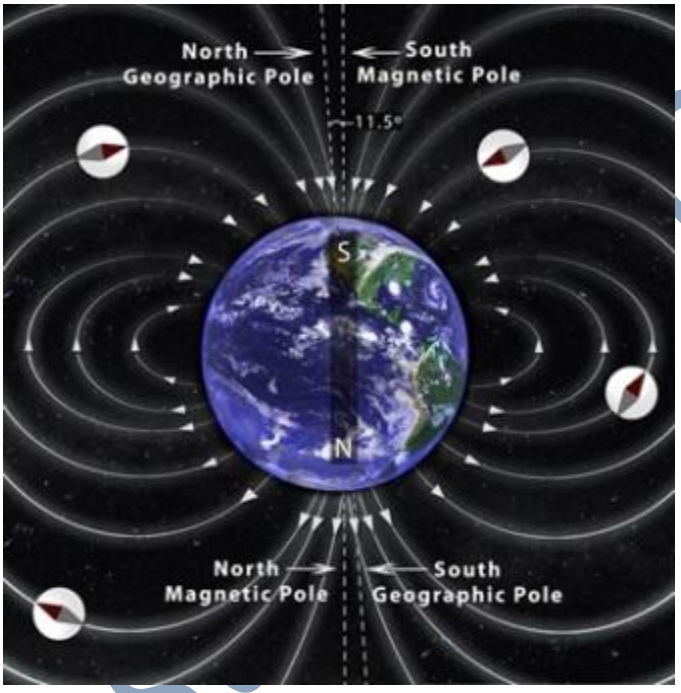
CHAPTER 5, FIG 5.7: EFFICIENCY OF RECTENNA ELEMENT

CHAPTER 6

6. THE BASIC IDEA OF TRANSFORMING ELECTRICITY TO WITRICITY

6.1 ELECTRICITY

The flow of electrons (current) through a conductor (like a wire), or charges through the atmosphere (like lightning). A convenient way for energy to get from one place to another!



CHAPTER 6, FIG 6.1: AN ILLUSTRATION REPRESENTING THE EARTH'S MAGNETIC FIELD

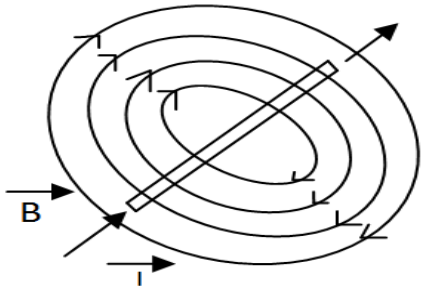
6.2 MAGNETISM

A fundamental force of nature, which causes certain types of materials to attract or repel each other. Permanent magnets, like the ones on your refrigerator and the earth‘s magnetic field, are examples of objects having constant magnetic fields.

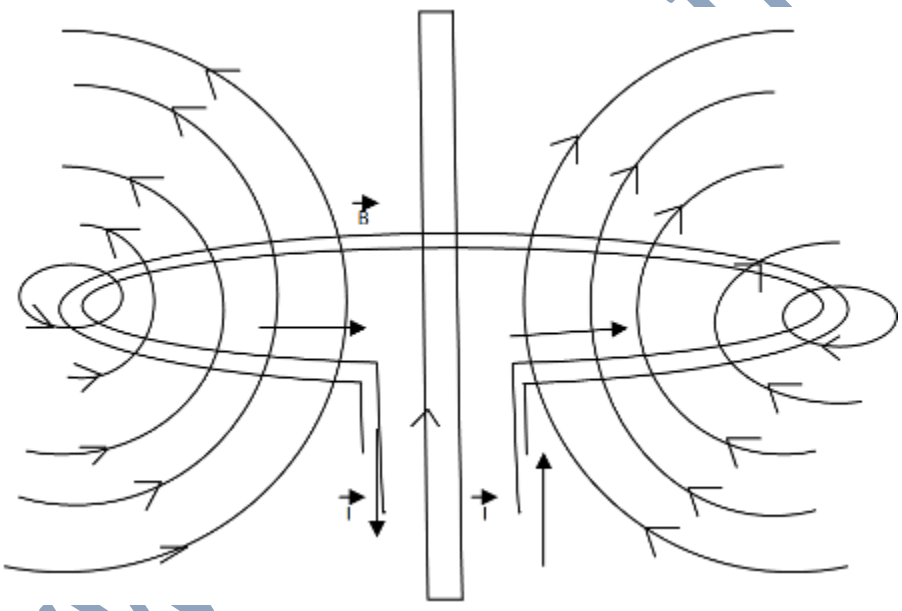
Oscillating magnetic fields vary with time, and can be generated by alternating current (AC) flowing on a wire. The strength, direction, and extent of magnetic fields are often represented and visualized by drawings of the magnetic field lines.

6.3 ELECTROMAGNETISM

A term for the interdependence of time varying electric and magnetic fields. For example, it turns out that an oscillating magnetic field produces an electric field and an oscillating electric field produces a magnetic field.



CHAPTER 6, FIG 6.2: FUNDAMENTALS OF MAGNETIC FIELD



CHAPTER 6, FIG 6.3: THE BLUE LINES REPRESENT THE MAGNETIC FIELD THAT IS CREATED WHEN CURRENT FLOWS THROUGH A COIL.

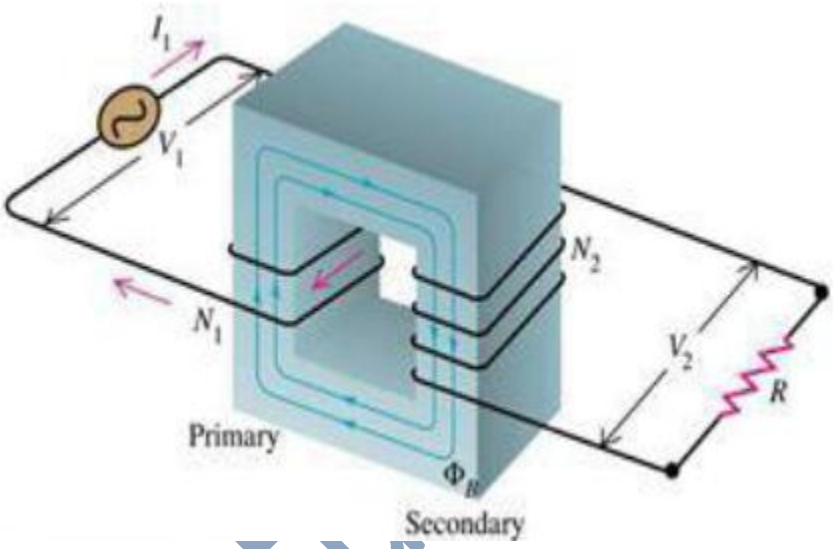
As electric current, I, flows in a wire, it gives rise to a magnetic field, B, which wraps around the wire. When the current reverses direction, the magnetic field also reverses its direction.

6.4 MAGNETIC INDUCTION

A loop or coil of conductive material like copper, carrying an alternating current (AC), is a

Very efficient structure for generating or capturing a magnetic field. If a conductive loop is connected to an AC power source, it will generate an oscillating magnetic field in the vicinity of the loop. A second conducting loop, brought close enough to the first, may capture some portion of that oscillating magnetic field, which in turn, generates or induces an electric current in the second coil. The current generated in the second coil may be used to power devices. This type of electrical power transfer from one loop or coil to another is well known and referred to as magnetic induction. Some common examples of devices based on magnetic induction are electric transformers and electric generators.

6.5 ENERGY/POWER COUPLING



CHAPTER 6, FIG 6.4: MAGNETIC INDUCTION

An electric transformer is a device that uses magnetic induction to transfer energy from its primary winding to its secondary winding, without the windings being connected to each other. It is used to transform AC current at one voltage to AC current at a different voltage. Energy coupling occurs when an energy source has a means of transferring energy to another object. One simple example is a locomotive pulling a train car the mechanical coupling between the two enables the locomotive to pull the train, and overcome the forces of friction and inertia that keep the train still and, the train moves. Magnetic coupling occurs when the magnetic field of one object interacts with a second object and induces an electric current in or on that object. In this way, electric energy can be transferred from a power source to a powered device. In contrast to the example of mechanical coupling given for the train, magnetic coupling does not require any physical contact between the object generating the energy and the object receiving or capturing that energy.

6.6 WITRICITY TECHNOLOGY

Witricity power sources and capture devices are specially designed magnetic resonators that efficiently transfer power over large distances via the magnetic near field. These proprietary source and device designs and the electronic systems that control them support efficient energy transfer over distances that are many times the size of the sources/devices themselves.

CHAPTER 6, FIG 6.5: WITRICITY POWER SOURCE

The WiTricity power source, left, is connected to AC power. The blue lines represent the magnetic near field induced by the power source. The yellow lines represent the flow of energy from the source to the WiTricity capture coil, which is shown powering a light bulb. Note that this diagram also shows how the magnetic field (blue lines) can wrap around a conductive obstacle between the power source and the capture device.

CHAPTER 7

7. PRINCIPLE & EXPERIMENTAL DESIGN

7.1 BASIC PRINCIPLE

WiTricity is nothing but the short name of Wireless Electricity. The basic concept behind this is Magnetic Resonance. Two resonant objects of the same resonant frequency tend to exchange energy efficiently, while dissipating relatively little energy in extraneous off resonant objects. In systems of coupled resonances, there is often a general Strongly Coupled regime of operation. If one can operate in that regime in a given system, the energy transfer is expected to be very efficient. Midrange power

Transfer implemented in this way can be nearly Omni directional and efficient, irrespective of the geometry of the surrounding space, with low interference and losses into environmental objects. The above considerations apply irrespective of the physical nature of the resonances. Magnetic resonances are particularly suitable for everyday applications because most of the common materials do not interact with Magnetic Fields, so interactions with Environmental objects are suppressed even further. We were able to identify the strongly coupled regime in the system of two coupled magnetic resonances by exploring Non radiative (near field) magnetic resonant induction at Megahertz frequencies.

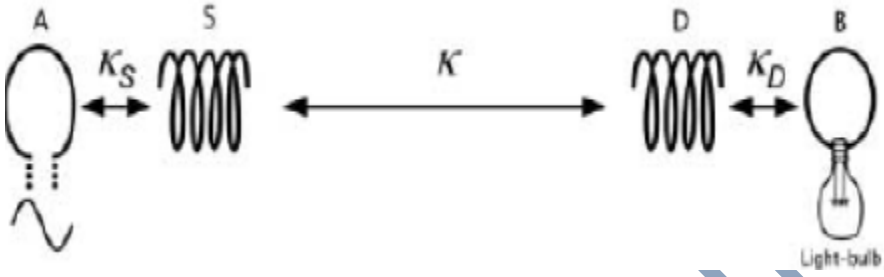
7.2 EXPERIMENTAL DESIGN

Experimental scheme consists of two Self resonant coils. One coil (source coil) is coupled inductively to an oscillating circuit; the other (device coil) is coupled inductively to a resistive load. Self-resonant coils rely on the interplay between distributed inductance and distributed capacitance to achieve resonance. The coils are made of an electrically conducting wire of total length land cross sectional radius a‘, wound into a helix of n‘turns, radius r‘, and height h‘. There is no exact solution for a finite helix in the literature, and even in the case of infinitely long coils, the solutions rely on assumptions that are

inadequate for this system. So here the method implemented is simple quasi static model to find the parameters. Those are in Electro Magnetic equations.

$$L = \frac{\mu_0}{4\pi|I_0|^2} \iint d_r d_{r\prime} \frac{j_{(r)} j_{(r\prime)}}{|r-r\prime|} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\frac{1}{C} = \frac{1}{4\pi\varepsilon_0|q_0|^2} \iint d(r)d(r') \frac{\rho(r)\rho(r\prime)}{|r-r\prime|} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$



CHAPTER 7, FIG 7.0: ENERGY TRANSFER BY COIL REPRESENTATION

7.3 RANGE AND RATE OF COUPLING

The range and rate of the proposed wireless energy transfer scheme are the first subjects of examination, without considering yet energy drainage from the system for use into work. An appropriate analytical framework for modeling this resonant energy exchange is that of the well-known Coupled Mode Theory (CMT) .Here, the field of the system of two resonant objects 1 and 2 is approximated by **F(r, t) =a_1 (t) F1(r) + a_2 (t) F2(r),** here $F_{1,2}$(r) are the modes of 1 and 2 alone, and then the field amplitudes a_1 (t) and a_2 (t). The lower order representation of the system is given by:

$$\frac{d(a_1)}{d(t)} = -i(\omega_1 - i\Gamma_1)a_1 + ika_2 \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\frac{d(a_2)}{d(t)} = -i(\omega_2 - i\Gamma_2)a_2 + ika_1 \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where $\omega_{1,2}$ are the individual frequencies, $\Gamma_{1,2}$ are the Resonance widths (Decay rates) due to the objects' intrinsic (absorption, radiation etc.) losses, and κ' is the coupling coefficient. The above equation show that at exact resonance ($\omega_1=\omega_2$ and $\Gamma_1=\Gamma_2$), the normal modes of the combined system are split by 2κ. The energy exchange between the two objects takes place in time Pi/κ and is nearly perfect, apart for losses, which are minimal when the coupling rate is much faster than all loss rates ($\kappa >> \Gamma_{1,2}$). It is exactly this ratio {κ /sqrt ($\Gamma_{1,2}$)} shows that, it will set as figure of merit for any system under consideration for wireless energy transfer, along with the distance over which this ratio can be achieved.

The desired optimal regime {κ/sqrt ($\Gamma_{1,2}$)>>1} is called Strong Coupling regime. There is No change in Energy, up to κ/Γ>>1 is true. Consequently, this energy transfer application requires resonant modes of High Quality factor, Q=ω/2Γ for low (slow) intrinsic loss rates Γ, so we used here the non lossy near field. Furthermore, strong (fast) coupling rate κ is required over distances larger than the characteristic sizes of the objects, and therefore,

since the extent of the near field into the air surrounding a finite sized resonant object is set typically by the wavelength, this mid-range non radiative coupling can only be achieved using resonant objects of Sub wavelength size.

Such sub wavelength (λ/r) resonances can often be accompanied with a high radiation Q, so this will typically be the appropriate choice for the possibly mobile resonant device object.

7.4 PARAMETERS FOR DESIGNING AND SIMULATION

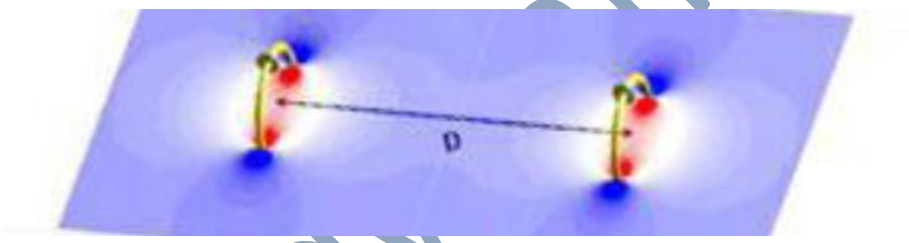
The coupled mode theory plays a vital role in solving the lower order equations of the system. Using perturbation technique of x(t)=A cos(ω 0t)+ B sin(ω 0t) The solution of this equation is by including decay rate due to loss Γ_0 is X(t)=C exp(I ω_0t)exp(t/ Γ_0) By considering all energy inputs and outputs we can conclude that at resonance condition decay loss by source and device is Γ= ω/2Q. The ratio κ/Γ is proportional to the Quality factor i.e. proportional to the power developed and inversely proportional to decay rate due to loss. so if κ/Γ is high the power output is high. The simulation process is going on in the above way such that to prove in strongly coupled mode at sub wavelength (λ/r) resonances by considering the following process.

Consider two loops at distance D between their centers, radius r1 and r2 of conducting wire with circular cross section of radius a‘and diameter d‘.via a dielectric of relative permittivity ε and everything surrounded by air. To calculate the RLC parameters used the method called Finite Element Frequency Domain (FEFD) simulations (for Maxwell‘s equations solving purpose). The wire has inductance L, the plates have capacitance C and then the system has a resonant mode, where the nature of the resonance lies in the periodic exchange of energy from the electric field inside the capacitor, due to the voltage across it and due to the current in the wire. The energy released is Magnetic energy. Losses in this resonant system consist of ohmic loss, Rabs inside the wire and radiative loss, Rrad into free space. μ0, ε0 are the magnetic permeability, electric permittivity and impedance of free space and σ is the

conductivity of the conductor. By the calculations of FEFD, we found $\kappa = \omega M/2*\sqrt{(L1L2)}$ $L=\mu_0 r[\ln(8r/a)]$ $C=\varepsilon_0 \varepsilon a/D$ $\eta=\sqrt{(\mu_0/\varepsilon_0)}$ where M is the mutual inductance of the two loops and it is dependent on r_1, r_2,D. $M=\{(Pi/2)* \mu 0* (r_1 r_2)^2\}/D^3$ Rabs≈ {(Pi/6)η r/a} Rrad≈{(Pi/6)η r/ λ } Qabs≈ωL/ Rabs Qrad≈ ωL/ Rrad And taking copper wires so that it is having ε=10 other considerations in **COMSOL software** and **Acoustics Module Tool**, designed the system as

7.5 RESONANT MAGNETIC COUPLING

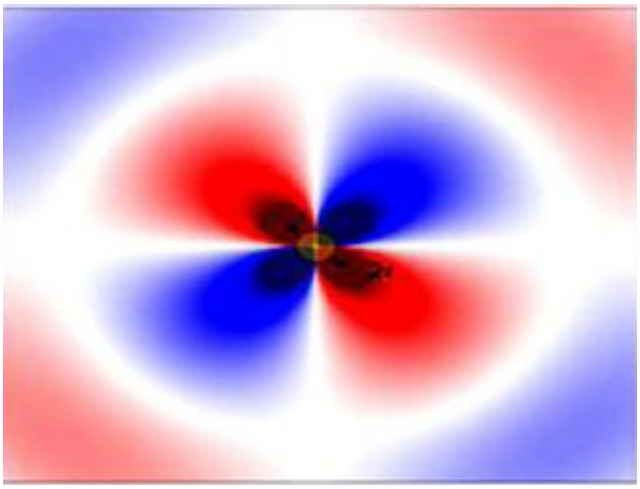
Magnetic coupling occurs when two objects exchange energy through their varying or oscillating magnetic fields.



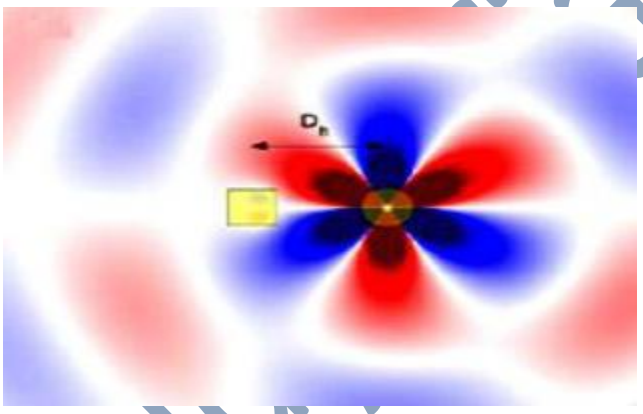
CHAPTER 7, FIG 7.1: ENERGY EXCHANGE

7.6 SIMULATION MODEL USING RESONANT MAGNETIC COUPLING

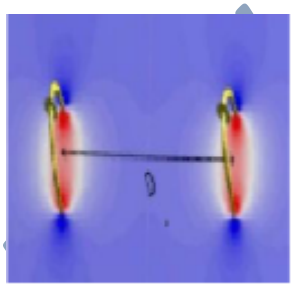
Two idealized resonant magnetic coils, shown in yellow. The blue and red color bands illustrate their magnetic fields. The coupling of their respective magnetic fields is indicated by the connection of the color bands. **Simulation Performance:** The results and performance given with and Without the External object in between the coils.



CHAPTER 7, FIG 7.2: ENERGY EXCHANGE (WITH EXTERNAL OBJECT)



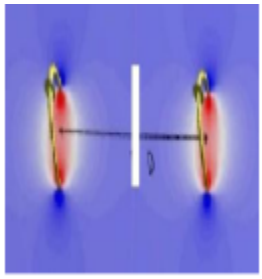
CHAPTER 7, FIG 7.3: ENERGY EXCHANGE (WITHOUT EXTERNAL OBJECT)



Two loops	D/r	Qrad	Q=ω/2Γ	ω/2κ	κ/ Γ
R=30cm,a=2cm, ε=10,d=4mm,Qabs=4886.	3	30729	4216	63.7	68.7
	5	29577	4194	248	17.8

CHAPTER 7, FIG 7.4: RESULTS WITHOUT EXTRANEOUS OBJECTS I

If we include a man having muscles of electric permittivity ε=49+16i so that observed the results that only decay is somewhat raised but got the required κ/ Γ ratio.



Two loops	D/r	Qrad	Q=ω/2Γ	ω/2κ	κ/ Γ
R=30cm,a=2cm, ε=49+16i, d=4mm,Qabs=4886.	3	30729	4136	62.6	67.4
	5	29577	4106	235	17.6

CHAPTER 7, FIG 7.5: RESULTS WITH EXTRANEOUS OBJECTS I

CHAPTER 8

8. PERFORMANCE OF DESIGN

8.1 ADVANTAGES OF DESIGN

There are so many advantages with this Witricity concept, some of those are:

a) Unaffected by the day night cycle, weather or seasons.

b) This is an ecofriendly.

c) It is a boon for the devices which use midrange power.

8.2 LIMITATIONS OF DESIGN

a) The resonance condition should be satisfied, if any medium error is there possibility of power transfer.

b) If there is any possibility of Very Strong ferromagnetic material presence, then there may be a possibility of low power transfer due to radiation.

8.3 PARAMETRIC CONCLUSIONS FOR DESIGN

Wireless Electricity concept is a boon for devices which uses midrange energy. The Power transfer is explained with the help of Magnetic resonance and Coupled mode theory. By the above paper we can concludes the below points.

a) The optimal regime of efficient power transfer is strongly coupled regime.

b) High κ/Γ ratio gives high power output. If no change in κ/Γ ration no chance in power transfer.

c) Designed the parameters with FEFD method and simulated for the κ/Γ ratio changes with and without the external objects and concluded that there is no large variation in κ/Γ ratio.

CHAPTER 9

FEATURES AND BENEFITS

9.1 BENEFITS: WITRICITY TECHNOLOGY WILL MAKE YOUR PRODUCTS

a) More convenient

a) No manual recharging or changing batteries.

b) Eliminate unsightly, unwieldy and costly power cords.

9.2 MORE RELIABLE

a) Never run out of battery power.

b) Reduce product failure rates by fixing the weakest link‘: flexing wiring and mechanical interconnects.

9.3 MORE ENVIRONMENTALLY FRIENDLY

a) Reduce use of disposable batteries.

b) Use efficient electric grid power ‘directly instead of inefficient battery charging.

9.4 FEATURES: 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.

9.5 ENERGY TRANSFER VIA MAGNETIC NEAR FIELD CAN PENETRATE AND WRAP AROUND OBSTACLES

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 WiTricityTechnology 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.

CHAPTER 10

10.1 APPLICATIONS

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:

10.1.1 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.

10.1.2 CONSUMER ELECTRONICS

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.

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

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

10.1.3 INDUSTRIAL

Direct wireless power and communication interconnections across rotating and moving joints (robots, packaging machinery, assembly machinery, machine tools) … eliminating costly and failure prone wiring. Direct wireless power and communication interconnections at points of use in harsh environments (drilling, mining, underwater, etc.) … where it is impractical or impossible to run wires. Direct wireless

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

10.1.4 TRANSPORTATION

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

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

10.2 OTHER APPLICATIONS

a) Direct wireless power interconnections and automatic wireless charging for implantable medical devices (ventricular assist devices, pacemaker, defibrillator, etc.).

b) Automatic wireless charging and for high tech military systems (battery powered mobile devices, covert sensors, unmanned mobile robots and aircraft, etc.).

c) Direct wireless powering and automatic wireless charging of smart cards.

d) Direct wireless powering and automatic wireless charging of consumer appliances, mobile robots, etc.

CHAPTER 11

11. SAFETY AND FUTURE SCOPE

11.1 IS WITRICITY TECHNOLOGY SAFE?

11.1.1 NON RADIATIVE ENERGY TRANSFER IS SAFE FOR PEOPLE AND ANIMALS

WiTricity technology is a non radiative mode of energy transfer, relying instead on the magnetic near field. Magnetic fields interact very weakly with biological organism's people and animals and are scientifically regarded to be safe. Professor Sir John Pendry of Imperial College London, a world renowned physicist, explains: The body really responds strongly to electric fields, which is why you can cook a chicken in a microwave. But it doesn't respond to magnetic fields. As far as we know the body has almost zero response to magnetic fields in terms of the amount of power it absorbs." Evidence of the safety of magnetic fields is illustrated by the widespread acceptance and safety of household magnetic induction cook tops. Through proprietary design of the WiTricity source, electric fields are almost completely contained within the source. This design results in levels of electric and magnetic fields which fall well within regulatory guidelines. Thus WiTricity technology doesn't give rise to radiofrequency emissions that interfere with other electronic devices, and is not a source of electric and magnetic field levels that pose a risk to people or animals. Limits for human exposure to magnetic fields are set by regulatory bodies such as the FCC, ICNIRP, and are based on broad scientific and medical consensus. WiTricity technology is being developed to be fully compliant with applicable regulations regarding magnetic fields and electromagnetic radiation.

11.2 FUTURE SCOPE OF WITRICITY

MIT's WiTricity is only 40 to 45% efficient and according to Soljacic, 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. The researchers are also currently working on the health issues related to this concept and have said that in another three to five years' time, they will come up with a WiTricity system for commercial use.

Witricity, if successful will definitely change the way we live. Imagine cell phones, laptops, digital camera's getting self-charged! Wow! Let's hope the researchers will be able to come up with the commercial system soon. Till then, we wait in anticipation! Human beings or other objects placed between the transmitter and receiver do not hinder the transmission of power. However, does magnetic coupling or resonance coupling have any harmful effects on humans? MIT's researchers are quite confident that WiTricity's 'coupling resonance' is safe for humans. They say that the magnetic fields tend to interact very weakly with the biological tissues of the body, and so are not prone to cause any damage to any living beings.

Reference

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